ARCI

ANNUAL REPORT 2019-20

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ARCI

ARCI is an autonomous R&D Centre of Department of Science and Technology (DST), Government of India, set-up with a mission to develop unique, novel and techno-commercially viable technologies in the area of advanced materials and subsequently transfer them to industries.

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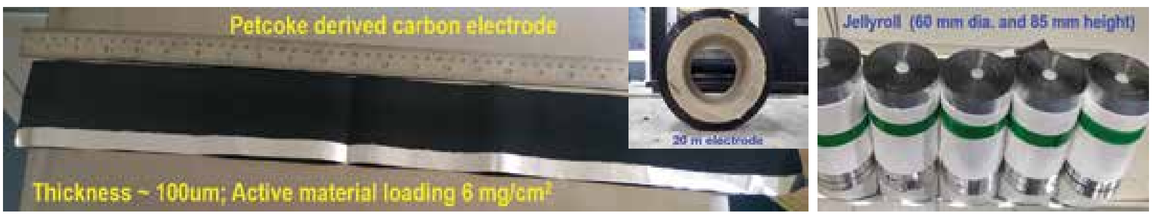
Director's Report

It gives me great pleasure to present this report on the activities and achievement of ARCI during 2019-20. It has been a great year in terms of technology development and transfer activities addressing the needs of alternative energy, aerospace, conventional power, manufacturing, biomedical and automotive sectors through the various expertise verticals of ARCI viz., Powder metallurgy, Ceramics, Coatings, Energy Materials, Laser processing and Additive Manufacturing.

Materials for energy systems, both for alternative as well as conventional energy has been the major direction during the year. Alternative Energy Materials & Systems activities were pursued across four Divisions of ARCI at Hyderabad and Chennai under the aegis of Technical Research Centre (TRC) funded by the DST. Substantial translation research was carried out during the year with focus of technology transfer to industries.

- In energy storage batteries program, NMC/Graphite type lithium ion cells of 26650- type (3.7 V, 2.5 Ah, ~200 nos.) have been fabricated and fast-formation protocol has been established. Assembly of a module of 48V, 1.5 kWh for field trials on e-scooter has been firmed up in collaboration with industrial partners. Our efforts to develop materials for Li-ion battery technology proceeded to the level of plant engineering for the bulk production of cathode (LFP) anode (LTO). International patents for the production of LTO were filed. Parallelly, indigenous synthesis of NMC (532) cathode material has been demonstrated at 50 g / batch. While intense work on Li-ion battery materials and cell technology was going on, considerable progress has been made on sodium ion battery technology as well. In-situ carbon coated NASICON-type cathode materials ($Na_3V_2(PO_4)_3$, $Na_3V_2(PO_4)_2F_3$) have been developed with good electrochemical performance. Discussions to launch a programme on solid state batteries also have been initiated.
- Development of supercapacitors gained momentum during the year through filing an Indian patent for the method of producing nanoporous carbon material from petroleum coke and its performance for Supercapacitor and Li-ion capacitor and setting up of a semi pilot plant facility for the fabrication of super capacitors (1000 F capacitance). NCO based asymmetric pseudocapacitor development was undertaken and a specific capacitance of 91.5 Fg^{-1} could be achieved.
- With reference to Fuel Cell technology, ARCIs PEM Fuel Cell technology was field demonstrated, including Tamil Nadu Disaster Management Centre, Chennai and Bhabha Atomic Research Centre, Mumbai and data has been collected. A marked increase among industries interested in this technology both at system level and component level has been observed. In order to demonstrate the technology at a higher scale, a semi-automated assembly line for the MEAs and the stacks have been conceptualized. When implemented, this line can produce stacks sufficient for 100 kW per year. The "One Day Workshop on Hydrogen and Fuel Cell for Sustainable Future" organized as part of Hydrogen day celebrations helped in further networking with R&D and industry partners. Efforts have also been made to form a R&D-Industry consortium to develop Solid Oxide Fuel cell technology.
- On solar energy materials front, easy-to-clean coating technology with features like easy application by simple spray and wipe technique was field tested on PV panels in different weather conditions and know-how has been transferred to M/s. NETRA (NTPC Ltd), New Delhi, for commercialisation. A technology transfer MoU has been signed with another industry

2.5 Ah NMC/graphite cylindrical cell



Petcoke derived activated carbon electrodes and jelly rolls prepared at pliot scale supercapacitor faciltiy as well. Efforts are also being made to incorporate superhydrophobicity in futuristic 'self-cleaning antireflective coating technology' for next generation solar energy conversion devices. With respect to inorganic solar cell fabrication, 8.2% power conversion efficiency of 50 mm x 50 mm perovskite solar module could be achieved. Solar absorber coatings were successfully demonstrated on 2-meter length solar receiver tube (Abs: 93-94% & Heat loss: 0.14 at 250°C), for medium temperature CST applications.

- Magnetic materials development has evolved as major vertical at ARCI for motor and alternator applications. A breakthrough has been achieved in the development of a new and cost-effective Fe-P alloy for alternator / motor applications through multiple prototype testing in collaboration with industrial partner. Production of this alloy has now been scaled up to 100 kg in collaboration with M/s. Midhani. The thermoelectrics program moved towards module fabrication using p-type PbTe and n-type $Mg_2Si_{0.4}Sn_{0.6}$ which was found to perform stably up to 400°C. Other avenues in photovoltaic and sensor applications were pursued. Magneto-caloric materials were explored for Hypothermia treatment.

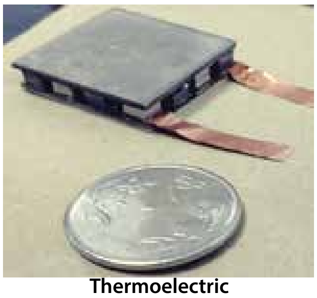
While the technology development activities towards alternative energy systems are progressing, a National Centre for Development of Advanced Materials and Manufacturing Processes for Clean Coal Technologies for Power Applications was set up under the aegis of the Clean Energy Research Initiative of DST. Development of new materials and fabrication technologies for improved life and performance of thermal power plant systems by leveraging ARCIs capabilities in advanced coating technologies, laser-based manufacturing technologies and high temperature oxide dispersion strengthened steels is the main aim of this programme. State-of-the art processing facilities and characterization facilities typically suited for fire side or steam side component evaluation have been successfully established. The first application, viz., laser cladded burner tip plate has been fabricated and deployed for field testing for life improvement. The feasibility of laser and laser-arc hybrid welding of thick sections for power plant applications in plate-plate and plate-tube configurations has been demonstrated.

Application of nano powders as additive in fabricating tungsten plates for aerospace components by powder metallurgy route and as an additive in jet fuel was successfully achieved and the technologies are ready for upscaling. Biodegradable Fe-Mn alloy was developed and fabricated into biomedical stent and given for in vitro and in vivo studies. Powder technology capabilities have been extended to develop high entropy alloys. Alloy developments were greatly facilitated by the commissioning of a 10 kg vacuum induction melting furnace (10 kg capacity). Ni-based superalloy powders for additive manufacturing were successfully made using the gas atomization technique. Powders performed as good as commercially available powders.

As a continuation of transparent ceramic activity, it is envisaged to establish a melt quenching facility to establish a process for producing glass ceramic materials which are currently being imported. As a logical extension, a programme has been launched to establish ultra-precision finishing technique of magnetorheological finishing (MRF) in collaboration with a Belarussian institute. Activities in the non-oxide ceramics were directed towards developing corrosion, wear and abrasion resistant SiC nozzles and seals.

Surface engineering activity at ARCI includes coating solutions for varied industrial applications including development of coating equipment. Indigenously developed Advanced Detonation Spray coating (A-DSC) system with enhanced throughput, efficiency and ease of use is now ready to be transferred to the industry. Similarly, the cold spray coating system which can cover a wide material spectrum is available for transfer to the industry. Titanium based coatings for biomedical

Advanced Detonation Spray System



Thermoelectric module

The PEMFC system along with its Balance of Plant deployed at BARC

Easy-to-clean nano coating sol

Coating demonstration on roof top of PV power plant

Technology know-how transferred to National Thermal Power Corporation

AM built Direction Control Valve

implants were successfully developed using cold spray coatings and are currently undergoing in-vitro and in-vivo tests. New recipes for depositing Ni-W and Ni-W/SiC coatings using Pulsed Electro Deposition (PED) have been developed for transfer to the technology receiver. Cathodic Arc - PVD based wear resistant coatings were successfully developed for helicopter engine blades and passed through 100's of hours of in-flight testing. Cold sprayed coatings on 4 m long rail guns with unique combination of high electrical conductivity and hardness have been developed for field trials. Micro Arc Oxidation (MAO) coatings have been successfully developed on Al-Si alloy die-cast components. ARCI-Industry Joint Aerospace Application Development and Demonstration center is now operational and is actively working with global aero-engine manufacturing agencies. Using wet chemical Sol-Gel Coatings applications such as anti-bacterial coatings on non-woven fabrics; anti-biofilm coatings for eye care products and for preventing surgical site infections; and corrosion protection coatings on steel sheets for automotive applications were pursued.

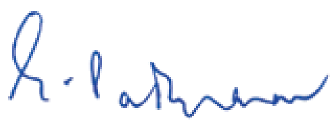
Additive manufacturing has been very intensively pursued by the laser processing centre. Several applications such as Microchannel disc, Valve Block, Brackets, and Gearbox casings with complicated geometries were built. Core pin with conformal cooling channels was successfully built for pressure die casting and field demonstrated for improved quality of the cast parts. Micro surface engineering on piston rings and cylinder liners showed promising results in terms of reduced oil consumption in IC engines. Innovative laser hardening techniques were developed for treating small bearing components. Major new initiative was launched in the area of laser-assisted machining to address challenges of machining different hard-to-machine materials, ranging from superalloys to ceramics.

Materials Characterization and Testing capabilities were enhanced beyond Transmission electron microscopy (TEM) to Atom Probe Tomography. An X-ray diffraction unit with a 9 kW rotating anode generator has served as work horse for large turnover specimens. The portal 'Facilities for Materials Characterization and Testing (FMCT)' is incorporated into the ARCI website and external users are able to access the facilities in the Centre regularly.

Collaboration linkages and understanding of user needs is a key to successful translational research. Formation of multi-disciplinary working groups in identified application areas has started yielding results. In Aerospace sector we have been invited to participate in new initiatives of ISRO and DRDO and a few industries are inviting us to be their partners. In the Bio-medical sector, about 10 applications including dissolvable stents have been conceptualized and a project also has been submitted. In the area of sensors, more clarity has emerged through the one-day work shop organized and I am glad to say that one technology for automatic operation of street lights is under field testing. At the same time, in order to support translational research activities and infrastructure fitness improvement, working groups have been formed including technical officers and staff who offer services to any division. The group on design and fabrication has already succeeded in providing solutions to laser centre and the Nano centre and more are in pipeline.

This year we have reached out in a big way not only to potential collaboration in the R&D and industry but also to students at all levels. The open day was a great success with more than 1000 visitors. We forged strong ties with VSSC, Sree Chitra Tirunal Institute-Trivandrum, CSIR-NEERI-Nagpur, CSIR-IMMT-Bhubaneswar, CSIR-CGCRI Kolkata, DRDO laboratories, PSG Institute of Advanced Studies Coimbatore, IIT-Madras, IIT-Hyderabad and several other institutions. A large number of agreements and technology transfer activities were spear headed by our Business Development Group.

Implementation of all these initiatives, strategies and activities towards translation of research into technology was possible due to continued support from each and every one at ARCI from Associate Directors to the Technicians, administrative and financial staff. Several technologies are on the verge of getting commercialized and I am very confident that given the hard work and enthusiasm of all the members at ARCI, we will be successfully realizing our goals of delivering useful technologies and solutions in line with the national needs.



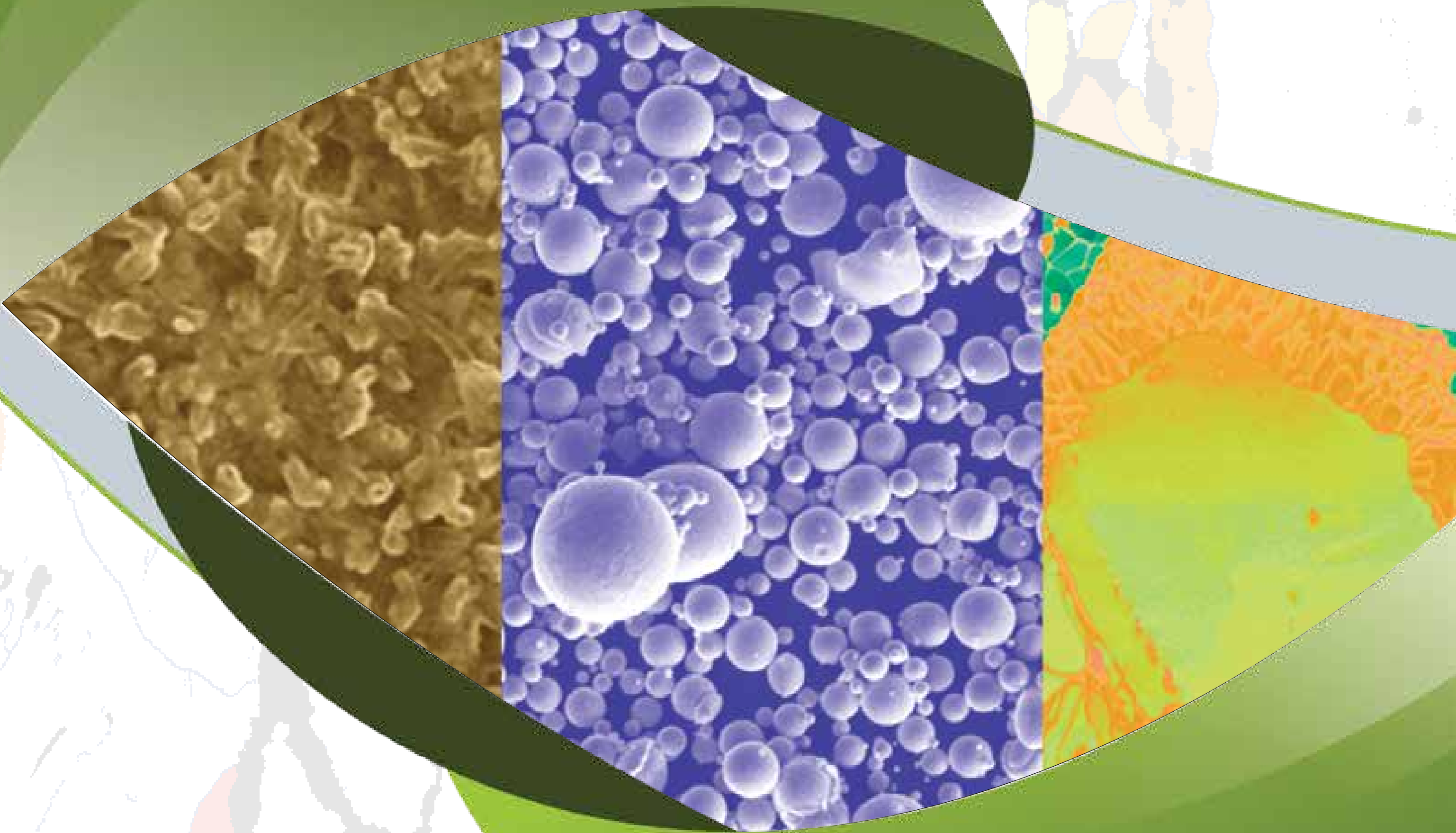
(G. Padmanabham)

Performance Indicators

Parameters	2019-20
No. of papers in refereed journals	139@
No. of chapters in books	3@
No. of papers presented in conferences and invited lectures	260
No. of foreign patent applications (inventions awaiting grant)	5*
No. of foreign patents granted	16*#
No. of Indian patent applications (inventions awaiting grant)	65*
No. of Indian patents granted	56*
No. of Ph.Ds produced	1
No. of research manpower trained (other than PhDs)	25
No. of technical manpower trained	67
No. of B.Tech/UG projects guided	56
No. of M.Tech/M.Sc/M.Phil projects guided	83
No. of technologies/designs and other IP commercialized	31
No. of technology leads awaiting transfer	20

**Cumulative figure up to the end of the financial year*
@Calendar year 2019
#Includes same inventions granted in multiple countries

Research and Technology Highlights



Centre for Automotive Energy Materials

The Centre of Automotive Energy Materials (CAEM) is one of the Centres of Excellence of ARCI located at Indian Institute of Technology Madras Research Park, Chennai. The primary objective of the Centre is to develop and demonstrate materials and components processing technology to Indian automobile industries as well as provide technical supports for their potential problems. The Centre has five major activities: (i) Technology demonstration of lithium-ion battery (LIB) for electric mobility as well for stationary applications with associated Materials technology demonstration; (ii) Sodium-ion battery for grid/off-grid storage; (iii) Soft and hard magnetic materials for motors and alternators in automotive application; (iv) Thermoelectric materials and device fabrication for waste heat recovery ; and (v) Magneto-caloric materials for magnetic refrigeration and bio-medical applications. The above major activities are being executed currently through Technology Research Centre (TRC) project on Alternative Energy Materials and Systems from the Department of Science and Technology, where translation of these research results into technology and transfer to industries is the main focus.

CAEM has achieved some major accomplishments in the above listed programmes during 2019-2020 and some of them are highlighted here. In LIB program, NMC/Graphite based cylindrical cells of 26650-type (3.7 V, 2.5 Ah, ~200 nos.) have been fabricated and successfully established the fast-formation protocol for these cells, which exhibited good rate capability and remarkable cyclic stability. A module of 48V, 1.5 kWh is being assembled with these cells for an e-scooter field trial with industries in PPP mode. In addition, indigenous processing NMC (532) material has been demonstrated at 50 g/batch and scale up of this Material technology is in progress. In sodium ion battery program in-situ carbon coated NASICON-type cathode materials ($Na_3V_2(PO_4)_3$, $Na_3V_2(PO_4)_2F_3$) have been developed with good electrochemical performance. As soft and hard magnets are critical for automotive sectors, Centre has made a breakthrough in successfully completing the prototype testing of a new and cost effective Fe-P alloy for alternator / motor applications and this alloy has now been scaled up to 100 kg in collaboration with M/s. Midhani to make more number of prototypes for acceptance trials with M/s. Lucas TVS. In thermoelectric program, scalable thermoelectric module fabrication process has been established using p-type PbTe and n-type $Mg_2Si_{0.4}Sn_{0.6}$ materials and the module has delivered a stable performance up to 400°C. In addition to the above, CAEM is also executing R&D on thermoelectric materials for photovoltaic and sensor application as well magneto-caloric materials for Hypothermia treatment. During the last one year, the Centre has also established new facilities such as Accelerated Rate Calorimetry, Confocal Raman Spectroscopy and Vacuum Induction Melting Furnace (10 kg capacity) to further strengthen the programmes.

2.5 Ah NMC/ graphite cylindrical cell

Accelerated rate calorimeter

Confocal Raman Spectrometer

Vacuum Induction Melting Furnace

Thermoelectric module

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In-house Developed NMC-Graphite based Lithium-ion Cell for Electric Mobility

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Electric mobility plays a crucial role in the minimization of greenhouse gas emissions in the transportation sector. The development of high performance and low-cost lithium-ion batteries (LIBs) dramatically accelerates the battery-driven electric vehicles (EVs) in the automobile industry. In this context, ARCI has set-up a pilot plant facility for the fabrication of large format lithium-ion cells, along with a comprehensive testing facility, for EV application. Under the Make-in-India approach, the indigenous development of LIB is anticipated to reduce the cost of the battery by ~20% and cater to the requirement of the FAME II plan launched by Government of India.

Previously, ARCI has successfully demonstrated on road trails of the indigenously developed lithium iron phosphate (LFP)/graphite based battery pack (48V, 850 Wh) with e-scooter, which yielded a consistent mileage of 52 km/charge. In addition, we have developed LIB module of 48 V, 1 kWh with nickel-manganese-cobalt (NMC)/ graphite based prismatic cells (20 Ah) and evaluated its performance on electric scooter under offline condition. Based on the requirement of OEM/industry collaborators, we have now started the fabrication of NMC/graphite based cylindrical cells (26650 type) with higher energy density and higher thermal stability (Fig. 1a). Aluminum (3003) has been chosen as the case material for fabricating the cylindrical cells due to its low density, high electrical & thermal conductivity and high mechanical strength for good weldability. Electrodes were fabricated via coma-reverse coating technique with a material loading of approximately 20 and 10 mg/cm^2 for the cathode and anode, respectively. The electrodes were calendered, slit to desire widths and welded multiple tabs on the cathode and anode to ensure the uniform current distribution along the length of the electrodes. Both cathode and anode along with two layers of separators were wound in the form of a jelly-roll. The positive and negative tabs were connected to the respective terminals. An appropriate volume of electrolyte was filled under vacuum, and the cells were kept under idle condition for about 3-4 days for electrolyte soaking to achieve a uniform open-circuit voltage. More than 150 cylindrical cells of 26650-type have been fabricated and formation of the cells was carried out with indigenously developed fast formation protocol at room temperature to form a stable solid-electrolyte interface layer on the graphite particles, which governs the long-term stability of the cells. A discharge capacity of 2.5 Ah was achieved at the end of formation cycles. The cells gave an initial capacity of 2.4 Ah at 0.5 C with a capacity retention of 99% after 100 cycles. At 1C rate, the cells exhibited a discharge capacity of 2.1 Ah with good cyclic stability (capacity retention of 86% after 550 cycles, Fig. 1b). The long-term cycling and thermal studies of the cells are underway. Meanwhile, these cells will be assembled to form a module of 48V, 1.5kWh (14s x 162p) for an e-scooter field trial. The field trial will be carried out in partnership with an OEM and an industry at the OEM's facility using standard test protocol.

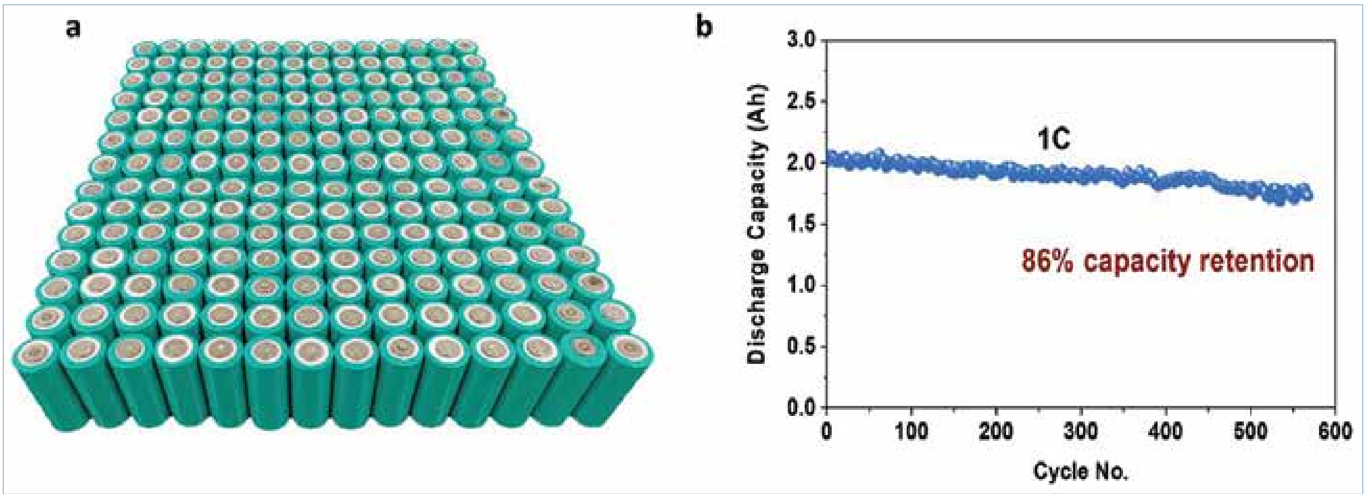

Fig. 1 (a) 2.5 Ah NMC/graphite cylindrical cells; (b) Cycle number and capacity profile at 1C charge/discharge rate

Contributors: L. Babu, Sumit Ranjan Sahu, V. V. N. Phani Kumar, Vallabha Rao Rikka, Laxman Manikanta, Mahendar Peddi, S. Vasu, Kumari Konda and R. Gopalan

Low-cost Novel-aqueous Binder based Micron-sized Tin Anode for High Power Lithium-ion Battery Applications

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Lithium-ion batteries (LIBs) for electric vehicles (EVs) requires high energy/power density batteries with fast charge-discharge capability and long cycle life. The existing LIBs use graphite as an anode due to its low operating potential vs. lithium, high thermal conductivity, and minimal volume expansion (12%) during charge/discharge cycling. However, the moderate capacity (372 $mAhg^{-1}$) and poor fast charging capability of the graphite anode are the main constraints for LIB to meet the requirement for EV applications.

Sn has been considered as one of the potential anode materials for EV applications due to its high capacity (993 mAhg-1), fast charging capability, and improved safety during rapid charge-discharge cycles. With an estimated worldwide production of 3,00,000 Tonnes per annum, it is highly desirable to develop Sn-based anode for a sustainable LIB technology. Previous studies showed that, the micron-sized Sn is not suitable for LIB application due to its high-volume expansion (300%) during charge/discharge cycling, which leads to micro-cracking of electrodes and drastic capacity fade within a few cycles. To circumvent such high-volume expansion, nano-size Sn has been used in various studies, which showed a significant enhancement in the cyclic stability. But the production of nano-Sn involves cost-intensive synthesis methodologies and low production yields, which in turn increases the cost of Sn anode. Switching from nano-Sn to micron-Sn could result in the cost reduction of the electrode fabrication process by nearly 20 times. Besides, opting for a water-based processing route could add a further advantage of cost-effectiveness and environmental benignity.

Here, we have demonstrated micron-sized Sn (10 μm) as a high-performance anode material for LIBs (Fig. 1a). In this context, a novel, environmentally benign, and low-cost aqueous binder carbonyl-β-cyclodextrin (CCD) was developed and used for the electrode fabrication.

The micron Sn anode delivers nearly two times higher capacity (532 $mAhg^{-1}$) than that of the conventional graphite anode (330 $mAhg^{-1}$) at a given current rate of 1C (Fig. 1b). But at higher current rate (5C), Sn anode delivers the capacity (478 $mAhg^{-1}$) four times higher than the graphite counterpart (112 $mAhg^{-1}$). In addition, the electrode exhibits a cycle life of >1500 cycles with capacity retention of more than 85%. Due to the typical cage-like structure of CCD, it establishes strong multidimensional contact-points with the Sn particles. Thus, it acts as a buffer against high volume expansion of Sn during charge/discharge cycling and prevents the cracking of electrodes during long cycling (Fig. 1c, d). Thus, it confirms the suitability of the Sn anode for fast charging applications like EVs. The low cost and superior performance of micron-sized Sn anode open a new window of opportunity in India in the field of LIB for EVs in alignment with the National Electric Mobility Mission Plan.

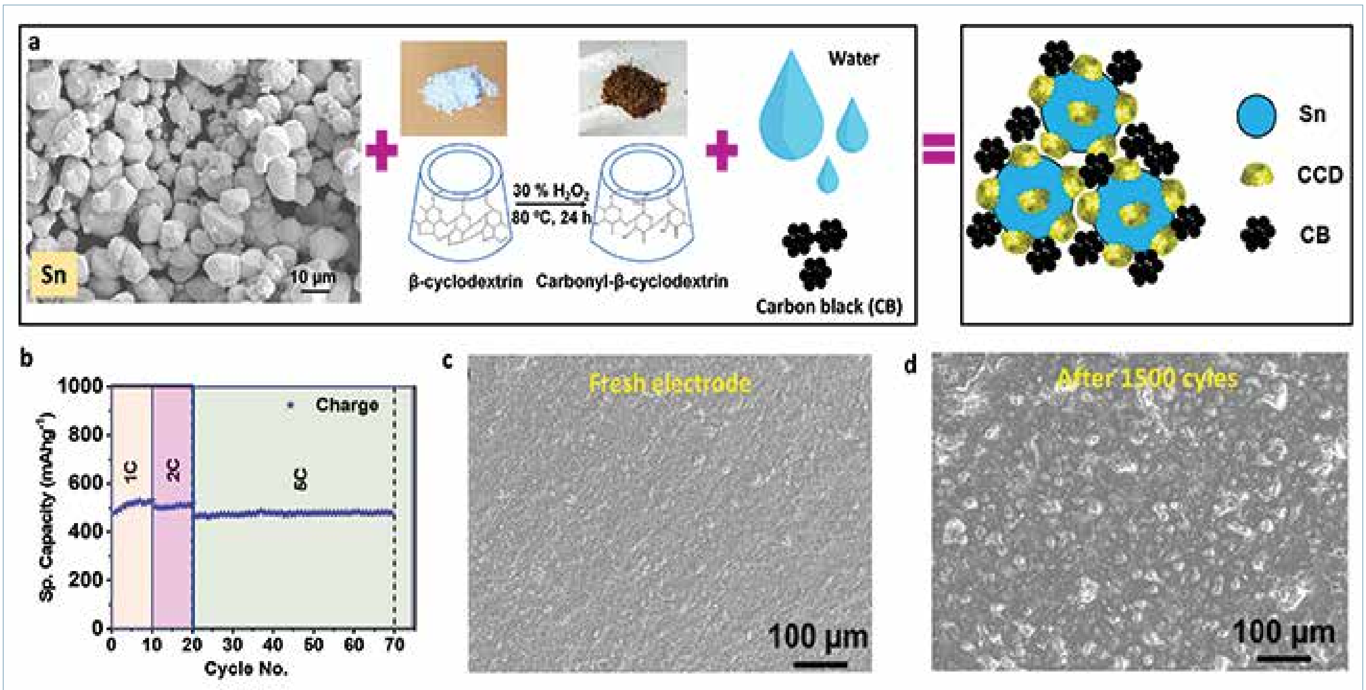

Fig. 1 (a) Fabrication of Sn-anode with aqueous binder (CCD), (b) Rate capability test, (c) Fresh electrode, (d) Cycled electrode

Contributors: Vallabha Rao Rikka, R. Prakash and R Gopalan

Investigation of Elemental distribution by Atom Probe Tomography and cross sectional SEM for Lithium Ion Battery cathode Materials

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Lithium Ion battery technology relies predominantly on the development of positive electrode materials with high energy density, excellent power capability and affordable cost. The fast charging/discharging coupled with longevity of the electrode depends on the rate of lithium diffusion and structural integrity maintained during long term cycling. In order to design a cathode material with high specific capacity and long durability, it is essential to understand the distribution of elements at microscale level as well as nano/atomic scale. Nickel rich layered oxide such as LiNi1-x-yCoxAlyO$_2$ (NCA), with high practical specific capacity are candidate cathode materials for high energy applications. However, when nickel content is high, NCA is known to react with electrolyte adversely and there by reduces the cyclic stability. Therefore NCA comprised of concentration constant core with high nickel content and gradient shell of reduced Ni concentration with simultaneous increase in Al concentration across the nano-micro hierarchical structure was synthesised. The compositional distribution of the elements at microscale and nano-scale level are investigated using cross-sectional Energy Dispersive X-ray Analysis (EDAX) and Atom Probe Tomography (APT) respectively. The cross sectional EDAX mapping of NCA (Fig.1) confirms that the concentration of Ni and Al is uniform and constant at the core, and at the surface nickel decreases sharply, while that of Al increases. For the comparisons the cross sectional elemental mapping of compositionally constant NCA is also provided. APT provides a quantitative chemical composition of cathode materials in 3-dimentional image with sub- nanometre scale spatial resolution. The atomic distribution of elements (given in figure below) were analysed by the field evaporation of surface atoms from the nano-sized needle-shaped tip of LiNi0.8Co0.135Al0.065O2 (layered oxide cathode materials) synthesized by co-precipitation assisted solid state technique. The atomic percentage of elements O 43.080%, Li 31.077, Ni 19.109, Co 5.695 and Al 0.657 matches well the bulk compositional analysis of SEM-EDS (Scanning Electron Microscopy –Energy Dispersive Spectroscopy) (Fig2a &b). The electrochemical performance of compositionally graded NCA (CG-O) at a higher cut off voltage of 4.4V vs Li/Li+ is superior to that of the compositionally constant NCA (CC-O).

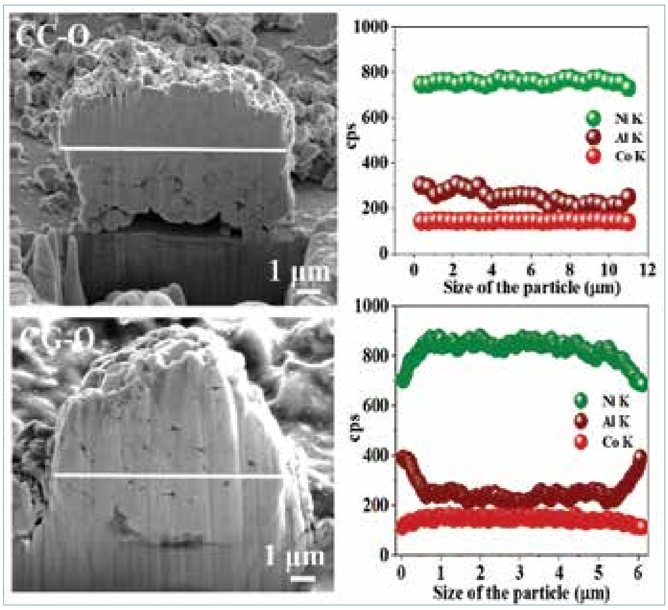

Fig. 1 SEM cross sectional EDAX mapping of of CC-O and CG-O

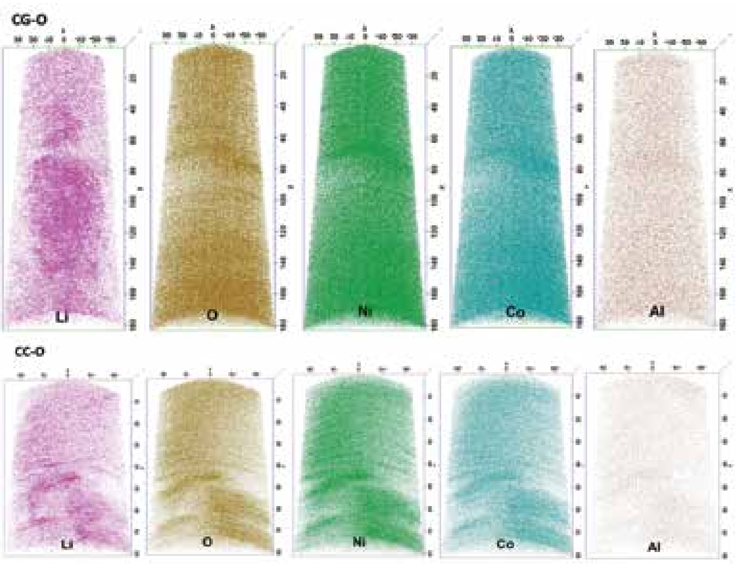

Fig. 2 APT of CC-O and CG-O

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Sodium Ion Battery: A low-cost Alternative for Stationary and Grid Energy Storage

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The increasing growth of renewable energies such as wind and solar power to circumvent the depleting fossil fuel, critically require a large-scale energy storage solution of low-cost, high efficiency and long durability for the smooth integration of their energies into grids and thus ensuring the grid sustainability. Among different energy storage systems, batteries based on electrochemical approach are considered as promising energy storage solution due to their high efficiency and flexibility. Lithium ion batteries (LIBs) have been found to be the best electrochemical energy storage systems for portable electronic devices to electric vehicles (EVs). However, limited and uneven distribution of lithium resources on earth's crust may not support LIBs to be used for large scale grid energy storage. As a low-cost alternative, sodium ion batteries (SIBs) are currently gaining huge attention for large scale grid energy storage due to abundance of sodium resources on earth's crust and their on par energy density to that of LIBs.

The R&D activities on SIBs have been initiated in ARCI and the main objective is being focused on the development of suitable electrode materials/ electrolytes with excellent electrochemical performance and demonstration of proto-type SIB using in-house developed electrodes/electrolytes. In this direction, various suitable electrolytes and electrode materials have been developed and characterised, which have shown promising electrochemical properties. The indigenous electrolytes, 1 M $NaClO_4$ dissolved in one or combination of organic solvents (e.g. PC, EC, DMC and DEC), have shown very high ionic conductivity (>10^{-2} S/cm) on-par with that of commercial Li-salt based electrolyte and their validation in large scale is under progress. Cobalt free layered type transition metal oxide cathodes, $Na_x(Mn_{1-x-z}Fe_xNi_z)O_2$ have been prepared by novel chemical approaches and have shown promising preliminary sodium ion storage performance. In-situ carbon coated NASICON-type sodium vanadium phosphate ($Na_3V_2(PO_4)_3$) and sodium vanadium fluoro phosphate ($Na_3V_2(PO_4)_2F_3$) prepared through ultra-fast gelation (<10 mins) using microwave have shown high and stable specific capacity (Fig. 8a-d). The carbon coated $Na_3V_2(PO_4)_3$ and $Na_3V_2(PO_4)2F_3$ showed ~110 and 120 mAh/g stable up to 20 cycles at 0.1C-rate, respectively. Large scale synthesis of these promising cathodes is under progress. Drastic improvement in the specific capacity and its stability has been noticed when carbon coating was performed onto the sodium titanates ($Na_2Ti_3O_7$), an ultra-low sodium intercalation metal oxide anode (Fig. 1e, f).

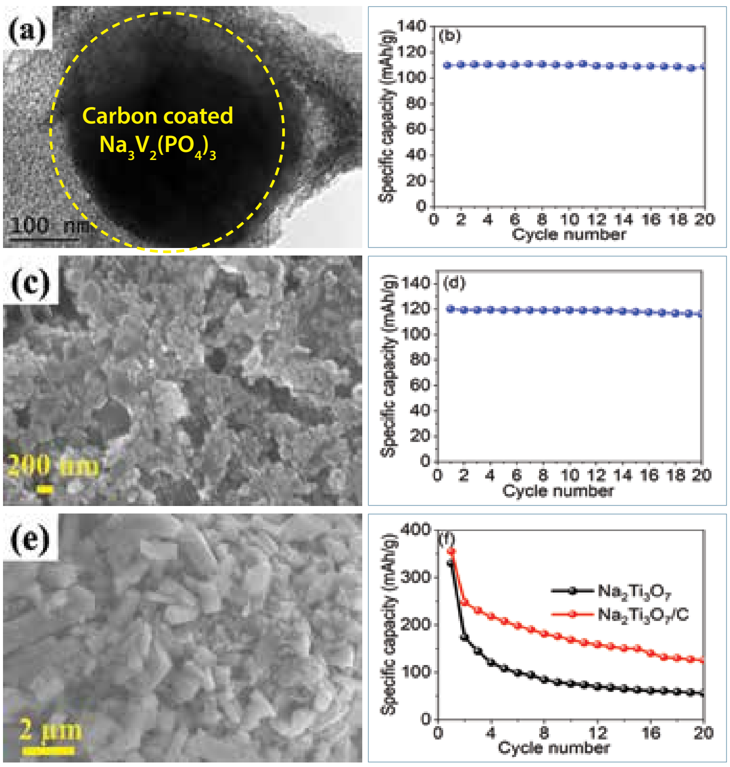

Fig. 1 (a) TEM image of $Na_3V_2(PO_4)_3$/C embedded in mesoporous carbon matrix. SEM images of (c) $Na_3V_2(PO_4)_2F_3$/C and (e) $Na_2Ti_3O_7$/C. Specific capacity vs. cycle number plots at 0.1 C-rate for: (b) $Na_3V_2(PO_4)_3$/C in the voltage window of 2.3-3.9 V vs. Na+/Na; (d) $Na_3V_2(PO_4)_2F_3$/C in the voltage window of 2.5-4.5 V vs. Na+/Na and (f) $Na_2Ti_3O_7$ and $Na_2Ti_3O_7$/C in the voltage window of 0.01-2.5 V vs. Na+/Na

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Development of Ce-La-Fe-B Permanent Magnet

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The $Nd_2Fe_{14}B$ magnet has the highest energy product among permanent magnets ($(BH)_{max}$ ~ 64MGOe). It has been gaining importance owing to the growing demand for miniaturization of high-end green technologies and renewable energy systems. The increasing consumption of rare earth magnets leads to increasing demand of critical rare earths like Nd/Dy/Tb which is a major concern. Hence there is a growing quest to develop an alternative or less Nd containing $R_2Fe_{14}B$ magnet to reduce the demand on Nd for future uses. In this context the overstocked and low cost Ce/La based permanent magnets can be potential alternatives for Nd due to the similar tetragonal structure between (Ce/La)$_2Fe_{14}B$. But the main challenge involved in Ce-La-Fe-B system is obtaining a single phase as Ce_2Fe_{14B} forms by peritectic reaction. In the present study, a systematic study on the effect of heat treatment on the phase evolution of Ce-La-Fe-B has been attempted.

(Ce,La)$_2Fe_{14}B$ was prepared by vacuum induction melting of Misch metal (65wt%Ce-35wt%La), Fe_2B and pure-Fe with suitable weight ratios. Extra (Ce-La) was added to compensate the material loss during melting. Subsequently, annealing treatment was carried out at 800, 850, 900, and 950 °C respectively, for a duration of 60, 110, and 160 h to obtain the (Ce,La)$_2Fe_{14}B$ single phase. The phase identification and microstructural features were examined using X-ray diffractometer (XRD) and Scanning Electron Microscope (SEM). Room temperature magnetic properties were studied using vibrating sample magnetometer (VSM) with a maximum field of 20 kOe. From XRD and microstructural studies, it is observed that the as cast and annealed samples have three phases namely (Ce,La)$_2Fe_{14}B$, $CeFe_2$ and α-Fe, and are marked as 1, 2 and 3 in Fig. 1. It can be observed that the volume fraction of (Ce,La)$_2Fe_{14}B$ is increases from 58% in as-cast sample to 74% for sample heat treated at 950°C for 160h.s The magnetization value decreased from 120 emu/g to 102 emu/g with increase in annealing time which can be attributed to the reduction in volume fraction of α-Fe phase (Fig 2(a)). The reduction in particle size increases the coercivity. With milling, the coercivity of sample annealed at 800 °C-60 h increased (Fig 2(b)). Further, optimization of the annealing treatment and suitable reduction of particle size, a cost effective (Ce-La)$_2Fe_{14}B$ magnet with good magnetic properties can be developed.

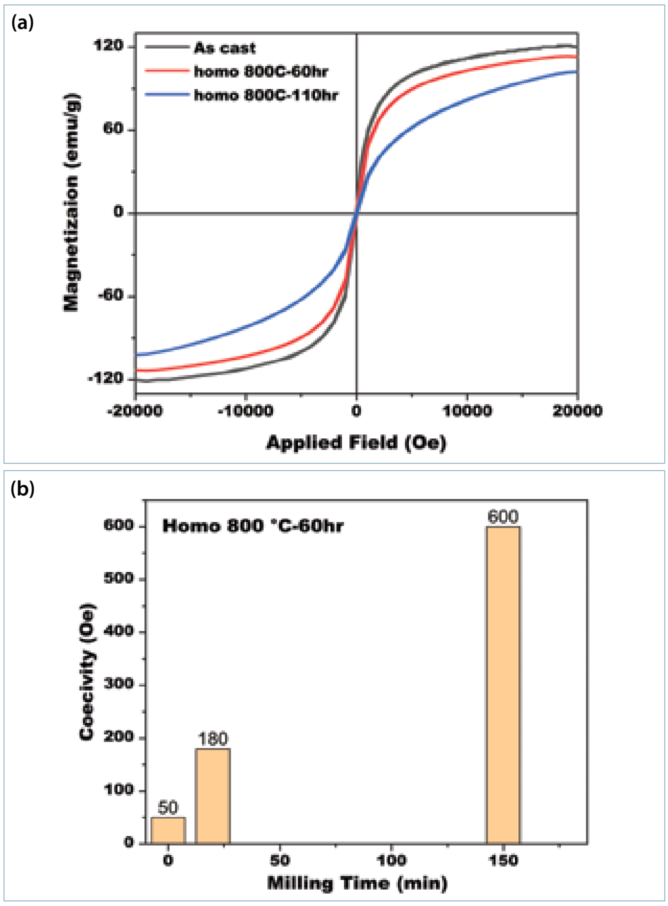

Fig. 2 (a) M vs H curves for as cast and annealed sample at 800°C (b) Coercivity change with crushing time in the annealed sample at 800°C -60 h sample

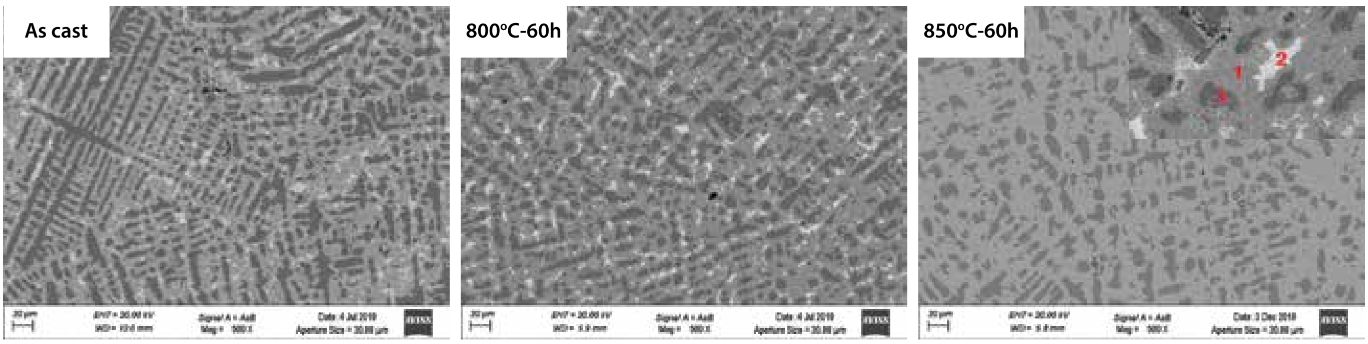

Fig. 1 SEM microstructures shows the different phases present in as cast and annealed sample; inset showing the phases present [1.] (Ce,La)$_2Fe_{14}B$, [2.] $CeFe_2$ [3.] α-Fe

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Hybrid Photovoltaic and Thermoelectric System for Improved Power Generation from Solar Energy

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In photovoltaic (PV) modules, the long wavelength solar irradiation which is not absorbed by the cell's band gap increases the cell temperature. The conversion efficiency reduces by such temperature raise, particularly to a significant extent in concentrated PV modules. Utilizing the thermal energy otherwise wasted as a part for power generation, by converting into electricity by the other types of energy harvesting technique such as thermoelectrics (TE) can improve the overall conversion efficiency of the PV panel.

In order to enhance overall energy harvesting from the solar irradiation, a hybrid energy harvesting system based on PV and thermoelectric generators (TEGs) is considered in this work. A commercially available poly-crystalline silicon solar PV panel (Vikram Solar, Model ELDORA VSP 60 AAA003) of the specification given in Table 2 is coupled with Bi_2Te3 thermoelectric modules of 5 % conversion efficiency. The IITM Research Park, Chennai, PV power plant, was selected as the location for this investigation, Fig. 1 shows the experimental arrangement. The daily performance of the hybrid system including the open circuit voltage (V_{OC}), and electrical power was monitored over the period from Feb-2020 to March-2020. The intra-day variation in power and its correlation with solar irradiance, humidity, wind flow was recorded from 9.00 AM to 5.00 PM every day and analysed.

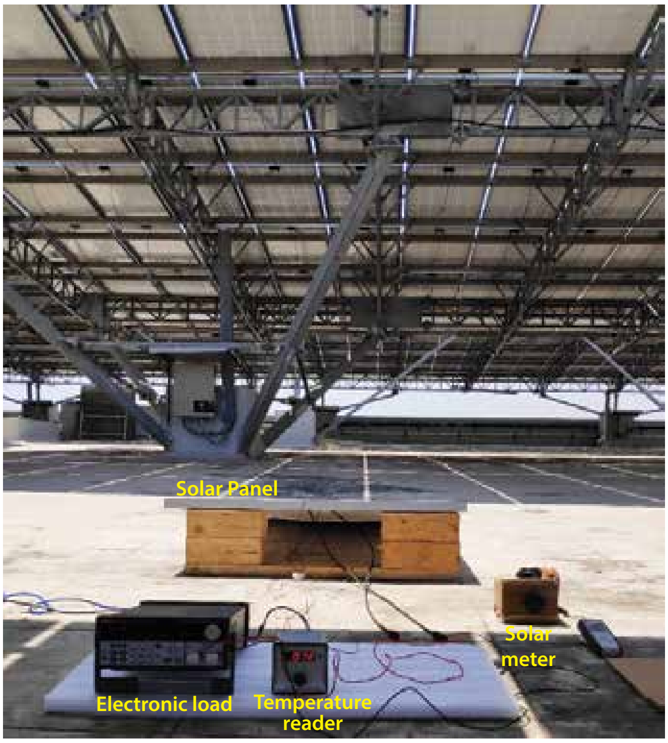

Fig. 1 PV+ TE set up

The results showed that under the complete insulation of panel backside, the temperature can reach as high as 85°C under the irradiance of 900-1000 W/m^2. In the absence of any insulation, the convective heat loss reduces the panel temperature to 54-60°C. The temperature difference between the front and back side of the panel varies from 4-8°C depending on the intensity of solar irradiation. From a single cell generating of Vmax = 0.28V, a single thermoelectric module attached at the bottom covering 7.5 % area of the cell generates Voc in the range of 0.04 - 0.14V (Fig. 2). The power under load from a single thermoelectric module is equivalent to 0.7 % of the overall power produced by a PV cell. The results show an overall system conversion efficiency of a PV cell increased by 0.6 % with just one single thermoelectric module during the peak hours of solar irradiation. The results, indicate that the considered hybrid system has high potential to play a significant role among future renewable technologies as a high-efficient hybrid energy harvester.

Table 1 Specifications of solar PV cell used in this work

Parameters	Irradiance-1000 W/m^2, T=25°C	Irradiance 800 W/m^2, T=20°C
Peak power (P_{max})	270	197
Open circuit voltage, V_{OC}, [v]	38.3	35.59
Maximum voltage, V_{max}, [v]	31.0	28
Maximum current, I_{max}, [A],	8.7	7
Short circuit current, I_{SC}, [A]	9.15	7.49
Efficiency, %	16.6	
Number of cells	60	
Area of each cell	270 cm^2	

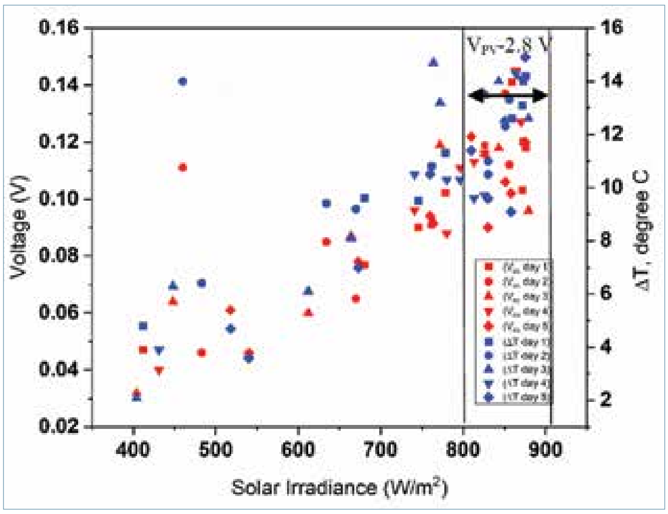

Fig. 2 V_{oc} vs ΔT vs solar irradiation in PV+ TE set up (Measurement carried out in the 2nd week of March 2020)

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Non-toxic and Cost-effective Mg_2Si Thermoelectric Materials for Power Generation

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Thermoelectric materials (TE) are the energy savers for automotive applications due to their superior power for transforming waste heat in automobiles into electrical energy and the efficiency of these materials depends on the figure of merit (ZT). Worldwide, significant research is going on to improve the ZT of the thermoelectric materials by nanostructuring, mesostructuring, band engineering and synergetically defining the key strategies to improve the ZT. Among the TE materials, Bismuth and its alloys, silicides, tellurides, antimoniodes and selenides are used in thermoelectric generators for waste heat recovery at low temperatures and intermediate temperature respectively.

In order to fabricate cost-effective TE devices, we have processed cost-effective silicide (Mg_2Si) TE materials by power metallurgy route. Polycrystalline $Mg_{2+\delta}Si$ (where δ is the excess Mg content in the starting composition of the samples and δ=0, 0.1, 0.15, 0.2) samples were processed by solid-state synthesis route using ball milling followed by rapid spark plasma sintering in order to minimize the Mg loss during processing. Hall effect measurement and Fourier Transform Infrared Spectroscopy analysis show that, the excess Mg content helps to enhance the carrier concentration and charge carrier effective mass due to the occupancy of Mg at the interstitial site in Mg_2Si structure as confirmed from the X-ray photo-emission spectra (XPS) as shown in Fig. 1(a). The influence of Mg content on thermoelectric properties, viz., electrical resistivity, Seebeck coefficient and thermal conductivity is investigated from 300 K to 780 K. A marked enhancement in thermoelectric power factor (~1.6 mW/mK^2) is obtained for $Mg_{2.15}Si$ sample at 780 K. The occupancy of excess Mg at interstitial sites reduces the lattice thermal conductivity by lowering lattice symmetry (Fig. 1(b)). A maximum figure of merit (ZT) ~0.39 $\pm$ 0.03 at 780K has been achieved in $Mg_{2.15}Si$ sample, the highest among that reported in n-type binary Mg_2Si system (Fig. 1(c)). This suggests that excess Mg content in the starting composition of $Mg_{2+\delta}Si$ helps in stabilizing the phase as well as improves the thermoelectric properties of the Mg_2Si.

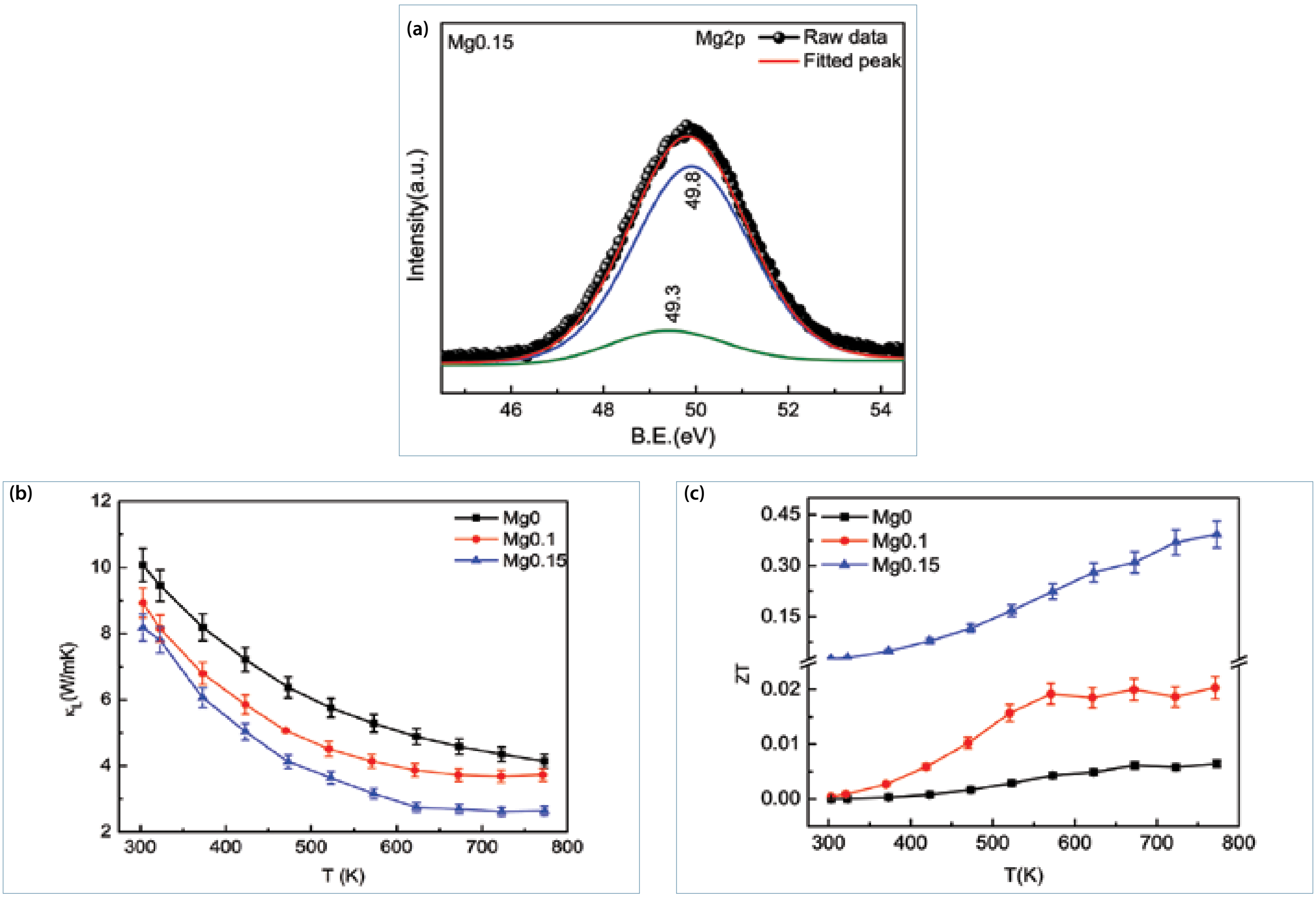

Fig. 1 (a) XPS spectra of $Mg_{2.15}Si$, (b) decrease of lattice thermal conductivity and (c) enhancement of figure of merit (ZT) with increase in Mg concentration ($Mg_{2+\delta}Si$ samples, δ =0, 0.1, 0.15 names as Mg0, Mg0.1 and Mg0.15 respectively)

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La-based Magnetocaloric Materials for Magnetic Refrigeration

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Magnetic refrigeration based on the magnetocaloric effect (MCE) has received much attention due to its advantages over conventional gas compression refrigeration as it is highly efficient, energy-saving and environment friendly. Among many other magnetocaloric materials, $La(Fe_{1-x}Si_x)_{13}$ compounds have become an intensive focus of research due to their large MCE, low cost, and tunable working temperature. NaZn13-type $LaFe_{13-x}Si_x$ ($1.0 \leq x \leq 1.6$) compounds were found to exhibit a first-order magnetic transition from the paramagnetic (PM) state to ferromagnetic (FM) state, accompanied by magnetic field-induced itinerant electron metamagnetic (IEM) transition and large volume changes near the Curie temperature (TC), which is also an important reason for the large MCE. $La_1Fe_{11.6}Si_{1.4}$, $La_{1.3}Fe_{11.6}Si_{1.4}$ and $La_{1.7}Fe_{11.6}Si_{1.4}$ were prepared by conventional arc melting. The as-cast samples are sealed in a quartz ampoule and annealed in a tubular furnace for seven days (168 hours) at 1100°C. The structural and magnetic characterization of the annealed samples was done by X-ray diffraction, and Phsyical Property Measurement System (QD-Dynacool-9T) respectively. XRD patterns (Fig. 1) show that $La_1Fe_{11.6}Si_{1.4}$, $La_{1.3}Fe_{11.6}Si_{1.4}$ have an almost single phase of NaZn13 with very less α-Fe impurity phase. Increasing La ($La_{1.7}Fe_{11.6}Si_{1.4}$) content results in 1:2:2 impurity phase in addition to α-Fe. Variation of magnetization with temperature in field cooled (FC) and field warming (FW) conditions for all the compositions taken in a field of 0.05 T is shown in the above panel of Fig. 2. To calculate magnetic entropy (ΔSM) using Maxwell's relation, isothermal magnetization curves were recorded in discontinuous mode. The bottom panel of Fig.2 shows the variation of magnetic entropy (ΔSM) with temperature. At an applied magnetic field of 3 T ΔS values are -7 J/Kg.K, -21J/Kg.K and -16 J/Kg.K for $La_1Fe_{11.6}Si_{1.4}$, $La_{1.3}Fe_{11.6}Si_{1.4}$ and $La_{1.7}Fe_{11.6}Si_{1.4}$, respectively. Huge | ΔSM| of 21J/Kg.K at a low field of 3 T is observed in $La_{1.3}Fe_{11.6}Si_{1.4}$. At ARCI, we are optimizing these alloys to obtain the magnetocaloric properties near room temperature.

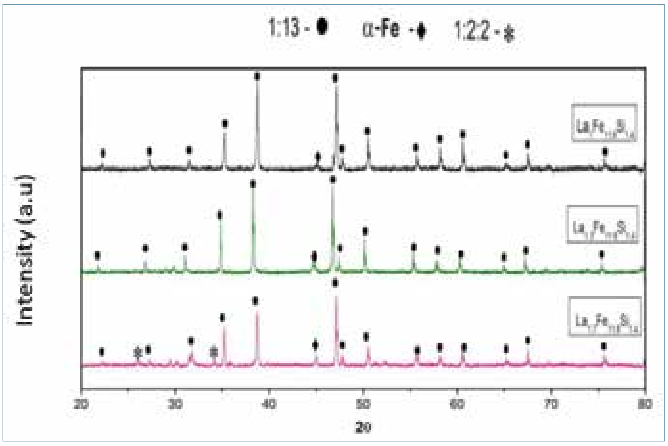


Fig. 1 XRD patterns of $La_xFe_{11.6}Si_{1.4}$ alloys

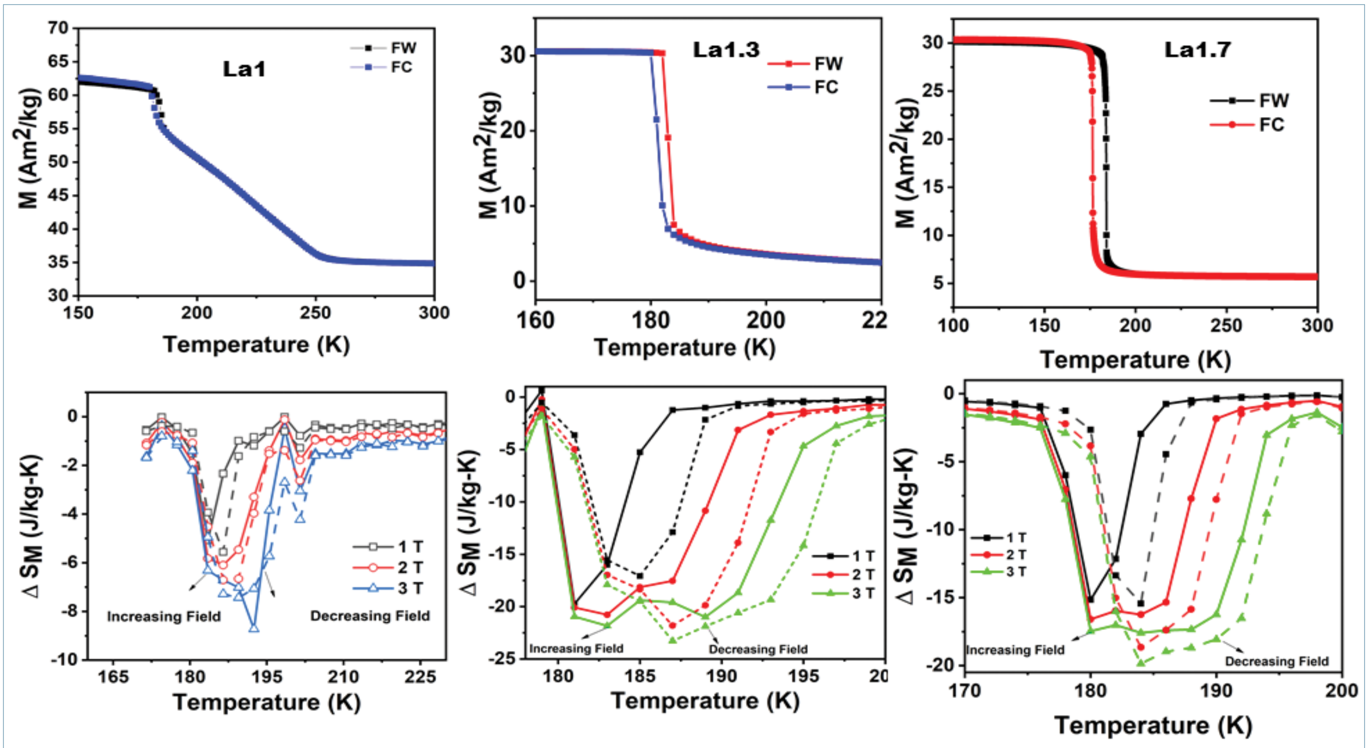


Fig. 2 Thermomagnetic curves (above panel) and variation ΔS with temperature (lower panel) in $La_xFe_{11.6}Si_{1.4}$ alloys

Contributors: Alagu Soundarya, V. V. Ramakrishna, and R. Gopalan

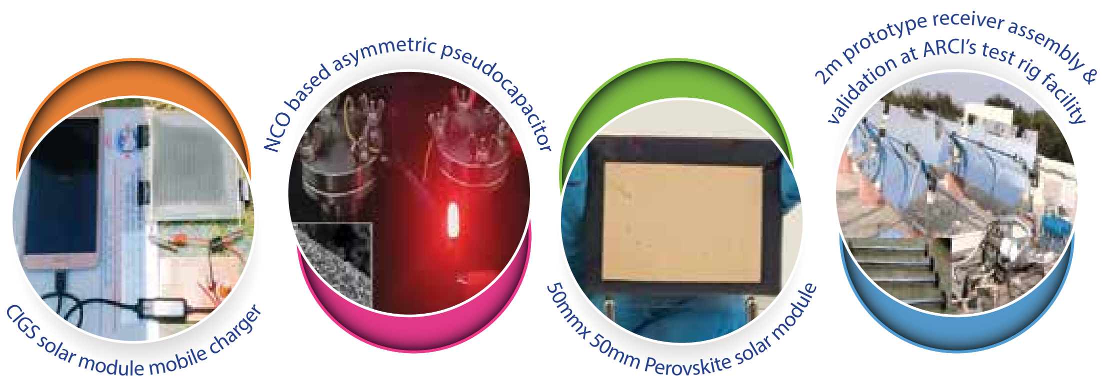
Centre for Solar Energy Materials

The Centre for Solar Energy Materials (CSEM) actively pursuing research and technology development activities on the entire value chain of solar thermal and photovoltaic with an emphasis on indigenous design, development and manufacturing of solar energy system and components.

The flagship technology development project on easy-to-clean coatings provides relief to high soiling losses (0.6%/day) observed in solar photovoltaics and garnered attention by the industry. Suitability for easy application by simple spray and wipes techniques and robustness in all sorts of Indian weather conditions attracted interest from solar panel manufacturers and power plant developers, as highlighted in bottom left figure. A technological know-how has been transferred to M/s. NETRA (NTPC Ltd), New Delhi, for commercial utilization. More recently, an agreement has been signed with M/s. Marichin Technologies, Mumbai for technology transfer, which plans to mass-produce the easy to clean material for broader PV market absorption. Now, we are focusing on the incorporation of superhydrophobicity in antireflective coating for the development of futuristic 'self-cleaning antireflective coating technology' for next generation solar energy conversion devices.

The sustained research and development activities carried out at CSEM over a last few years now reached the stage of prototype and field level performance assessment, as shown in bottom right figure. Notable achievements include monolithically integrated 100mm x 100mm CIGS thin film solar module, the demonstration of NCO based asymmetric pseudocapacitor with specific capacitance of 91.5 F g^{-1}, fabrication of 50mm x 50mm perovskite solar module with 8.2% power conversion efficiency and 2-meter length solar receiver tube with targeted properties (Abs: 93-94% & Heat loss: 0.14 at 250°C) for medium temperature concentrated solar thermal (CST) applications.

Easy-to-clean coating technology demonstration and transfer to the industry



Prototype development and field level performance validation

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Novel Spinel Nanostructure based High Thermal Stable and Wide-Angle Spectral Selective Absorber Coating

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Spectrally selective absorber coating (SSAC) is an essential component for a CST system that selectively absorbs and emits the radiation at a cut off wavelength depending upon the operating temperature. SSAC having wide-angle absorption in the CST system is a great advantage to improve the photothermal efficiency of a system, since the solar absorptance is a function of the angle of the incident light. Furthermore, our atmosphere comprises ≈10% diffused sunlight from incident solar power, which is a substantial fraction. Thus, in order to achieve high photothermal conversion efficiency, SSAC is required to have a wide-angle absorption to capture the diffused radiation. In addition, current CST systems have fallen short of photothermal conversion efficiency due to lack of high thermally stable SSAC with good optical properties.

In this regard, we have developed a novel spinel nanostructure-based high thermal stable and wide-angle SSAC by using a facile Sol-gel dip-coating technique. We utilized the tri transition metal (Cu, Mn, and Ni) precursors for the development of novel spinel structured SSAC and optimized process parameters such as individual metal content, withdrawal speeds, annealing temperature, and duration. Figure 1(a) and 1(b) shows the schematic illustration and reflectance spectra of spinel nanostructure-based tandem absorber, respectively.

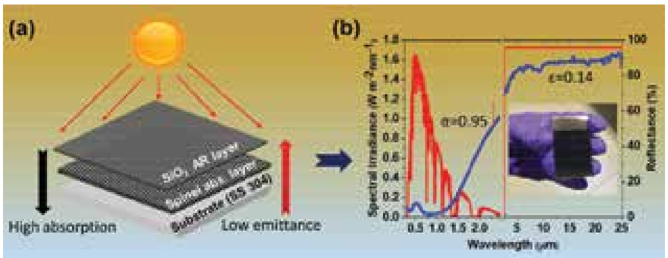

Fig. 1 (a) Schematic illustration of spinel nanostructure-based tandem absorber (b) reflectance spectra of the tandem absorber (Inset: Tandem absorber (5mm(L)x3mm(W)x1mm(T))

The developed spinel SSAC exhibited good optical properties such as solar absorptance (α)=0.88 and low spectral emittance (ε)=0.14. Further, a SiO_2 nanoparticle layer deposited over on a spinel nanostructured absorber to act as an antireflective layer for the improvement of solar absorptance. Thus, the developed tandem layer exhibited an excellent solar absorptance (α)=0.95 and low spectral emittance (ε)=0.14, respectively. In addition, the spinel nanostructure-based tandem layer has exhibited outstanding wide-angle solar absorptance with a net enhancement of 5 to 74% over an angle of incidence ranging from 10 to 80°. Figure 2(a) shows the contour plot of the tandem absorber and (b) angler selectivity graph for spinel and tandem absorbers.

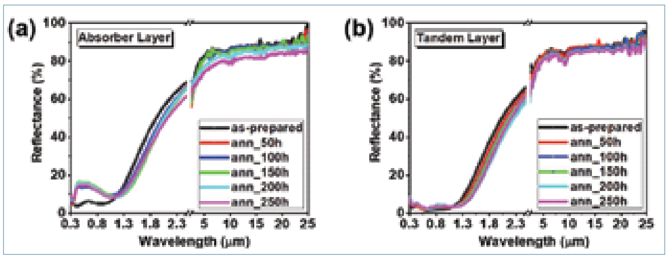

Fig. 2 (a) Contour plot and (b) Solar absorptance spectra of the tandem absorber (Inset: Schematic illustration of sample measurement from the angle of incidence 10 to 80°)

The deposited SiO_2 nanoparticle layer plays a vital role as an antireflective cum thermal barrier layer on top of spinel absorber. It serves as a protective layer to prevent further oxidation of spinel absorber and exhibits high thermal stability at 500°C for 250h. Figure 3(a & b) shows the reflectance spectra of spinel absorber tandem layers at 500°C for 250h.

Apart from that, the developed coatings were widely characterized by Grazing Incidence XRD, thermogravimetric techniques, High-Resolution Transmission Electron Microscopy, and Universal Measurement Accessory to study the structural and optical properties. The developed high thermal stable wide-angle SSAC presents an excellent steadiness of solar absorptance and spectral emittance in air at higher temperatures makes them ideal candidates for medium and high temperature solar thermal applications.

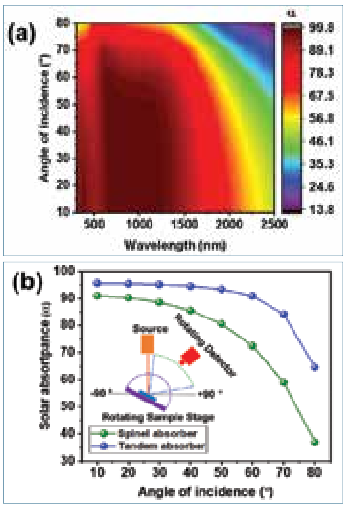

Fig. 3 (a) Reflectance spectra of (a) spinel nanostructured absorber and (b) tandem absorber annealed at 500 °C in air for 250 h with 50h interval

Contributor: M. Shiva Prasad

Transition Metal-based Spinel Oxide as High Photo-Thermal Conversion Efficient Coating for Concentrated Solar Thermal application

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Solar energy to thermal energy conversion has more potentiality in the coming years, as most of the energy we consume for the heating & cooling sector and which requires eco-friendly conversion technologies to reduce the global-warming problem. For any process heat application of < 300°C temperature, Concentrated Solar Thermal (CST) technologies like parabolic trough, linear Fresnel reflector are most suitable for Indian geographical conditions. But the technologies are not yet attained Levelized cost of energy, because of the high system and component level costs. In both of these technologies, the solar receiver tube is one the key important element contributes to the high cost and required much more attention to convert solar energy into thermal energy efficiently. Wet-chemical based deposition method is one of the economically viable processes to develop solar receiver tube for process heat application.

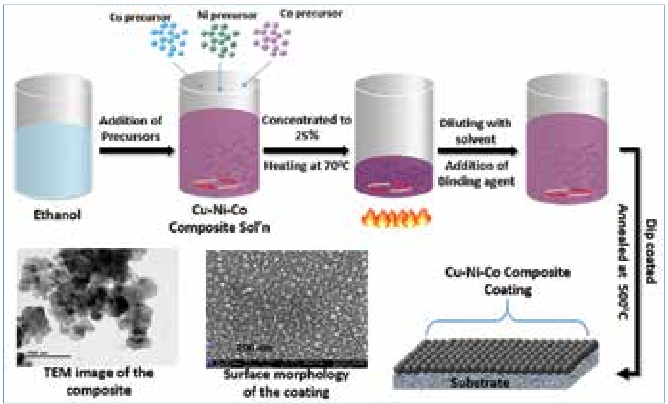

Fig. 1 Schematic of the sol preparation and coating formation, properties of the spinel oxide coating.

The main objective of this work is to develop a cost-efficient solar receiver tube in wet-chemical method for CST application. The materials like spinel oxide have attracted more attention to get high-temperature stable and solar selective absorber coating for receiver tube application. Spinels (AB_2O_4) has characteristic properties like inter and intra band transitions, metal to metal or ligand to metal transitions, made the materials optically selective for solar applications. In order to coat the spinel material as a solar selective absorber, wet-chemical based deposition method has been chosen and developed transition metal-based spinel absorber on stainless-steel substrate (Figure 1). Spinels like $NixCo_{3-x}O_{4-z}$ and $Cu_xNi_yCo_{3-x-y}O_{4-z}$ are prepared as a base absorber layer and an optical enhancement layer of SiO_2 has been coated on base absorber layer to improve the optical properties. Finally, the multi-layer tandem stack formed as a solar selective absorber coating (absorptance: >95% and emissivity: <15%) with temperature stability of 400°C. The stable tandem absorber layers exhibited wide angular selectiveness from 10 to 50° for binary based spinel tandem absorber and 10 to 60° (Figure 2) for ternary based spinel tandem absorber, thus making them to attain higher concentration ratios. Further, the real photothermal conversion efficiencies have been calculated by considering the radiative loss from the absorber surface and achieved about 90% of conversion efficiency for the tandem layer stacks of both binary and ternary metal spinel absorbers at 300 and 400°C (Figure 3). From the observed results, the ternary spinel based tandem absorber exhibits high spectral selectivity, wide angular selectivity, low thermal emissivity and high photothermal conversion efficiency. Therefore, the tandem layer approach of ternary spinel-based absorber coating by the wet-chemical method is a good candidate for high photothermal conversion efficiency for the receiver tube in concentrated solar thermal system.

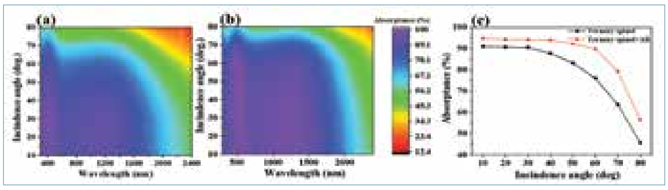

Fig. 2 The contour plots of (a) single layer coating of ternary metal based spinel (b) tandem layer coating on ternary metal based spinel absorber and (c) comparison graph for the angular selectivity of single and tandem layer coatings

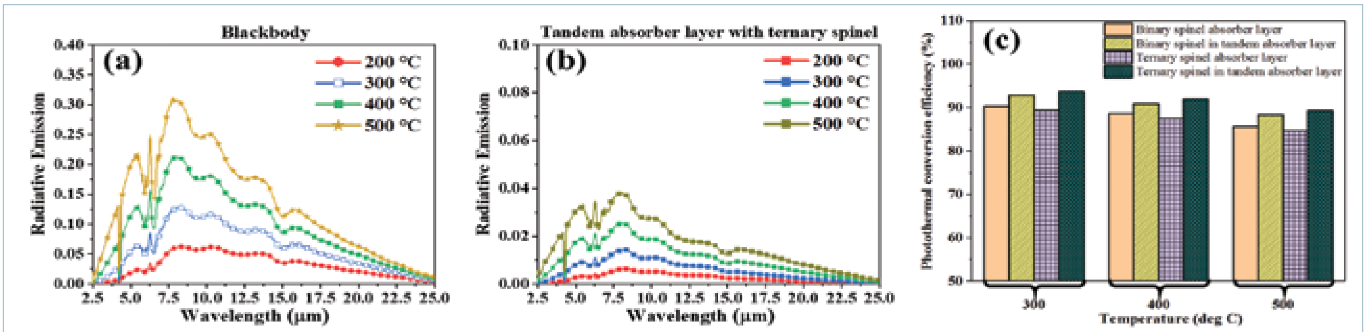

Fig. 3 Radiative emission spectra of (a) the blackbody (b) tandem absorber layer with ternary metal spinel measured through FTIR at various temperatures and (c) photothermal conversion efficiencies of different absorber layers at different temperatures

Contributor: S. Sakthivel

Synthesis of Stable Dion-Jacobson Quasi-2D Perovskites for Highly Durable Perovskite Solar Cells

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Perovskite solar cells (PSC) are getting lot of attention in the last decade, due to promising photovoltaic performance (25.2%). In spite of these excellent performances, PSC could not be commercialized due to the instability issue in ambient atmosphere. To solve the issue, researchers have developed quasi-2D perovskite, which is combination of long-alkyl chain organic material (benzylamoonium) and short-alkyl chain organic material (methylammoniium). The newly developed quasi-2D has high moisture tolerance due the hydrophobic nature present in the long-chain organic molecules. Eventhough, the bulky cations gives high stability; it decreases the power conversion efficiency (PCE) because of wide bandgap (beyond 1.7eV). And also it increases the exciton binding energy more than 300 meV (depends on incorporated cation properties and composition), due to quantum confinements as well as dielectric confinement effects. Therefore, it's a big challenge to synthesize highly stable perovskite without sacrificing PCE. Figure 1 showing the schematic diagram of bifunctional conjugated cation based Dion-Jacobson quasi 2D perovskite and its corresponding charge transport in a typical PSC.

In this work, we introduced a novel bifunctional conjugated organic molecule (3-ABAHI) based quasi 2D perovskite, which is extremely stable in high humidity environment with a narrow energy bandgap. Here, newly synthesized 3-ABAHI mixed with methyl ammonium iodide (MAI) in different stoichiometry molar ratio and synthesized Dion–Jacobson quasi 2D perovskite with molecular formula (ABA)(MA) n-1PbnI3n+1. We increased the incorporation of 3-ABAHI from 0% (for n=∞) to 50% (for n=2) by mol at the place of MAI in MAPbI3 crystal. The bandgap of newly synthesized Dion-Jacobson (DJ) quasi-2D perovskites are similar with the bulk perovskite (1.57eV to 1.58eV). It may be due to the absence of effective quantum confinement or dielectric confinement effect. Since, it formed a single spacer layer, where 3-ABAHI is a bifunctional conjugated molecule with benzene backbone provide efficient charge carrier transport path instead of a bi-space layer of low dielectric constant & high potential barrier.

We measured small-angle X-Ray diffraction of (ABA)(MA)2Pb3I10 & MAPbI3 film and we got diffraction peaks in lower 2θ values (5° to 8°) only for (ABA)(MA)2Pb3I10 that confirms the formation of layered quasi 2D structure. Figure 2a shows the photographic image of the bulk perovskite (3D) and DJ-quasi-2D perovskite from day 1 to day 30. From day 6-8 bulk perovskites started color change, which indicates the degradation, whereas the DJ-quasi-2D perovskite remains the same even after 30 days. Tauc plots (Figure 2b and c) of the corresponding films were measured, which also reveals the bulk perovskite degraded back to precursor stage (PbI2 phase); where the bandgap changed from 1.57eV to 2.34 eV. But the new perovskite bandgap almost remains the same. This shows the new DJ-quasi-2D perovskite not only can yield high stability, which may not also affect the PCE. PSCs are being developed using this new perovskites.

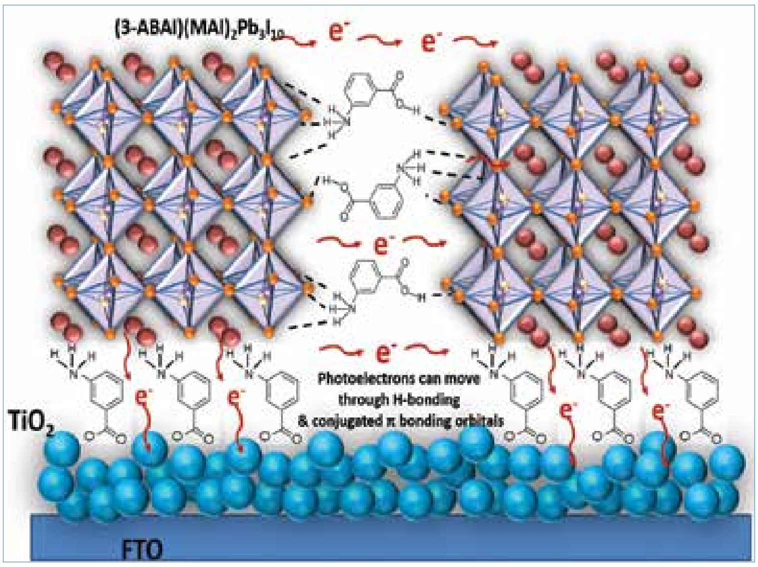

Fig. 1 Schematic illustration of bifunctional conjugated cation based Dion-Jacobson quasi 2D perovskite and its corresponding charge transport in a typical PSC

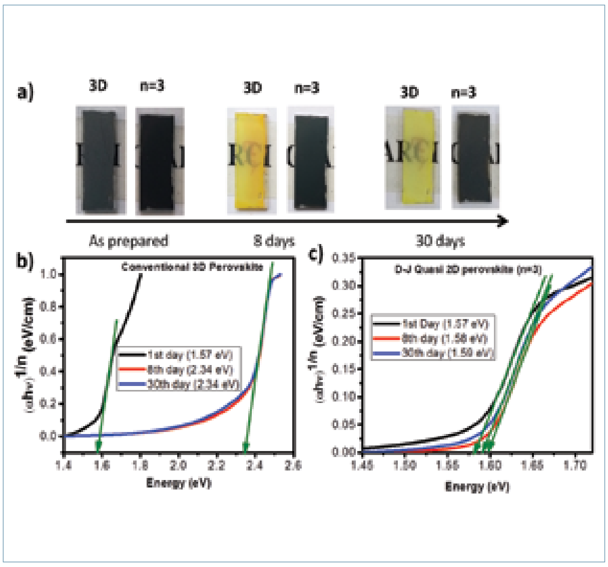

Fig. 2 (a) Digital photographic images of the bulk perovskite MAPbI3 (3D) and new DJ-quasi-2D pervoskite from day 1- day 30, (b) and (c) Tauc's plot for the same

Contributors: Arya Vidhan, Easwaramoorthi Ramasamy and Suresh Koppoju

Development of 12.95 % efficient $Cu(In,Ga)Se_2$ solar cells and method of scaling to monolithically integrated prototype modules on 100 cm^2

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Solar photovoltaic (PV) devices are playing noteworthy role in terms of its considerable contribution in renewable energy. Apart from highly matured silicon based technology, thin film solar cell technology in last few years has emerged as potential candidate to contribute and increase its application in various sectors mainly in building integrated PV as CIGS is advantageous over others, such as its application in diffuse light, it has high absorption coefficient and it can be easily made on various substrates.

For high efficiency CIGS solar cells, the high degree of compositional uniformity, Ga grading for graded band gap and very high quality interfaces is essential. Here we use a two-step process, sputtering of CuGa-In precursor followed by atmospheric rapid thermal selenization using elemental selenium to make CIGS absorber on in-house made 25 cm^2 Mo coated glass substrate. CIGS absorber with large grains and high degree of Ga grading was obtained by optimizing selenization conditions, as can be seen in cross section FESEM and EDS elemental mapping obtained by line scan across the film, Fig 1. High concentration of Ga towards the bottom of CIGS absorber expected to result in graded band gap in CIGS. CdS buffer layer was coated on prepared CIGS, the device fabrication was competed using ZnO/AZO front contact. 24 number of devices of the size of 0.48 cm^2 was isolated using mechanical scribing on 16 cm^2 full area. We report, maximum power conversion efficiency up to 12.95% on single device with average of 8.35% from 24 devices, isolation pattern and device configuration shown in Fig 2.

A statistical data analysis of the PV performance parameters of each device on 16 cm^2 area was systematically mapped to further design and scale up the process to develop monolithically integrated modules on 25 cm^2 area. P1, P2 and P3 scribing was employed during processing steps, schematic in the inset of Fig 3. Greater than 5% efficiency with open circuit voltage of 3.7 V was attained on 25 cm^2monolithically integrated CIGS solar module. The process was further scaled to fabricate 100 cm^2 prototype module in monolithical integrated configuration. The module comprises 19 number of cells (each cell 9 cm x 0.5 cm) serially interconnected by monolithic configuration, exhibiting open circuit voltage of 7.8 V and efficiency about 2%. A real time application demonstration of mobile phone charging using continuous power output from 100 cm^2 prototype module is presented in Fig 3. Further improvement in performance and exploration of various other application of these modules is underway.

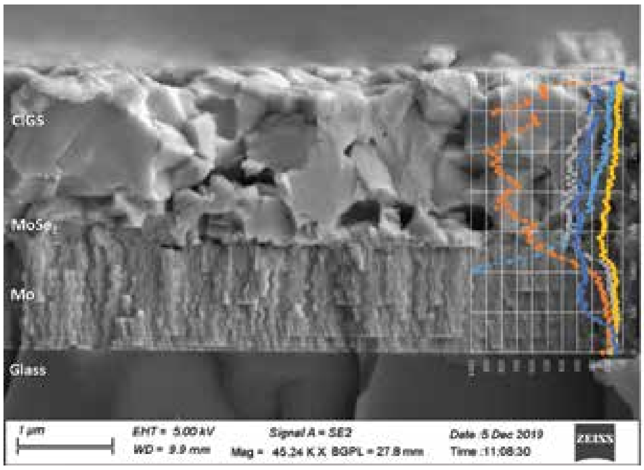


Fig. 1 FESEM cross section and EDS elemental line scan indicating compositional variation across the Mo/CIGS thin film

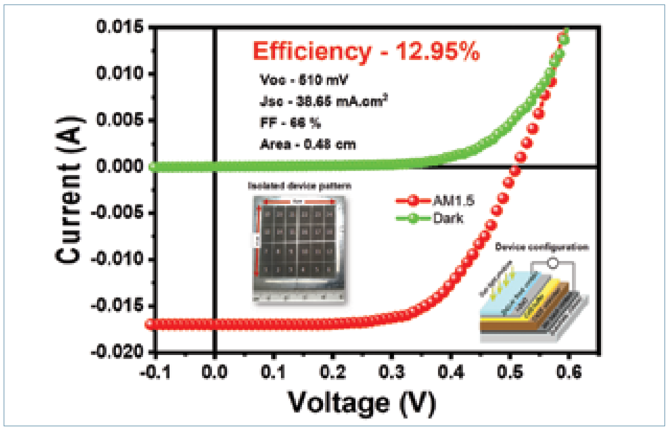
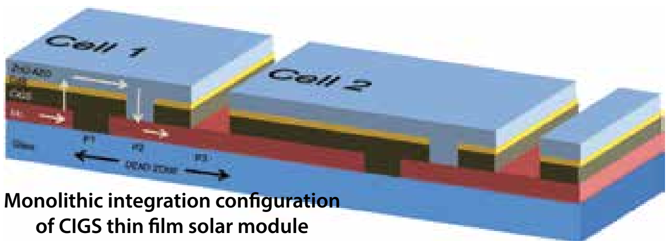


Fig. 2 Representative I-V characteristics of CIGS thin film solar cell on 0.48 cm^2 area, cell configuration inset



Monolithic integration configuration of CIGS thin film solar module

Fig. 3 Real time application demonstration of 100 cm^2 monolithically integrated prototype CIGS module for charging cell phone

Contributors: Amol C. Badgujar, Brijesh Singh Yadav, Golu Kumar Jha and G. V. Reddy

Oxygen Vacancy Induced $NiCo_2O_4$ Nanosheets: A strategic Approach towards High Performing Pseudocapacitors

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Greenhouse gas generation is an inevitable consequence of energy infrastructure that relies on the combustion of fossil fuels. Renewable energy sources like wind and solar act as practical alternative solutions. However, the intermittent energy produced from these sources needs to be stored and released on demand. This challenge highlights the significance of energy storage technologies and in particular, "Supercapacitors". Over the past few years, transition metal oxides have witnessed a huge research interest owing to their non-toxicity, abundance and superior electrochemical activity than EDLC's. Many transition metal oxides are employed as electrodes for supercapacitor applications including RuO_2, MnO_2, NiO, $NiCo_2O_4$, Co_3O_4, V_2O_5 etc. Amongst all spinel $NiCo_2O_4$ (NCO) is of particular interest due to its high theoretical capacity, cost-effectiveness, superior electronic conductivity and electrochemical performance than its individual counterparts. However, the low electronic conductivity of the metal oxides still inhibits their commercialization due to their poor cycle life stability and inevitable agglomeration. Therefore, the current research is focused more on improving the conductivity and synthesis of these oxides to their nanoscale level.

In our work, we have synthesized NCO by a cost-effective, sustainable and highly scalable electrodeposition technique on carbon paper substrate followed by a post annealing treatment resulting in a binder free electrode devoid of any additives or current collector requirements. With an aim to improve the conductivity of the synthesized NCO, oxygen vacancies were introduced by a less toxic chemical reduction method employing varying molar concentrations of NaBH4 as an oxygen scavenger to obtain nanosheet morphology (Fig.1a). Introduction of oxygen vacancies has three main advantages; namely enhancement of diffusion of charge carriers to increase the conductivity of metal oxides, increment in the adsorptivity of hydroxide ions in the aqueous medium, and the oxygen vacancies itself acting as dynamic sites for faradaic mechanisms, thereby increasing the specific capacitance (C_{sp}) of pseudocapacitors. The electrode thus synthesized has resulted in a superior electrode performance with a maximum Csp of 2065 F g^{-1} at 1 A g^{-1} current density and an excellent capacitive retention of 89.3% for 10000 charge-discharge cycles. This is due to the fact that the electrons that were present previously on the oxygen 2P orbital are now at closer proximity to the Ni^{2+}, Co^{2+} and O atoms, increasing the electron delocalization, conductivity and thereby the charge transfer kinetics leading to higher charge storage.

With the electrode thus designed an asymmetric supercapacitor (ASC) was fabricated having NCO as positive electrode and activated carbon derived from jute stick as the negative electrode. The device so formed resulted in a high specific capacitance of 90.5 F g^{-1} at 0.5 A g^{-1} with an impressive cycle stability of 90.6% for 10000 cycles as shown in Fig.1(b-c). Thereafter, in a view to illustrate the capability of the fabricated device for a new generation of electronic systems an LED and a DC fan were run by connecting the two devices in a series connection (Fig.1 d). This shows that the approach used herein is not only facile and scalable, but the oxygen vacancies incorporated NCO is a promising electrode for next generation supercapacitors.

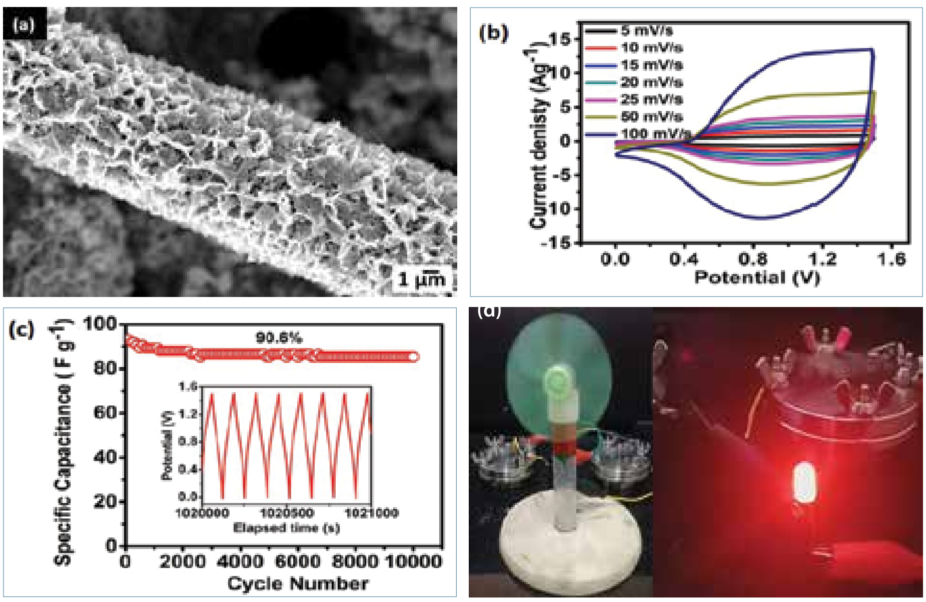

Fig. 1 (a) FESEM image, (b) Cyclic voltammetry of ASC at different scan rates, (c) Cycle stability at 2 A g^{-1} and (d) Practical demonstration of LED and DC fan

Contributors: Pappu Samhita and T.N. Rao

Operational Stability of Perovskite Solar Cells as per evolving ISOS norms

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Metal halide perovskites emerged as potential candidate for solution-processable high performance solar cells. The energy conversion efficiency of perovskite solar cells (PSCs) rapidly progressed and state-of-the art PSCs based on composition engineered perovskite absorber material show > 25% under standard test conditions. Degradation of metal halide perovskites in the presence of moisture, light, temperature and electric field affecting the stability of PSCs. Grain boundaries in perovskite absorber layer as active cites for moisture ingress from ambient and result in structural and performance degradation. This is due to the amorphous intergranular layer, which consists of a non-stoichiometric ratio of lead iodide (PbI2) and methylammonium iodide (CH3NH3I) that allows rapid diffusion of moisture into the film. Hence, one of the substantial route to make the PSC stable without increasing its complexity is the intrinsic modification of the material itself. By increasing the grain size or by decreasing the number of grain boundaries, stability of PSCs can be improved. The grain boundaries also act as recombination sites for charge carriers, resulting in lower diffusion lengths, higher trap densities, shorter carrier lifetime, and mobility leading to efficiency losses. Single crystalline perovskite promises to address these shortcomings due to the absence of grain boundaries. Here, we have developed large-grain MAPbI3 perovskite absorber by inverse temperature crystallization (ITC) technique to address this issue. Polycrystalline MAPbI3 films made up of sub-micron size grains also developed as a control.

The International Summit on Organic Photovoltaic Stability (ISOS) protocol is used at large by the scientific community to assess the stability of PSCs. One such test ISOS-D-3 is a preliminary study routinely employed for the evaluation of moisture stability of perovskite absorber material. Figure 1 shows FE-SEM images of MAPbI3 perovskite film subjected to various temperature (35, 60, 85 ˚C) and 85 % RH for 6 hours. As the temperature increases from 35 ˚C to 85 ˚C, polycrystalline MAPbI3 no longer contains perovskite phase and transforms to PbI2 as evident from XRD analysis while large-grain MAPbI3 film still has the perovskite phase intact with a slight presence of PbI2 which is also seen in the digital photographs. The grains coalesced due to the effect of high temperature and humidity whereas polycrystalline film degraded completely revealing the substrate surface beneath. This result shows that large grain films are more stable to stable to moisture and number of grain boundaries plays a crucial role in the degradation of halide perovskites.

Perovskite solar cells are fabricated in a HTM-free and mesoporous device configuration and their device parameters monitored over period of time (Fig.2). The conventional device retained only 35% of its PCE when aged for 1500 hrs. This decrease in efficiency is due to the decreased absorbance and morphological transformation that happens over time. On the other hand, device prepared using large-grain absorber film retained more than 70 % of its PCE even after 5000 hrs of aging, which is one of the highest reported stability amongst HTM-free PSCs. Work is in progress to extend the stability studies in harsh environmental conditions (combination of high temperature and moisture) prescribed in ISOS framework.

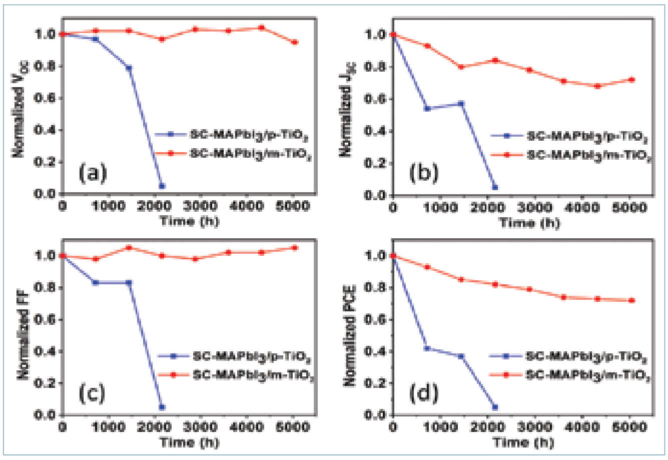


Fig. 2 Stability of perovskite solar cells aged in the ambient at open-circuit conditions

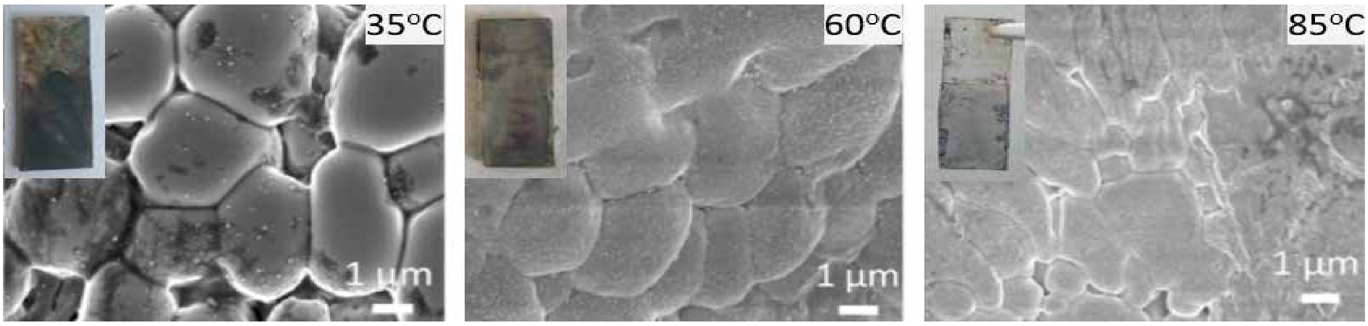


Fig. 1 FESEM images of large-grain perovskite films grown by Inverse Temperature Crystallization method subjected to three 3 different temperatures and 85% RH. Inset shows the digital photograph of the corresponding electrodes

Contributor: B Ramyakrishna

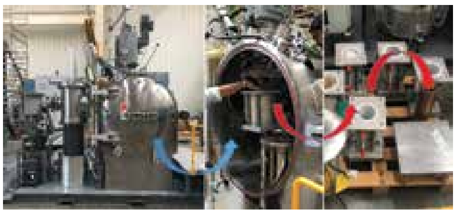
Centre for Nanomaterials

The major research activities being carried out at Centre for Nanomaterials are: (i) Large scale production of both anode (Lithium titanate) and cathode (Lithium iron phosphate) materials for Li ion battery, (ii) Super capacitors for electric vehicle applications, (iii) oxide dispersion strengthened steels for high temperature applications, (iv) Development of tungsten (W) based jet wanes, (v) Two dimensional transitional metal sulphides as additives to the lubricants and grease and as catalysts in oil refineries and petrochemical industries, (vii) Development of powders for additive manufacturing, (viii) Bio-degradable alloys for implant applications, (viii) Aerogels for paint as well as for water filtration, (ix) Coated Fe/Fe alloy composites for soft magnetic applications and (x) Solar hydrogen generation materials.

Plant engineering for the bulk production of cathode (LFP), anode (LTO) and porous carbon material was carried out for the economic feasibility. International patents for the production of LTO were filed in USA, Germany, Japan, South Korea and China. Further, an Indian patent for the method of producing nanoporous carbon material from petroleum coke and its performance for Supercapacitor and Li-ion capacitor was filed. Field trials for the application of both LTO and LFP materials are being carried out for eventual technology transfers. Successfully developed 100 mm dia. W plates for jet wane application and supplied 32 numbers to Defence Research and Development Laboratory (DRDL) against the supply order for field trials. An Indian patent for the method of producing W plates was filed. Development of nano boron powder as an additive to jet fuel was successfully completed under ARDB project and 1 kg of nano boron powder was supplied to Gas Turbine Research Establishment (GTRE) against the supply order for field trials. An Indian patent for the method of producing nano boron powder was filed. The new activity initiated last year progressed towards the development of biodegradable Fe-Mn alloy stents, which are under in vitro and in vivo studies. More activities like development of solid state electrolytes, electrode materials for Na-ion battery and high entropy alloys were initiated.

Major facilities like vacuum induction melting furnace (10 kg capacity), semi pilot plant facility for the fabrication of super capacitors (1000 F capacitance) and low as well as high cycle fatigues machines (RT - 1000°C) were established. Other minor facilities like powder classifier, pot mill, glove box and high temperature tubular furnace were also established.

Tungsten (W) Jet wane



Vacuum induction melting furnace

Low and high cycle fatigue testing machines

Biodegradable Fe-Mn alloy stents

Semi pilot plant for the production of supercapacitors and photograph of jelly rolls as inset

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Large Scale Production of $Li_4Ti_5O_{12}$ anode for Hybrid/Electric Vehicles Application

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Conventional Lithium Ion Batteries (LIBs) are unsuitable for vehicles applications with high-power requirements, as they exhibit low rate capability. For Electric vehicles (EVs) to become attractive, battery charging should be completed in a few minutes. Recently, lithium titanium oxide (LTO) batteries are considered as advanced lithium-ion battery technology that replace the graphite in the anode with LTO nanocrystals, giving it a larger surface area over carbon, allowing the electrons to enter and exit the anode very quickly. This, in turn, makes it one of the faster-charging batteries in the Li-ion category. Further, carbon free and lower operating voltage of this technology avoid thermal runaway or overheating which is a main cause of fires in traditional Li-ion batteries. LTO based batteries are used in Mitsubishi's i-MiEV Fit EV models and TOSA's Electric bus, Switzerland. Globally, at present, Toshiba, Altairnano, Microvast and Leclanche manufacture LTO based batteries for electric vehicle and utility applications. LTO batteries are more attractive for Indian climatic conditions where the temperature reaches 45-48°C in summer. This motivates for indigenous electrode materials technology and associated components that are essential for the manufacturing of Li-ion batteries within the country.

ARCI successfully developed indigenous LTO material technology by adopting a simple, cost-effective and solid state high energy milling process with the production capacity of 50 Kg per month using Ti (TiO_2) and Li (Li_2CO_3) precursors. Further efforts were made to synthesize LTO by utilizing different indigenous Li_2CO_3 (SRL, Toyota, & BARC) and TiO_2 (Indian-TTP-Kerala, VVTP-Tamil Nadu) sources available in India and found that devloped LTO technology siuitable for all sort of precursors as evident from the electrochemical performance (Fig. 1). Fabrication of single/multilayre pouch cell with the capacity of 0.5Ah has been fabricated using ARCI's large scale synthesized LTO as anode and commercial NMC (532) as cathode as shown in Fig. 2. Bench mark studies revealed that the specific capacity of LTO synthesizedby high energy milling process (170 mAh/g) is higher than commercial LTO (116 mAh/g). Interestingly, it was found that the cost required for production of ARCI indigenous LTO is less than the cost of commercial LTO electrode material. The indigenous methodology developed by ARCI to produce LTO will significantly lower the battery cost per kilowatt-hour kWh, thereby making Li-ion batteries affordable. Further the developed LTO technology has been filed in India as well as foreign countries including USA, Japan, Germany, South Korea and China and possible technology transfer to automobile companies has been initiated.

Fig. 1 Process flow chart for the production of LTO

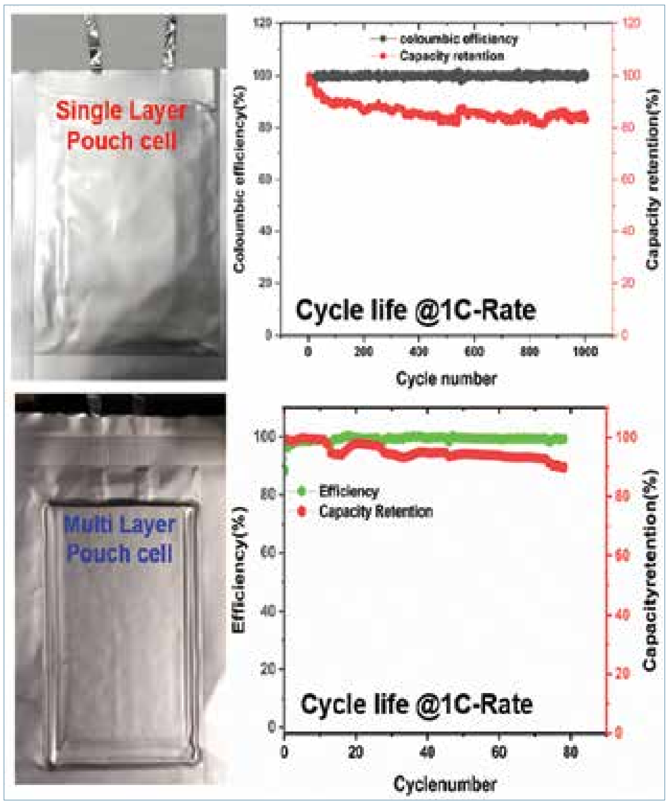

Fig. 2 Single/Multilayer Pouch Cell synthesized using ARCI's large scale synthesized LTO material and their electrochemical performance

Contributors: Pavan Veluri Srinivas, R. Vijay and T. N. Rao

Development of High Power Cathode Material (C-$LiFePO_4$) By High Energy Milling Process

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Li-ion batteries are the workhorses for electric vehicles which are being aggressively promoted because they are free of pollution. Currently, India imports 100% of these expensive batteries mostly from China. It is important to understand that 40% of the battery cost comes from the cathode and the anode materials and therefore, the indigenization of these electrode materials technology and associated components are essential for the manufacturing of Li ion batteries within the country.

$LiFePO_4$ (LFP) is a olivine (rock-forming mineral), discovered by John B Goodenough, who shared the 2019 Nobel prize in chemistry for the development of Li-ion batteries. It is an excellent cathode material by virtue of the intriguing features like the high maximum available capacity of 170 milliampere hours per gram (mAh/g), has a single voltage plateau of 3.45 V. Its characteristic features of non-toxicity (cobalt free) economic viability and long cycle life make it an ideal material for Lithium-ion batteries. The thermal stability of LFP is high and excellent with no exothermic reactions up to 400°C and hence ideal for Indian climatic conditions. Since India are unable to afford high end battery chemistries (NMC, NCA) due to high cost, the development of LFP based batteries which are suitable to India is need of the hour.

Realizing the need of $LiFePO_4$ in India, ARCI, developed innovatively a cost-effective, scalable and single step process for the synthesis of in-situ carbon coated $LiFePO_4$ (LFP) for Lithium-ion batteries. The process involves a modified solid state method for the preparation of kg level batch carbon coated LFP with high rate performance by adopting a high energy milling based solid state process. X-ray diffraction analysis demonstrate the formation of highly crystalline $LiFePO_4$ phase with an ordered olivine pnma structure. The smaller particles (350-500 nm) of $LiFePO_4$ and thin layer (6-10 nm) uniform carbon coating on LFP particles are observed by morphological analysis. Small particles and homogeneous carbon coating ensures higher electronic conductivity and reduced diffusion path length for Li-ions respectively, thereby expect to enhance the performance and cycle life of LFP. The evaluation of electro-chemical performance was carried out with a potential window between 2.5 to 4V at different current densities ranging from C/20 to 2C using pouch cell made from ARCI's C-LFP as cathode and commercial graphite as anode. For comparison, the pouch also fabricated using commercial C-LFP (Geyon, China) as cathode and graphite as anode and its performance compared with pouch cell made from ARCI's C-LFP. ARCI's C-LFP pouch cell exhibit capacity of 0.8 Ah at C/10 and showed promising performance even at higher C-rate, i.e., at 2C, it showed capacity of 0.75Ah with 90% capacity retention. On the other hand, pouch cell made using commercial LFP showed inferior electrochemical performance, i.e., it can able to deliver capacity till C/2 rate and beyond C/2 rate, it fails miserably. The superior electrochemical performance ARCI's C-LFP pouch cell is attributed to the presence of smaller LFP particles and formation of thin layer & homogeneous carbon coating on LFP, which significantly enhances the ionic and electronic conductivity and thereby improves the power capability of C-LFP even at high C-rates.

Further, ARCI is working on to bring down the production cost of C-LFP to a comparable level of imported C-LFP by using cheaper raw materials as well utilizing the pilot plant facility for the production at a level of 25 Kg/day. Further scale-up will make the process more economical.

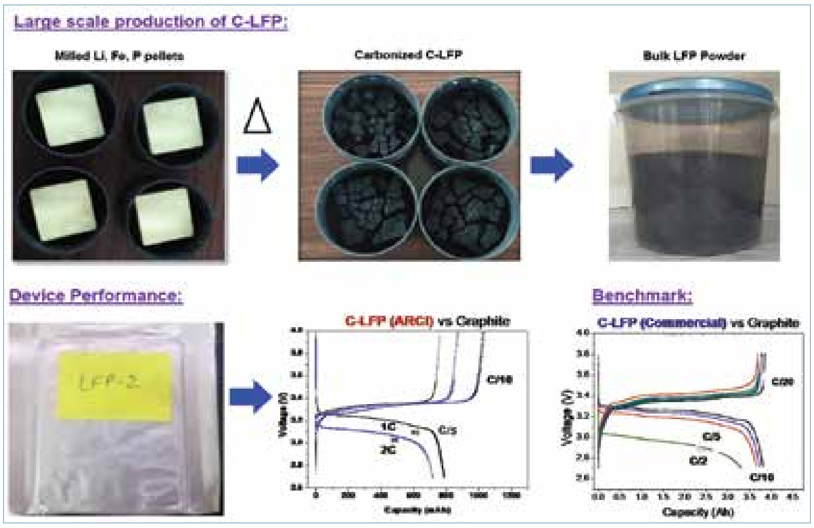

Fig. 1 Process flow chart for the mass production of LFP, performance of LFP pouch cell and benchmark

Contributors: Pavan Veluri Srinivas, R. Vijay and T. N. Rao

Indigenous Fabrication of Supercapacitor Cells and their Application in Electric Vehicles

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Supercapacitors are a promising energy storage device delivering energy/power component for many applications, covering a variety of industries such as automotive (IC engine & electric vehicles), space technologies, power electronics, industrial & consumer electronics, solar energy harvesting/storage systems and other upcoming areas. For example, in the automobile sector, supercapacitors are widely deployed for full/hybrid electric vehicles to improve the power handling capability of the batteries. Currently, in India the entire supercapacitor requirement is met through imported cells. In India, auto manufacturers in the country are also looking for the development of indigenous technology for supercapacitors for upcoming hybrid electric vehicles (HEV) application under the National Mission for Electric Mobility program. Therefore, all these major industries & strategic sectors, namely, ISRO, DRDO & DAE, would be the beneficiaries for this technology and hence development of indigenous supercapacitor technology will have high techno-economic impact. In fact, the major driving force and impact for supercapacitors is from consumer and power electronics followed by the automobile sector.

ARCI envisioned the technological importance of supercapacitors for Indian market and is determined to develop technology know-how starting from activated carbon production to cell level fabrication on a pilot scale. Initial efforts were made in identifying potential carbon precursors which are abundant, cost-effective bio/industrial wastes such as jute sticks, cotton waste and petroleum coke. Petroleum coke, a by product in the oil refining process is abundant and inexpensive (less than $100 per ton) and usually used as an alternate burning fuel to coal in India. Statistics reveal that India is the 2nd largest consumer of petroleum coke in Asia, after China. The petcoke byproduct with high carbon content has been shown to be a good source as a feedstock to produce activated porous carbons for supercapacitor application. The production of activated carbon from the identified sources (jute stick bio-waste, petroleum coke) is optimized to 100g per batch and the target is to get 5 kg activated carbon in a single batch.

The supercapacitor performance of indigenous carbon electrode materials was found to be excellent in comparison to commercially available activated carbon materials (Kuraray, YP-50). A pilot scale fabrication facility has been established at centre for nanomaterials to fabricate 1000F supercapacitor cells. Fabrication of supercapacitors cells using the established facility is ongoing with indigenously developed carbon materials. After succesful fabrication of supercapacitor cells, modules of the same will be deployed into eletric vehciles for assisting peak power requirements.

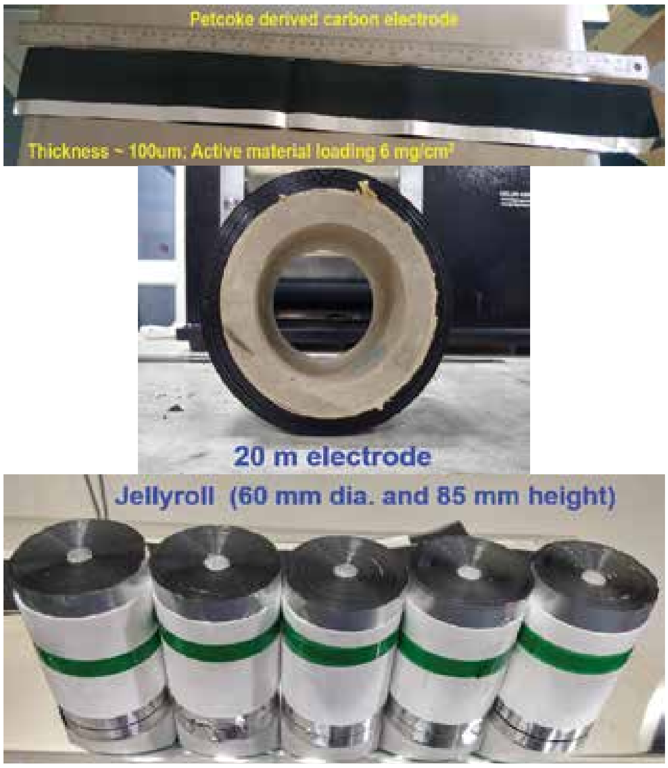

Fig. 2 Petcoke derived activated carbon electrodes and jelly rolls prepared at pliot scale supercapacitor faciltiy

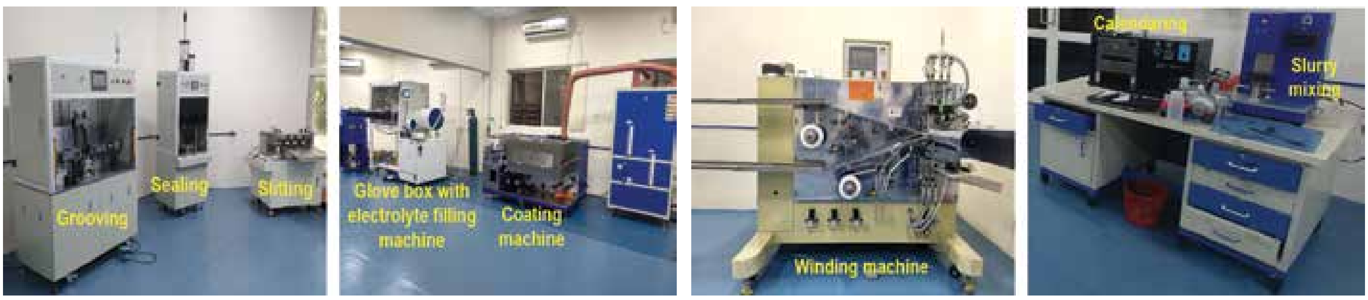

Fig. 1 Pilot scale facility for supercapacitor cell fabrication established at the Centre

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ODS Austenitic Steel for High Temperature Applications

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Austenitic steels are among the promising structural materials not only for fusion and fission reactors but also for thermal power plants as well as gas turbines owing to their excellent creep, corrosion and oxidation resistance. However, austenitic steels suffer from inferior ultimate tensile strength and stress corrosion resistance at high temperatures. The mechanical properties of austenitic steels at ambient as well high temperatures can be improved by oxide dispersion strengthening (ODS). This improvement in strength at elevated temperatures is attributed to high thermal stability of oxide particles and their ability to act as barriers to pin the dislocations. Mechanical alloying (MA) is a proven technique to produce ODS alloys. However, incorporation of oxides into an austenitic matrix is more challenging than ferritic due to the ductile nature of the former, which invariably leads to powder sticking to the milling media and thus decreasing the powder yield. The problems of powder sticking and reduced powder yield can be addressed by the addition of process control agents (PCA) such as stearic acid. However, the structural stability of dispersoids in the presence of carbon containing PCA was observed to be poor when exposed to 700°C for longer times. To circumvent the problems encountered with the addition of PCA, a two–stage milling is employed, in which, first stage milling is aimed at dispersing the oxides into ferrite matrix and second stage milling to transform the ferritic ODS steel into austenitic ODS (AODS) steel by the addition of Ni.

During milling, the powder particles are subjected to repeated cold welding and fracture, which form very fresh and active surfaces. When nitrogen is used as PCA during milling, it gets absorbed on the surface layers of powder particles and makes them brittle. However, as the milling proceeds, the ratio of cold welding to fracture shifts to equilibrium. Interstitial elements such as nitrogen, carbon and boron provide significantly higher strengthening effect in austenitic steels than the substitutional elements and among them; nitrogen is the most effective. In addition, nitrogen in steel improves toughness, creep strength and corrosion resistance along with increased resistance to form undesirable phases like δ–ferrite and α–martensite. Moreover, milling under nitrogen atmosphere results in enhancement of grain refinement and ferrite to austenite transformation. Austenitic steel with a combination of nitrogen in solid solution and finely dispersed oxides is likely to show much better mechanical properties.

ODS austenitic steel of nominal composition Fe-18Cr-22Ni-1.6W-0.23Ti-0.35Y_2O_3 was produced by mechanical milling of pre-alloyed powders and nano yttria in a high-energy horizontal ball mill (Simoloyer CM-08). The milled powders were upset forged at 1050°C and subsequently hot extruded at 1150°C with an extrusion ratio of 9 to get 16 mm diameter rod. The extruded rod was solution annealed at 1075°C for 2 h and water quenched. The density of extruded and solution annealed sample is 99.6% of the theoretical. The average grain size of AODS was found to be 350±0.042 µm. Transmission electron microscopy (TEM) was performed to observe microstructure and for analysis of size and chemistry of dispersoids. High resolution transmission electron microscopy bright field image as shown in Fig. 1(a) displays oxide particles of size 3–40 nm. The size distribution of oxides counted from micrographs with Gaussian distribution fit is shown in Fig. 1(b), indicate a mean of 7.5±3.2 nm. EDS analysis on these particles showed enrichment of Y and Ti, indicating them as Y–Ti–O complex oxides.

The material exhibited a yield strength of 1232 MPa and a fracture strain of 21% at room temperature, which exceed the published values for the similar AODS steels. The calculated contributions showed that these superior mechanical properties were mainly attributed to grain boundary and Orowan strengthening.

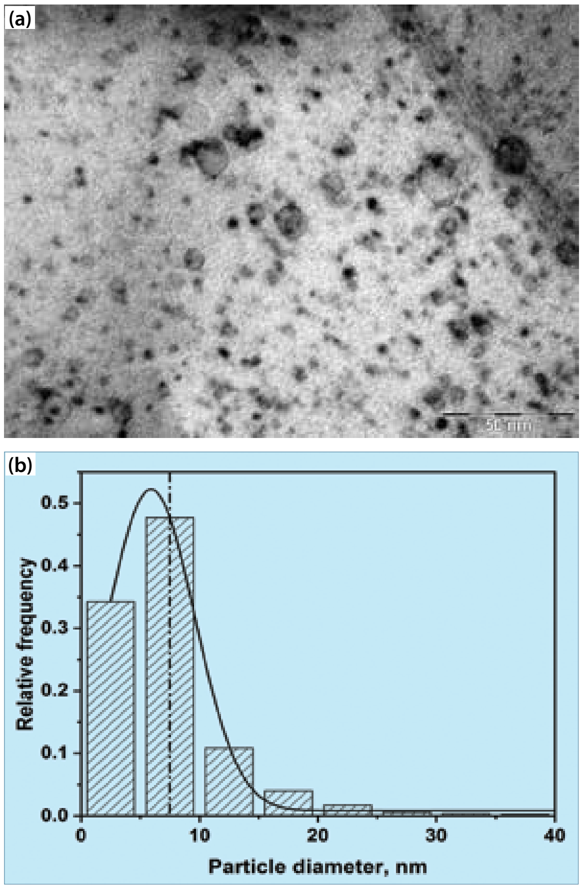

Fig. 1 (a) High resolution TEM image of solutionized sample and (b) particle size distribution

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Oxide Dispersion Strengthened Iron Aluminides for Turbine Blades

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Iron aluminide (Fe_3Al) with DO_3 structure generates more interest towards high temperature turbine blade applications due to its low cost and attractive properties such as high strength, low density and extremely good resistance to oxidation/corrosion and sulfidation. These virtues of Fe_3Al are considered as alternatives to high alloyed stainless steels and nickel based super-alloys. However, the instability of Fe_3Al above 545°C, inadequate creep resistance, low fracture toughness and insufficient ductility for fabrication are limiting their commercial applications at high temperatures. ARCI attempted to improve these properties by incorporating nano oxide dispersoids into the Fe_3Al matrix. The oxide dispersion strengthened (ODS) Fe_3Al alloy is produced by milling pre-alloyed (inert gas atomized at ARCI), zirconium and yttrium oxide powders in Zoz CM20 high energy ball mill for 10 h, then degassed and vacuum sealed in mild steel cans followed by upset forging, hot extrusion and heat treatment. The equi-axed and elongated grain structure with an average grain size of 580 nm was observed in EBSD grain orientation map, as shown in Fig. 1(a). In ODS Fe_3Al, presence of very fine and stable nano-sized dispersoids such as $Y_4Al_2O_9$, $YAlO_3$ and $Y_2Zr_2O_7$ promote grain refinement by effective pinning of grain boundaries, which inturn improve ductility, creep resistance and fracture toughness. The fine oxide dispersoids with an average size of 8.35 nm, which are mentioned above can be seen from TEM bright field image as shown in Fig. 1(b). The yield strength of ODS Fe_3Al at room temperature (RT), 400°C, 600°C and 800°C are around 1100, 972, 526 and 173 MPa respectively, and total elongation is 15, 22, 39 and 43 respectively. The tensile properties revealed that ODS-Fe_3Al exhibited very good combination of strength and ductility at RT as well as at high temperatures as shown in Fig. 2(a). ODS Fe_3Al developed at ARCI has superior tensile properties at RT when compared to various Fe_3Al alloys, which are shown in Fig. 2(b). Efforts are going on to produce ODS Fe_3Al gas turbine blades.

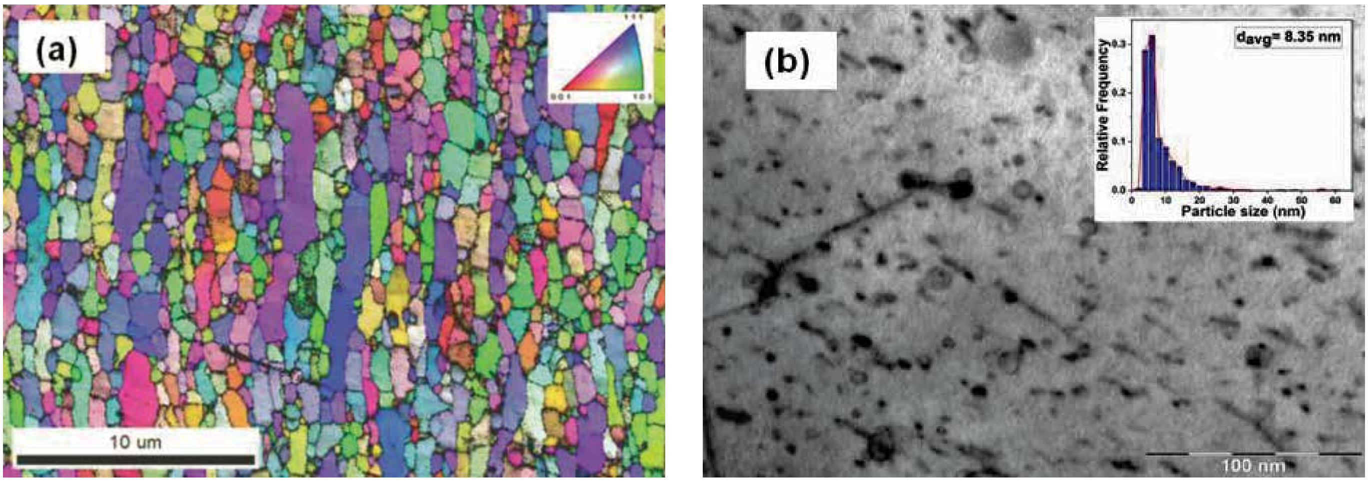

Fig. 1 (a) EBSD orientation map (b) TEM bright field image showing dispersoids with size distribution plot (inset)

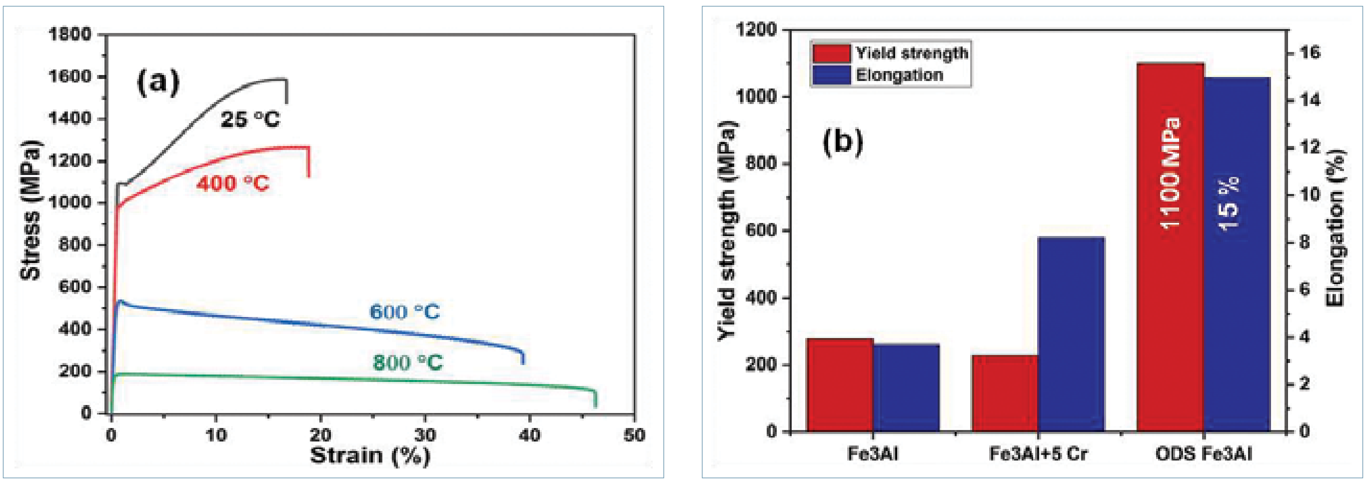

Fig. 2 (a) Tensile curves at various temperatures (b) Comparison of tensile properties at RT

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High-Strength Tungsten-Based Structural Component by Field Assisted Sintering

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Spark plasma sintering (SPS) technique was used to fabricate high-dense, high-strength W-TaC composites for making jet vanes used in missiles. The commercially available tungsten components are fabricated using the cost-intensive and complex hot-rolling process followed by sintering or HIP, which yields anisotropic properties in the components leading to their failure. By adopting the current process using SPS the technical drawbacks of the commercial component could be overcome and the process could be made economic. The components fabricated by SPS retain a fine uniform grain size ~2.5 μm with no abnormal grain growth and a narrow size distribution. Optimized composition (W-2wt% TaC) and SPS conditions (1650°C-50 MPa) yield high Vickers hardness ~ 540 HV10 and transverse rupture strength (TRS) ~ 1050 MPa, thereby qualifying the material for the targeted application. A typical gray scale EBSD image in Fig. 1 shows the microstructure of the optimized sample. A sheet of 95 mm diameter and 10 mm thickness processed by SPS is shown in Fig. 2 and a jet vane component for actual commercial application machined out from the sheet is shown in Fig. 3.

Extensive microstructural investigations using TEM revealed some interesting features. The presence of second phase nanoparticles ~ 30-50 nm were observed within the grains and at the grain boundaries. SAED patterns from these particles indicate the presence of TaC and Ta_2O_5 phases along with traces of WC. The particle/matrix interface boundary appears to be coherent in nature as the lattice mismatch is minimal between atoms on either side of the boundary. The coherent interface boundary facilitates dislocation accumulation (or pinning) leading to an increase in fracture strength in the composite samples following the well-known dispersion strengthening mechanism. The overall enhancement in strength and hardness in the current work can be attributed to a combination of factors: the dispersion strengthening of the carbide particles and the merits of the SPS process-mediated gains in terms of the finer grain size and the uniform distribution of the second phase particles in the matrix.

Fig. 2 High-strength, high-dense W-TaC sheets of 95 mm diameter fabricated by SPS

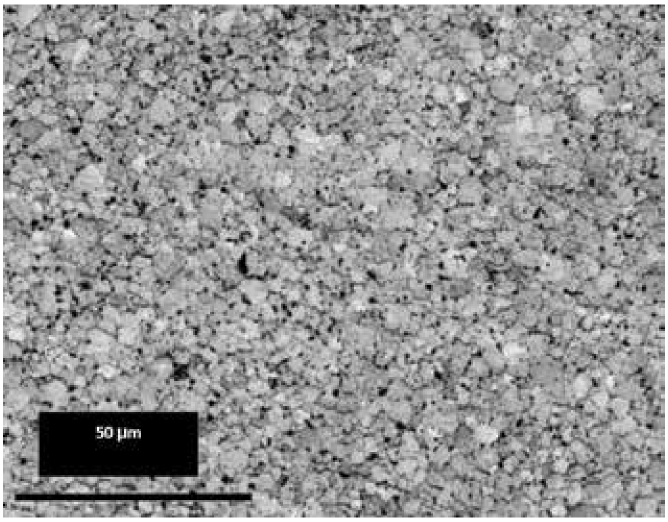

Fig. 1 Gray scale EBSD image of W-TaC sample sintered at 1650 °C

Fig. 3 Jet vane component of dimension 78 x 63 x 9 mm for commercial application machined out from the sheet shown in Fig. 2

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Next Generation Biodegradable Fe-Mn Based Metal Implants

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Metallic implants that are being used presently remain permanently in the body and cause long term side effects like systemic toxicity, chronic inflammation, thrombosis; which necessitates a second surgical intervention. One of the ways of overcoming this problem is by developing new biodegradable materials (Fe, Mg, Zn and polymer) which are intended to participate in the healing process and then degrade gradually by maintaining the mechanical integrity without leaving any implant residues in the human body. These kind of materials should degrade in 12-24 months and exhibit integrity for 3-6 months with a corrosion rate of 0.02 mm/year. While all these biodegradable implants exhibit good biocompatibility in the human body, iron has better strength and has less cost. Iron-Manganese based alloy Fe-Mn (Mn>29 wt%) is a promising biodegradable metallic implant which exhibits single austenitic phase with nonmagnetic properties and MRI compatibility.

ARCI has embarked on development of Fe-Mn based alloys for biodegradable metal implants in association with Sri Chitra Tirunal Institute of Medical Sciences. Both conventional melting and powder metallurgy techniques are employed to manufacture the Fe-Mn based biodegradable alloys and stent (Dia: 2 mm, L: 12 mm and Wall thickness: 175 µm) is fabricated by laser micromachining. The photographs of billet, extruded rods and stent along with stress-strain curve are shown in Fig. 1. The as developed material exhibited 99% density with impressive mechanical properties (Yield strength: 300MPa, Ultimate tensile strength: 816 MPa, Young's modulus: 88 GPa and Elongation: 47%) and behaved as a nonmagnetic material even under a strong magnetic field of 20 Tesla. The mechanical properties are comparable to presently used permanent Ti and SS316L metallic implants. The material showed a degradation rate in the range of 0.14-0.026 mm/year in the simulated body fluid which matches with the target values. During the degradation process, calcium phosphate deposits on the implant due to local alkalization and saturation of calcium and phosphate, allow cells to adhere onto the surface to form tissues.

Based on the impressive results, it can be said that the Fe-Mn based alloys developed at ARCI are suitable for biodegradable stent and orthopedic implant applications. In vivo and in vitro studies are being planned at Sri Chitra Tirunal Institute of Medical Sciences.

Efforts are also being made to achieve control in corrosion rates through alloying addition and surface engineering and employ advanced manufacturing process like additive manufacturing to realize complicated shapes.

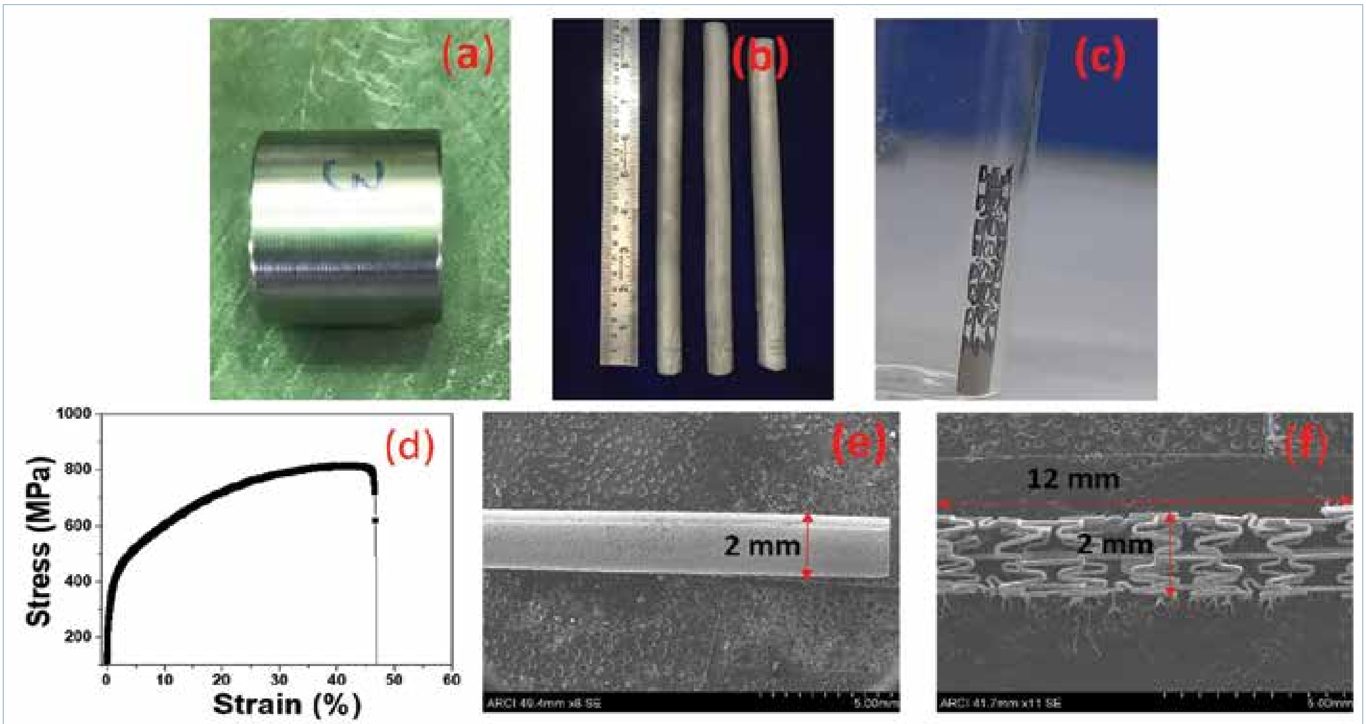

Fig.1 (a) As cast Fe-Mn-Si alloys billet, (b) Extruded and heat treated rods, (c) Stent made by laser micro-machining, (d) Stress-Strain curve of the alloy, (e) and (f) SEM images of tube and stent

Contributors: Hemin Desai, Ravi N Bathe (Stent fabrication) and R. Vijay

Development of Powders for Additive Manufacturing

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Additive manufacturing (AM) is creating a paradigm shift in manufacturing worldwide, and fast emerging as a key modality to produce near-net shaped metallic components. The applications span critical aerospace, biomedical and automobile components. In AM technology, components (3 dimensional objects) are built by adding the material layer by layer and laser processing for consolidation. AM process has many advantages like ease of manufacture of near-net shaped components, material saving, significant reduction of time in evaluation of properties and performance and cost effectiveness. However, AM process has certain potential disadvantages like incidence of porosity, formation of deleterious phases, difficulties in assessing the quality of powders (composition, morphology, etc.) and possible debit in mechanical properties. It should be noted that AM is still relatively new manufacturing process and it is expected that engineering and scientific research in this field will enable us to overcome most of the disadvantages – through proper material chemistry, powder morphology, process selection, optimisation & control and equipment design. Development of new critical aeronautical and biomedical components can be time consuming in view of the long time taken from conceptualisation to production stages. This disadvantage can easily be overcome by AM since it is possible to realise the component once the design is finalised. It has been reported that for the production of surgical tools, the technology can reduce 62 steps into 7 steps.

While it is universally acknowledged that the quality of final AM component depends on the quality of the metallic powder that one starts with, the specific attributes of this powder quality are not understood. Additionally, the process yields in manufacturing of metallic powders for AM are generally very low (<20%). For material and energy conservation, there is great need for:

1. Understanding the powder characteristics that are essential for high-quality AM products, and
2. High-yielding processes for production of metallic powder

AM requires powders with optimum morphology, size distribution, flowability, chemistry, tap density and bulk density. Spherical nature is needed for better flowability. Flow of the powders is critical when these powders are dispensed from equipment that builds the prototype part. Fineness and high apparent density of the powders are required to achieve better density during the powder fed AM machines. However, more than the required amount to fines in a powder may lead to undesired effects on AM built parts, for example, cracks and defects. The apparent density can be affected by particle size, shape and size distribution. The finer the powder, the lower is the apparent density. But powder flow and particle size have an inverse relationship. In addition, other powder characteristics such as surface roughness and chemistry also play an important role in AM.

These desired powder properties can only be met by production of powders through inert gas atomization. At present, there are no manufacturers of gas atomized powders in general and Ni based superalloy powders in particular in India. The requirements are currently being met by imports and so the powders are prohibitively expensive. This in turn pushes up the cost of additive manufacturing. ARCI, having the state of the art inert gas atomizer facility has embarked upon the development of powders for AM, Fig. 1. Inset in Fig. 1. shows the particle size distribution of the powders produced at ARCI (SS403). Coupon level components were developed using IN625 powders produced at ARCI for AM applications.

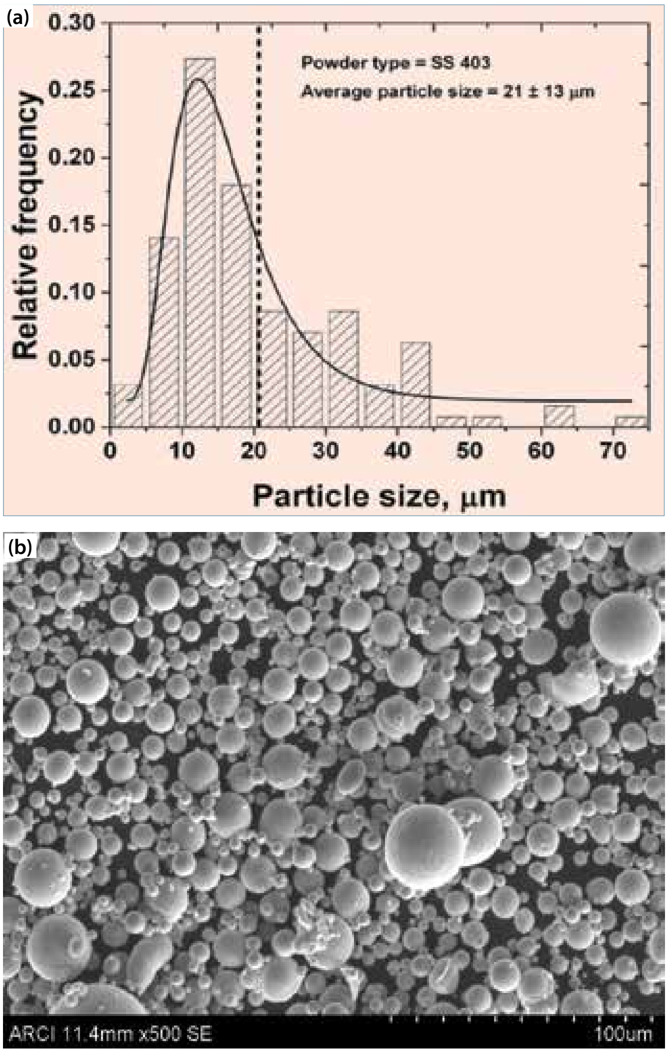

Fig. 1 (a) SEM morphology of SS403 powder produced at ARCI and (b) shows the particle size distribution

Contributors: Mr. Sai Karthik and R. Vijay

Synthesis of 2D-mixed Sulfide Based Nano Composites

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Nanostructured two - dimensional (2D) - transitional metal dichalcogenides (TMDCs) exhibit unique catalytic/ elecrocatalytic, opto-electronic as well as self-lubricating properties. The wide range of properties makes them in high demand in aerospace, automotive, electronic and chemical industries. Recent studies have shown that mixed sulphides, transition metal doped sulphides and sulphide composites exhibit superior catalytic and energy applications.

Our recent efforts have been focussed on bulk synthesis of 2D- mixed metal sulphide based composites viz. (W/Mo, Cu/ Co)S_2. The synthesis of the composite involved sulfurization of mechanically activated nano-oxide precursors via solid-gas reaction under controlled temperature and pressure. It may be noted that this method has been developed and patented by ARCI and previously used successfully for the synthesis of 2D-WS_2 and MoS_2 in bulk quantities. Figure 1a shows the XRD pattern of the as synthesized WS_2-Cu_2S nanocomposite. The corresponding 2D-XRD pattern is shown in Fig. 1b. The 2D structure of the mixed sulphide is indicated by the low intensity of the basal plane reflection in the x-ray diffraction pattern (Fig. 1a). Figure 2 shows the FE-SEM images of the mixed sulphide composite at different magnifications. Distinct 2D feature is evident from the FE-SEM microstructure.

The bandgap of the 2D-WS_2-Cu_2S composite, as determined experimentally from the UV-Vis studies (Fig. 3), was found to be about 1.6eV. This is a significant drop from a bandgap value of 2.0eV, as observed in 2D-WS_2. This indicates that the 2D-mixed sulphide composite can possibly exhibit improved catalytic properties under visible light.

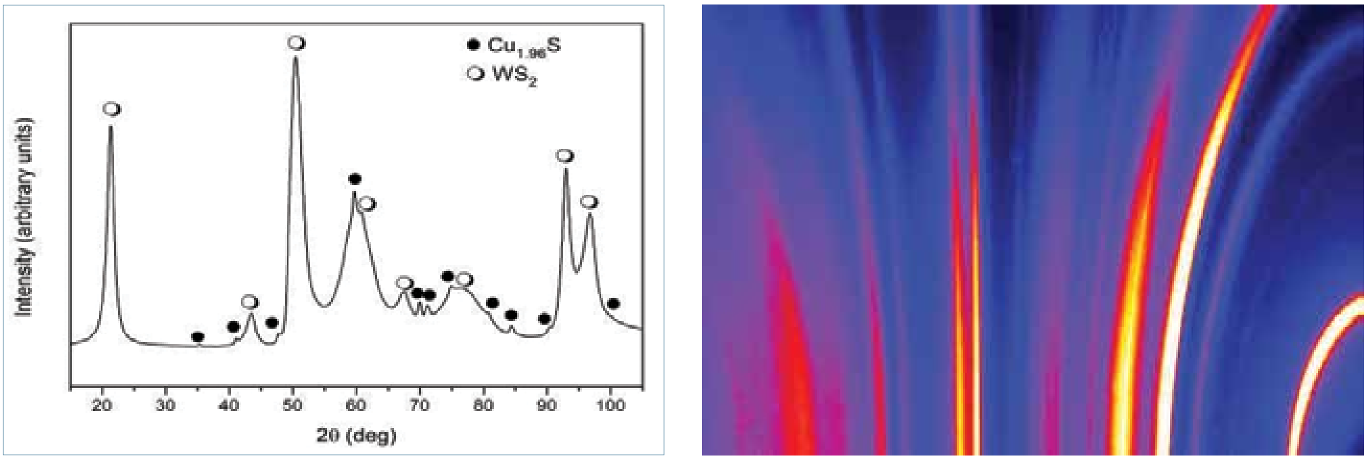

Fig. 1 (a) XRD pattern of WS_2-Cu_2S nanocomposite (b) 2D-XRD pattern of the nanocomposite

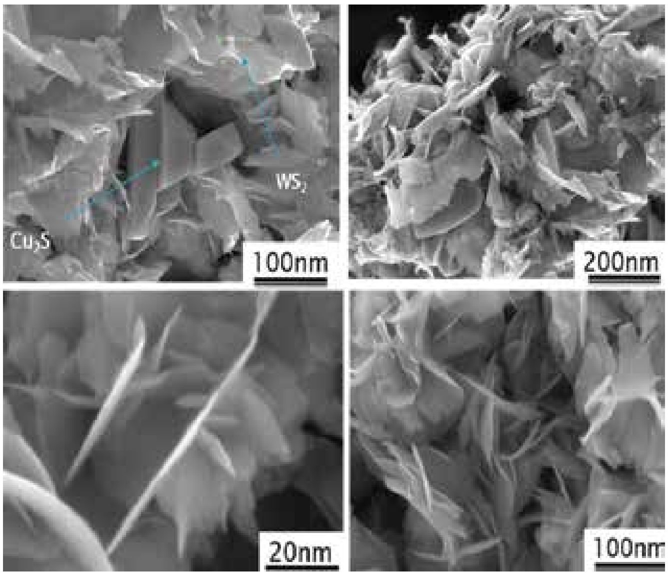

Fig. 2 FE-SEM image of 2D-WS_2-Cu_2S nanocomposite

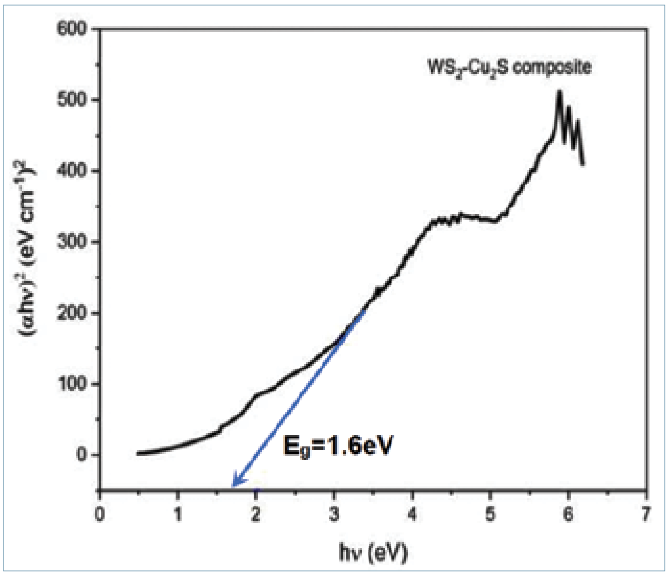

Fig. 3 Tauc plot indicating band gap of Cu_2S-WS_2 nanocomposite

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Thermal Characteristics of Nano Boron Powder

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Boron based fuel-rich propellant is an emerging fuel for air-breathing propulsion applications due to increased energy density. The use of boron is primarily due to the highest volumetric combustion energy density (135 MJ/L) and its excellent gravimetric combustion energy density (58.5 MJ/ Kg). At present, the boron used in the fuel-rich propellant is the nano boron. Nano-sized boron provides a large surface to volume ratio, which facilitates more contact area for rapid oxidation. Such a feature is expected to play an active role in overcoming the problems of solid fuel-rich propellants such as ignition delay, high burning time, and low thrust. As the physicochemical properties of nano boron are different from the micro-sized boron, it is vital to study the reaction characteristics of the nano boron used in the fuel-rich propellant. TG and DTA are one of the effective methods to study the thermal properties of the nano boron. The present article explains the study the reaction characteristics of micron-sized boron and nano boron using TG and DTA technique.

Nano boron was developed at ARCI through cryo-milling with average particle size is in the range of 200-300 nm, as shown in Figure 1. Figure 2 shows the thermal analysis plots (TG/DTA curves in the air) of the powder before (micron-sized) and after (nano-sized) cryo-milling. The TG and DTA curves of nano-sized boron significantly different compared to those of the micron-sized powder. The TG curve of micron-sized powder is almost linear during heating of the powder till 1436ºC with a small mass gain of 5% due to the boron's oxidation. In the case of nano boron powder, there is initial moisture removal at around 100ºC, substantial mass gain that occurs between 537ºC and 1436ºC is due to the conversion of nano-boron to boron oxide. The oxidation process is accompanied by a significant heat release that is evident from the exothermic peak in the DTA curve. The heat release is maximum at about 700ºC, indicating that the nano boron powder exhibits superior oxidation kinetics than the micron grade boron powder. This oxidation kinetics shows that the reduction of boron's particle size from micron to nano size is a suitable approach for improving the combustion properties. So nano boron is more reactive than micron-sized boron to use in propellant application.

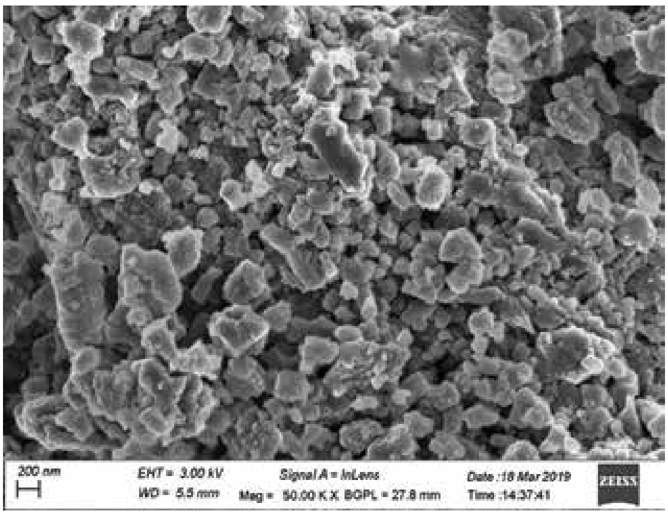

Fig. 1 Cryo-milled nano boron powder

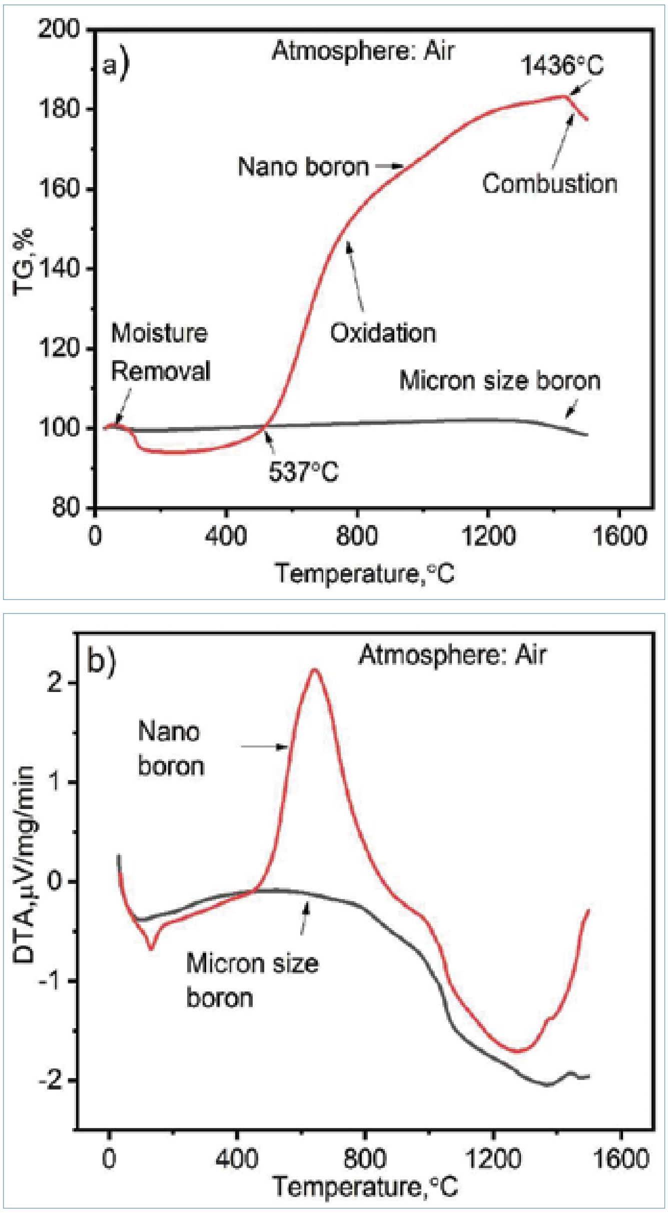

Fig. 2 (a) TG and (b) DTA curves of micron size boron powder and cryo milled nano boron powder

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Light-Dependent Resistor (LDR) Based Sensors for Energy Conservation

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Automation based on sensors replacing the manual operations can limit the wastage of the power and aid in significant energy conservation for several vital applications. Nanostructured and quantum structure tuned opto-electronic thin film of metal-chalcogenides (MCs), those exhibit functional opto-electronic properties, are the potential candidate materials for such sensor applications. Further, nanostructures of II-VI MCs systems (Zn/Cd–S/Se/Te/O) is adaptable for dimensional tuning, thus yield property modulation which enhances the performance of the devices. Key requirement of sensors is response to light and transduce the signal to readable output electrical parameters.

Nanostructured opto-electronic thin film can be deposited by various techniques. At ARCI, we have successfully used spray pyrolysis deposition (SPD) in preparing photosensitive nanostructured chalcogenide based thin films. SPD technique is based on the thermally stimulated chemical reaction between chemical species of sprayed droplets to form the desired stoichiometry on to a preheated substrate through pyrolysis. Desired property of the thin film is dictated by process parameters such as flow rate, spray cycles, spray time etc. In the current study, parameters are optimized and FeSEM images of the nanostructured thin films are shown in Fig. I (a).

SPD coated nanostructured opto-electronic thin film produced under optimized conditions has been utilized for fabrication of a "circuit integrated photo-sensor" device, and the prototypes has been demonstrated for its performance as an automatic light switching device (Fig.1 b&c). The device has several advantages wrt. planar configuration, transparent substrate based sensor and related sensitivity and surface area improvement that leads to improved device. SPD technique is scalable and shows tremendous potential for commercialization, indicating the wide commercial viability of this work as a whole.

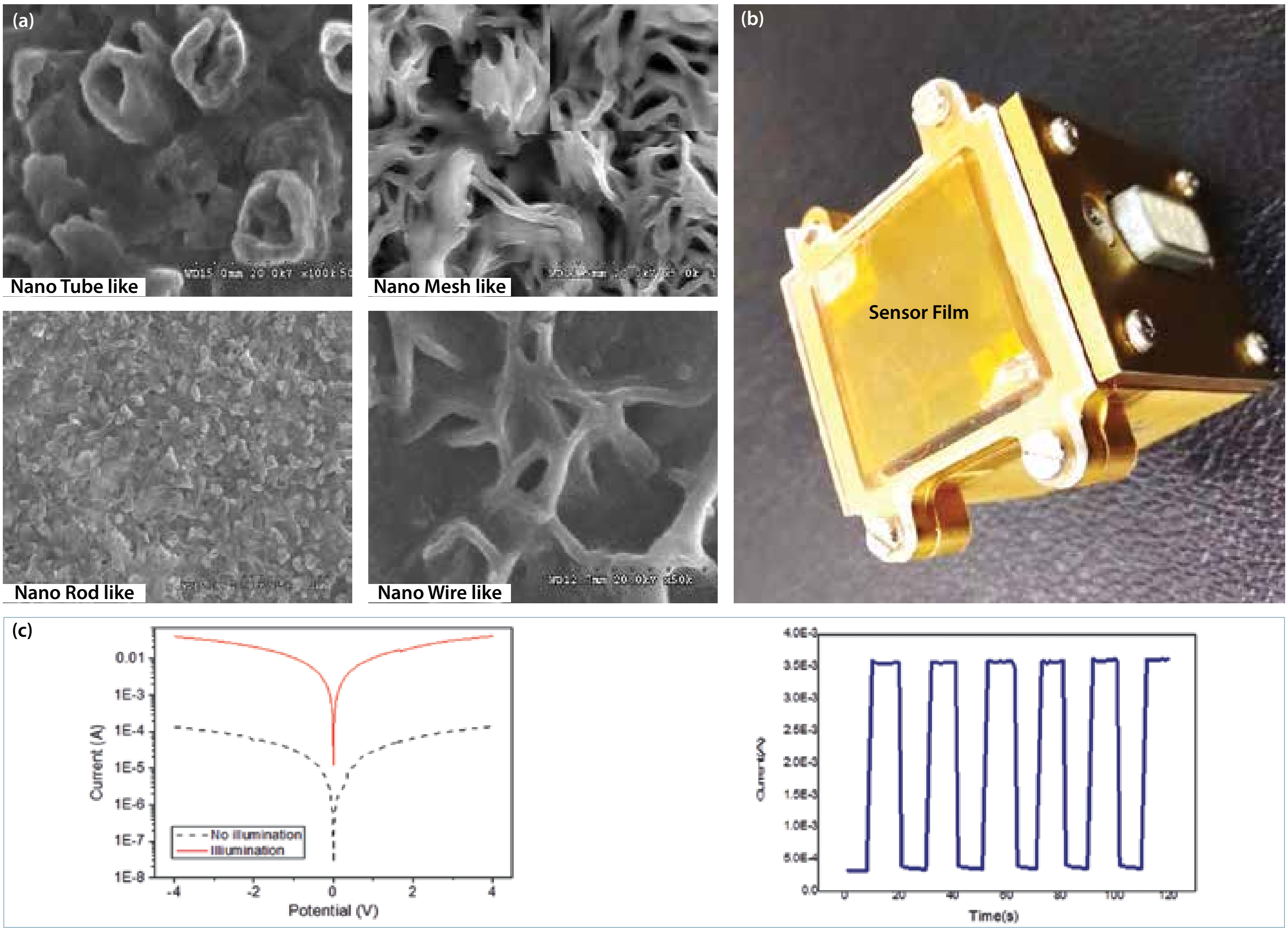

Fig.1 (a) FeSEM of nanostructured sensing film (b) device photograph of "circuit integrated photo-sensor" prototype, fully made in ARCI (c) Solar photon switching behavior of the photo-sensor that is used for automatic light switching

Contributors: Ravi N Bathe, S. Nirmala and Roy Johnson (Sensor Development Group)

Coated Fe/Fe Alloy Composites for Soft Magnetic Applications

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During the last few decades, the invention of new magnetic materials including pure iron and its alloys are in vogue in electromagnetic applications. In recent times Particulate materials(PM) composites are finding increasing use in electrical motors, replacing existing laminate materials with attractive magnetic properties (good relative permeability and magnetic saturation), but with high electrical resistivity at competitive price. PM processed soft magnetic composites (SMCs) combined with 3D-design solutions for new machine design rules and improved powder compaction techniques like warm compaction, hot consolidation, encapsulation techniques, resin and wet chemical coating processes, have several advantages including reduction in weight and size with lower electromagnetic loss characteristics of SMCs. The need of the day is to develop different series of iron based SMCs like (1) Fe-powder with resin (2) sintered Fe-based powders, (3) pure Fe-powder plus organometallic constituents (4) Fe-inorganic coatings, etc. for axial or transverse transverse flux machines of electrical drives demanding high power.

ARCI has been working on inorganic/organic coated SMCs for DC to medium range frequencies of 1KHz with moderate permeability. Though a limited use of layered or hybrid Fe powder composites are found in literature, at the product stage very few companies have been successful in developing inorganic-insulating coatings on iron powders for various processing/consolidation reasons. The different systems of Fe based SMC systems like Fe, Fe-resin-lubricant, phosphate, silica, silica-resin hybrid, Mn-Zn-Ferrites is reported. An R&D sponsored by Tata Steel Limited, Jamshedpur (TSL) for SMCs is presently ongoing for futuristic applications of Fe-powder made in TSL is used. Fe powders obtained from different PM routes like PM grade Fe powder, electrolytic Fe powder, Pune and fine Fe powder from TSL were used for detailed study and results of Hoganas based powders and compositions are presented.

Table 1 DC Magnetic properties of PM processed Fe and Fe based SMCs

PM Fe/ Fe based SMCs	Density, g/cc (% theor.)	Field (A/m)	Bs (T)	Hc (Oe)	Permeability μ_{max}
Fe (Hoganas std)	7.4 (94)	15000	1.4	2.77	1000
Fe-0.45P	7.4 (94)	15000	1.38	3.44	350
Fe-0.2 resin	6.9 (94)	15000	0.9	3.35	297
Fe-0.2 SiO_2	7.3 (94)	15000	1.41	3.56	348
Fe-0.1SiO_2-0.1resin	7.0 (94)	15000	0.82	2.7	334
Table 1(a) SMCs with TSL Fe powder					
Fe (TSL)	7.4 (94)	15000	1.67	2.44	1147.7
Fe-0.2$Mn_{0.5}Zn_{0.5}Fe_2O_4$	7.4 (94)	15000	1.51	2.68	1066.7
Fe-0.2$Mn_{0.5}Zn_{0.5}Fe_2O_4$ @50 Hz	7.4 (94)	10000	0.98	4.56	525.4

Fe-powders were coated using chemical technique and consolidated either by press-compaction-sinter route in Fe/Fe-P powders, warm compaction & curing in hybrid (Fe-silica-resin) powders, and in hot pressing or SPS. Toroid specimens of compacts were measured using Hysteresis-Loop-tracer under DC conditions (Table 1). It was found that both DC properties of plain Fe compacts as well as composites developed from core shell powders of Fe-0.2 MZF had better values compared with other composites and hence were further studied for potential furture applications. Typical microstructural and phase analyses for selected composition of Fe-0.2MZF SMC, where MZF represented $Mn_{0.5}Zn_{0.5}Fe_2O_4$ were studied. FESEM & EDS analysis on powder cross section shows presence of Mn, Zn, Fe & O on the periphery, whereas the centre portion revealed pure Fe (Fig. 1). Phases analysis of Fe-0.2 MZF using micro XRD confirms presence of Fe, FeO and Fe-0.2 MZF in the soft magnetic composites developed. DC hysteresis loops of compacts made from Fe powder supplied by TSL versus core-shell SMC composites of Fe-0.2MZF is shown in Figure 2 while AC properties of Fe-0.2 MZF composition measured at 50 Hz are tabulated in Table1a. Futher heat treatment and optimisation studies to be continued for improving the Saturation magnetization 'Bs' to 1-1.1 T.

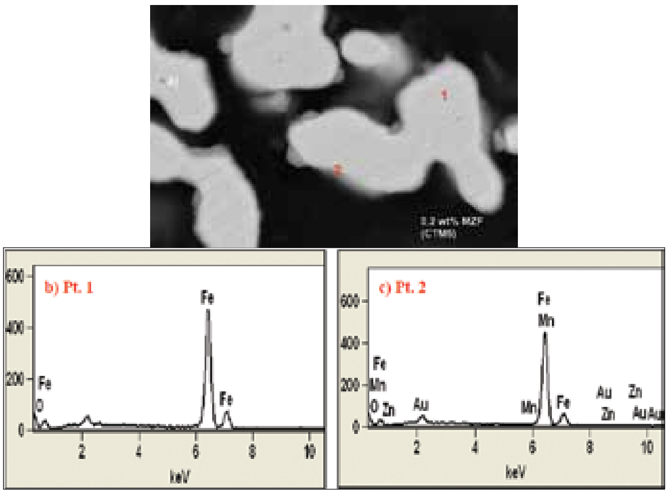

Fig. 1 Fe-0.2 MZF powder cross section (a) SEM (b) & (c) EDAX of points 1 & 2 of 1(a)

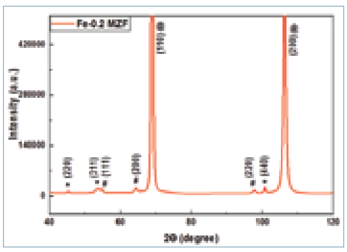

Fig.2 XRD using Rigaku-Micro XRD

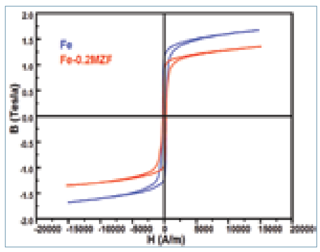

Fig.3 DC plots of TSL-Fe, Fe-0.2MZF

Contributors: Pramod H Borse, Joydip Joardar, PVV Srinivas, Hiba Aizaj and Ch VS Raju

Development of Safety Inspired Electrolytes for Next- Generation Energy Applications

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Solid-state batteries are emerging as next generation attractive batteries owing to their safety and high performance in lower cost. In addition, they also offer additional advantages as low flammability, high electrochemical stability and high energy density than the existing liquid electrolyte batteries.

At present, numerous attempts were being made to develop solid-state electrolytes such as purely organic (polymer), inorganic and composite electrolytes. The main difference between organic/polymer and inorganic/ceramic electrolytes is their mechanical stability. Ceramic electrolytes are mostly suitable for high temperature conditions and rigid battery systems as they have high elastic modulus, where as organic/ polymer electrolytes are mostly suitable for flexible devices as they have low elastic modulus. Fabrication and processing cost of polymers is very less than that of ceramic electrolytes.

The most importantantly, in solid electrolyte batteries SEI (solid-electrolyte interface) layer formation is not seen which leads to the very low self discharge, that ultimately results in long life approximately 50-100 times than conventional batteries. The best known solid-state batteries facing some operational problems, several Research groups and industries all over the world are actively working on improving their existing properties and take them forward to the commercialization.

In the recent times, ARCI initiated to work on certain important, efficient ceramic as well as polymer based solid electrolytes for Lithium ion battery applications. Also studied their detailed physico-chemical & electrochemical properties to understand and improve the further electrolyte properies. Based on the obtained properties, checked for their feasibility in suitable electrochemical devices.

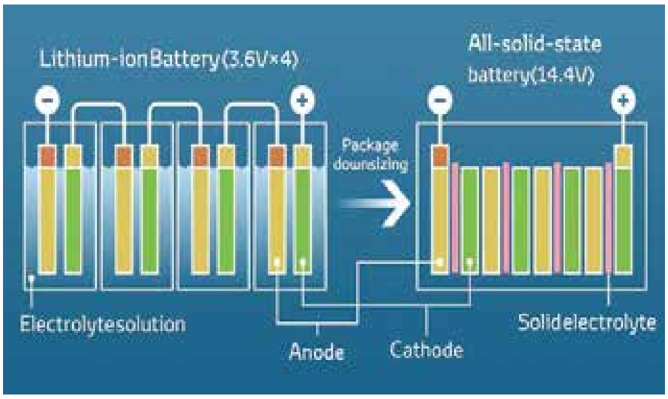

Fig. 1 Solid-state batteries hold a higher charge in a more compact shape, potentially doubling the driving range of electric cars today.

In that regard, ARCI has successfully developed a new strategy to make a ceramic electrolyte based all solid lithium ion battery. The synthesised and sintered ceramic electrolyte pellet FE-SEM images shows their good particle contact and continuity. Which resulted in better performance in device level. The fabrication method followed is relatively simple and could be readily scalable. The fabricated solid electrolyte based Lithium ion battery (Li/CE/LTO) has shown a good intial capacities (Discharge-162 $mAhg^{-1}$ & Charge-153 $mAhg^{-1}$ at 0.05C) as well as cyclic stabilities (Discharge-145 $mAhg^{-1}$ & Charge ~140 $mAh\ g^{-1}$ were obtained even after 70 cycles).

So far, the obtained results were quite encouraging and there is definite scope for the future improvement in the performance of materials as well as device. The on-going efforts are being made at that direction.

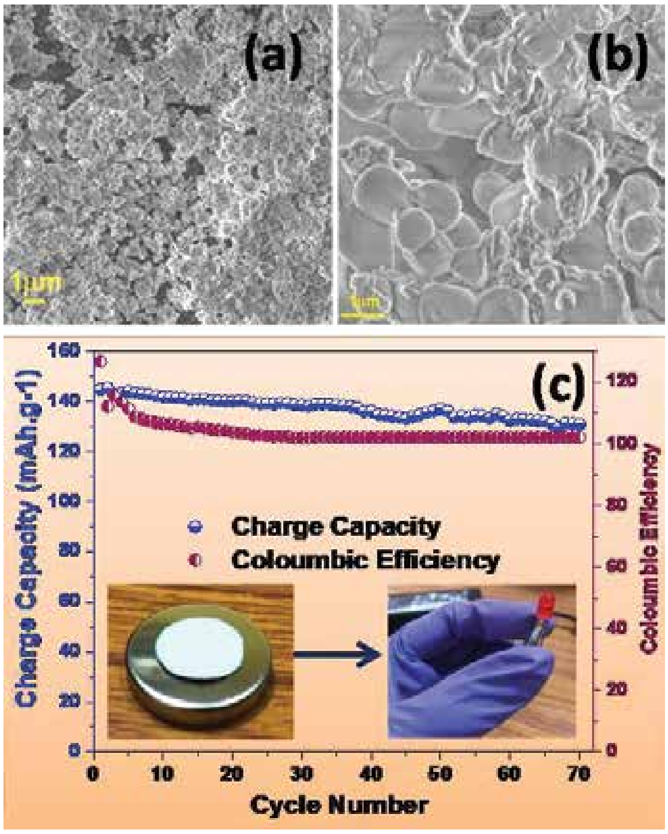

Fig. 2 (a) and (b) corresponds to the FE-SEM images of ceramic electrolyte in powder and sintered pellet form. (c) Corresponds to the performance and cyclic stability of Li/CE/LTO fabricated cell.

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Development of Vanadium sulfide as a Na-ion Battery (SIB) Anode

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In last few decades, lithium-ion battery (LIB) has drawn immense attention as an energy storage device due to its unparalleled advantages compared to the other systems. But, due to the certain challenges of LIB, such as, the irregular distribution of Li-source and expensive raw materials, researchers are looking for alternative energy storage systems. Among the several alternatives, sodium-ion battery (SIB) has been emerged out as one of the best options from India's perspective due to the high abundance of sodium, and cheap raw materials. Furthermore, the existing LIB technology can be implemented to develop SIB, as the working principle and the reaction mechanism of a SIB pretty much follow the same of a LIB. Another major advantage of SIB is that transportation can be done at 0 V, unlike LIB. However, the energy density of SIB is expected to be lower from the LIB due to the less negative reaction potential of Na compared to Li. Though there is no commercial SIB available right now, few foreign start-up companies and R&D based institutes have already developed a few prototypes of SIB. For example, FARADION, a UK-based company already developed a prototype of SIB using cobalt-free layered material as the cathode and hard carbon (HC) as an anode. To date, several materials have been tried and tested as cathode material for the development of SIB prototype whereas HC is the only material used as anode having specific capacity of ~300 mAh/g. Thus, the pursuit of a suitable anode material for SIB comes up with a great challenge.

Here at ARCI, it is aimed to develop advanced anode material for SIB. In addition to this, the layered transition metal dichalcogenide (TMD) as an alternative to HC has been chosen due to its unique physicochemical behavior. It exhibits larger interlayer spacing compared to the graphite and high electrical conductivity compared to the transition metal oxide. Due to the unique chemical and electronic behavior of vanadium, vanadium sulfide has been chosen as the desired material for the current study. The synthesis via the wet chemical method (hydrothermal and room temperature synthesis) has been tried so far to prepare vanadium sulfides. The objective is to find out a cost-effective procedure for the synthesis of gram-scale material. Room temperature synthesized vanadium sulfide was characterized via XRD and FESEM techniques and after preliminary analysis, it was found that the as-prepared material possess the X-ray diffraction characteristic peaks of VS2 (JCPDS no-89-1640) having nanorod morphology (Fig. 1 (a) & (b)).

A few primary electrochemical testings have also been carried out assembling a 2032 type coin cell with the as-prepared vanadium sulfide as a working electrode and Na metal as a counter electrode. The electrochemical testing was carried out within the working potential of 0.01 V to 3 V (vs Na+/Na) and it was found that the as-prepared material exhibits discharge capacity of 198 mAh/g and charging capacity of 126 mAh/g at 25 mA/g current, respectively having Coulombic efficiency of 63% (mass of the active electrode was 1.77 mg) (Figure 1c & d). Of note, the Na-reaction potential with the as-prepared material is near 0.5 V (vs Na+/Na) i.e. Na-plating can be avoided, unlike HC. Currently, ARCI is working on the optimization of the material via suitable synthesis procedures, detailed physical characterization of the as-prepared material, and its complete electrochemical study as anode material for SIB.

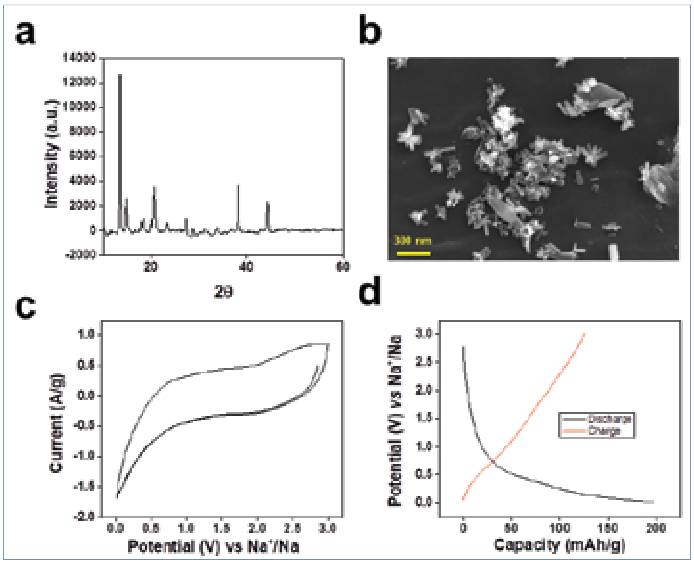


Fig. 1 (a) & (b) XRD and FESEM of the as-prepared vanadium sulfide (c) & (d) CV (at 1 mV/s) and CD (at 25 mA/g) curve of the as-prepared material

Contributors: S. Anandan and T. N. Rao

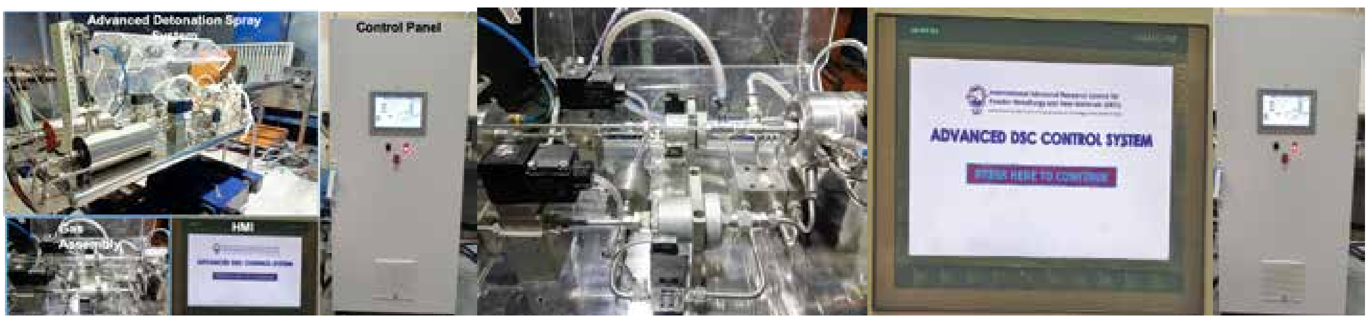
Centre for Engineered Coatings

The Centre for Engineered Coatings (CEC) has forged ahead swiftly in the past year and maintained its preeminent status as an advanced surface engineering solution provider in the country by delivering on multiple fronts. In addition to catering to a wide range of industries by broad based coatings technology solutions and targeted application development, it has also made significant strides in emerging as a key player in the aerospace sector including future space programs.

Indigenously developed Advanced Detonation Spray coating (A-DSC) system with enhanced throughput, efficiency and ease of use is now ready to be transferred to the industry. Similarly, indigenously designed and developed cold spray coating system with a globally competitive material spectrum and a wide process window, is available for transfer to the industry. Furthermore, new recipes for depositing Ni-W and Ni-W/SiC coatings using Pulsed Electro Deposition (PED) have been developed for transfer to the technology receiver. In terms of application development, surface engineering solutions were provided for a wide range of applications spanning across different industrial sectors. Most significantly, CA-PVD based wear resistant coatings deposited on helicopter blades have successfully undergone 100's of hours of in-flight testing and a continuous commercial demand for the same is anticipated in the near future. On a similar note, cold sprayed coatings on 4 m long rail guns with unique combination of high electrical conductivity and hardness have been developed for field trials. Furthermore, Micro Arc Oxidation (MAO) coatings have been successfully developed on Al-Si alloy die-cast components. Solutions are also being provided in newer areas such as biomedical engineering. For instance, Titanium based coatings for biomedical implants were successfully developed using cold spray coatings and are currently undergoing in-vitro and in-vivo tests to ascertain the bio-compatibility. Collectively, these technology/application development activities have firmly cemented CECs role as a key player in surface engineering at the national stage.

ARCI-SSCT Joint Aerospace Application Development and Demonstration Center that was conceived in the previous years is now operational and is actively working with global aero-engine manufacturing agencies. In addition, several activities specifically targeted towards repair and refurbishment of aerospace components are being pursued, including supply of refurbished (Ni-Cr coating using DSC) first rotor bearing support housing of a helicopter, CA-PVD TiN coatings for aerospace brackets and other components. Such activities are expected to facilitate the establishment of a first of its kind exclusive aero-engine maintenance, repair and operations (MRO) facility in the country. In addition, ARCI has been recently registered to be a partner and vendor for a variety of coatings required for next-generation aero-engine program and these activities will certainly help strengthen CECs capabilities.

In addition to above activities that have been successfully accomplished, initiatives have been taken up including establishment of state-of-the-art coatings facilities under National Centre for Development of Advanced Materials and Manufacturing Processes for Clean Coal Technologies for Power Applications (NCDAM-CCT). The key coating and characterization facilities have been successfully established and process optimization is underway. Looking ahead, CEC is also expected to play a crucial role in partnering with ISRO under the S-NAP program to provide various materials related solutions for future missions including GAGANYAAN.



Advanced Detonation Spray System **Gas Assembly** **HMI** **Control panel**

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Development of Corrosion-fatigue Resistant Aluminum Alloys for Aerospace Structural Applications

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In the context that the structural parts of aircrafts such as landing gear components, wing spar, helicopter rotor blade demand simultaneous protection against wear, corrosion and fatigue degradation, the corrosion-fatigue response of light weight Al alloys becomes an important aspect of development. Although the micro arc oxidation (MAO) coatings developed at ARCI are well proven to impart excellent protection against wear, corrosion and fatigue independently, the effect of simultaneous action of these degradation mechanisms even at a global level is not well-known. ARCI has already developed a duplex treatment for Al alloys comprising of prior shot peening under optimized conditions followed by MAO coating. Such a duplex treatment, provided onto different high strength aerospace Al alloys namely 6061, 2024 and 7075 grades has been demonstrated to exhibit 10 times improved fatigue life than uncoated (bare) Al alloys, 20 times better than commercially available hard anodized coatings. Utilizing such a duplex treatment, further investigations were continued by depositing MAO coatings of different thicknesses on 6061-T6 Al alloy substrates with (SP+MAO) and without (Plain MAO) the prior shot peening followed by plain corrosion, plain fatigue and corrosion-fatigue (CF) performance evaluations under the simultaneous action of completely reversed cyclical loading (stress ratio, R= -1) while exposed to 3.5 wt.% NaCl corrosion medium.

The electrochemical corrosion response of the thicker MAO coated Al alloys, irrespective of substrate prior treatment condition, demonstrate up to 85 times reduction in corrosion current density than the corresponding bare substrate confirming the barrier nature of MAO coatings against the corrosion. Both the plain-fatigue (PF) and corrosion-fatigue lives of bare Al alloy evaluated as function of max. alternating stress levels is provided in Fig. 1(a). It was clear that a substantial life reduction (represented by hatched region) is noticeable between the corrosion-fatigue life and the plain-fatigue (absence of corrosion medium) life. Further, the life reduction is more significant at the lower stress levels that indicates the detrimental effect of corrosion during the prolonged exposure duration while such a degradation is minimal at high stress levels where the cyclic loading dominates the corrosion phenomenon in adjudging the total life. Furthermore, the corrosion-fatigue life of three different thick Plain MAO and SP+MAO coatings in comparison with the bare substrate as investigated at different alternating stress levels were represented as S-N curves as shown in Fig. 1(b). It is apparent that the corrosion-fatigue life of Plain MAO coatings is significantly inferior to that of corresponding bare substrate. In contrast, the moderately thick (10 and 50 μm) SP+MAO coating's fatigue life is marginally superior to the bare substrate's life and significantly superior to all Plain MAO coatings.

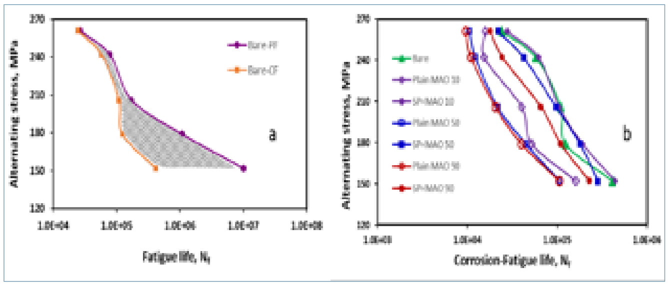

Fig. 1 (a) Comparative performance of bare 6061-T6 Al alloy under high cycle plain-fatigue (PF) and corrosion-fatigue (CF) conditions and (b) Corrosion-fatigue (SN curves) performance for bare, plain MAO and SP+MAO coatings

The extent of reduction or enhancement in corrosion-fatigue life as proposed for the first time is computed by taking ratio of average corrosion-fatigue life of coating to the corrosion-fatigue life of corresponding bare substrate (normalized corrosion-fatigue index-NCFI). It is noteworthy that the NCFI value equal to 1.0 implies no role for the coating to play while the index values < 1.0 indicate the degradation and > 1.0 indicate the improvement in corrosion-fatigue life. Now it is quickly identifiable from Fig. 2 that the Plain MAO coatings have mostly exhibited the NCFI values less than 0.5 illustrating inferior corrosion-fatigue life. This particular observation reiterates that the significantly enhanced corrosion protection is not necessarily translatable into better corrosion-fatigue life. Whereas, the SP+MAO coatings distinctly performs better than Plain MAO coatings. Therefore, the parameter NCFI, which is an important outcome of present study, emerges as a quick benchmarking (ranking) tool and enables the effective quantification of life extension / degradation due to corrosion-fatigue of diverse materials, enabling the new direction for rapid development of materials that are prone to corrosion-fatigue degradation.

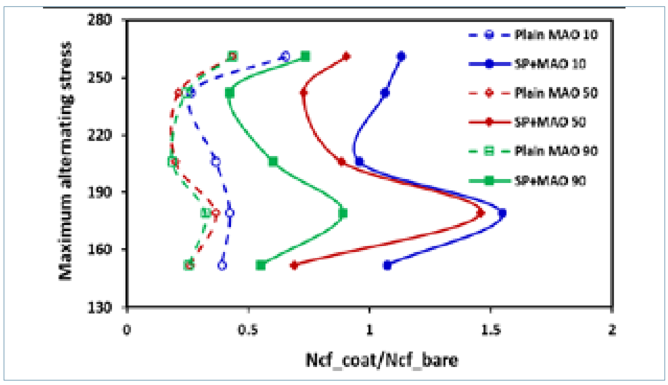

Fig. 2 Normalized corrosion-fatigue life index as a function of maximum alternating stress

Contributions: Y. Madhavi, D. Srinivasa Rao and G. Padmanabham

Hot Corrosion Behaviour of Plasma Sprayed and Detonation Sprayed Coatings for T91 Steels used in AUSC Power Plants

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Materials degradation under hot corrosion that prevail in the flue gas environment is a major concern in coal based power plant components. Protective coatings with alloys designed to form chromia and alumina layers during exposure to alkali sulphates/chloride atmospheres are preferred. The influence of Chromium to Aluminium ratio also plays a major role in futurstic alloy design for hot corrosion.

5 different candidate materials (Ni-5Al, Co-23Cr-13Al-0.65Y, Ni-23Co-17Cr-12.5Al-0.55Y, Ni-20Cr and Ni-17.5Cr-5.5Al-2.5Co-0.5Y_2O_3) were coated on T91 steel using Plasma spray (APS) and Detonation spray to around 230 µm thickness. The hot corrosion tests were conducted in a thermal cycling furnace at 650°C for 100 cycles (1 cycle= 1 h holding and 20 mins air cooling) under a mixed salt deposit containing 37.5 Na_2SO_4-37.5K_2SO_4-25%Fe_2O_3(Mol%), which is highly aggressive and forms in situ $(Na,K)_3Fe(SO_4)_3$ alkali iron tri-sulphates.

Based on the studies, it was found that NiCr with maximum Cr:Al ratio performed the best, while NiAl with least Cr:Al ratio (zero) suffered highest hot corrosion damage. The testing temperature is insufficient to produce protective Al_2O_3 and rather, Al underwent internal oxidation rather than protective scale formation. The presence of protective Cr_2O_3 mixed with $NiCr_2O_4$ spinel is found to resist the corrosion ingress. The performance ranking and the corrosion products from the studies are shown in Table 1 and typical microstructures are shown in Fig. 1. Hence, chromium content in the coating was able to help with the passivation and DSC coatings are better than APS due to better inter-splat bonding and dense microstructure.

Table 1. Hot corrosion performance ranking (from best to worst)

Rank	Coating	Max. Corrosion depth (µm)	Corrosion products/ Remarks
1	D-Gun NiCr	10-12	Presence of Cr_2O_3 and $NiCr_2O_4$; No NiO found
2	D-Gun NiCoCrAlY	18-24	Presence of $NiCr_2O_4$ and NiO
3	APS NiCr	22-26	Presence of Cr_2O_3 and $NiCr_2O_4$ and NiO
4	D-Gun CoCrAlY	30-34	Co_3O_4 top scale with thin Cr rich layer beneath
5	APS NiCoCrAlY$_2$O$_3$	45-50	$NiCr_2O_4$ spinel found; No protective top scale found.
6	APS CoCrAlY	53-56	Thick Co_3O_4 top scale with thin Cr rich layer beneath
7	APS NiCoCrAlY	80-85	Thick NiO top scale with $NiCr_2O_4$ spinels beneath
8	APS NiAl	100-118	Pitting type attack; No σ-Al_2O_3 formed

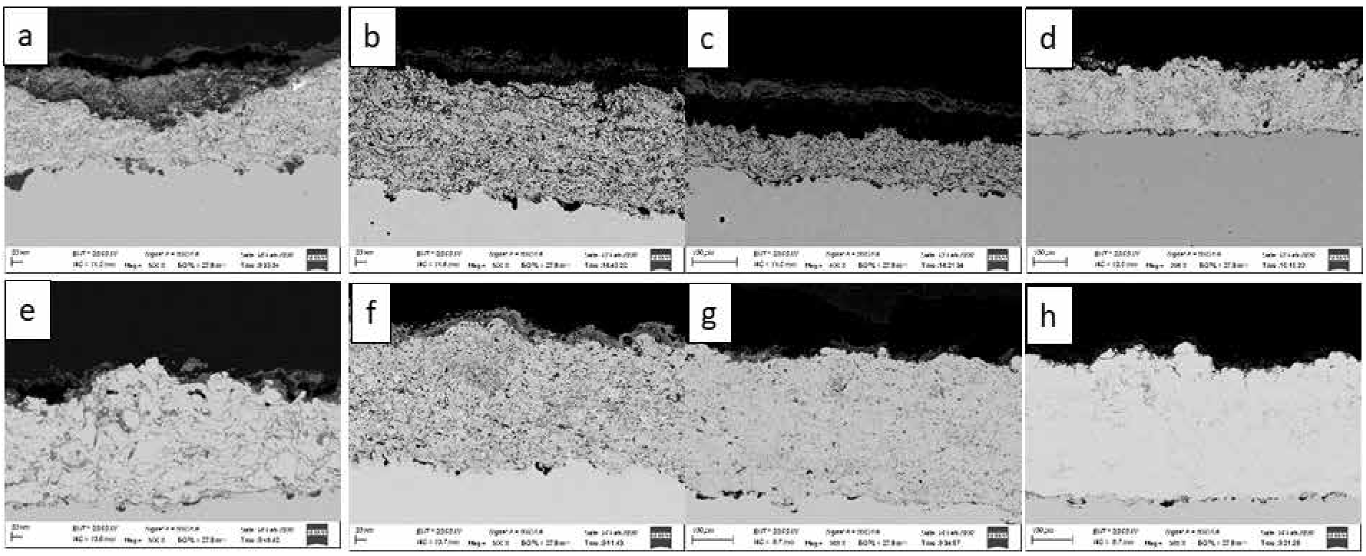

Fig. 1 Cross-sectional images of hot corroded coatings for (a) APS NiAl (b) APS CoCrAlY (c) APS NiCoCrAlY (d) APS NiCr (e) APS NiCoCrAl+Y_2O_3 (f) DSC CoCrAlY (g) DSC NiCoCrAlY and (h) DSC NiCr

Contributors: C. Sundaresan and D. Srinivasa Rao

Corrosion Resistant Ni-W Coatings by Pulsed Electrodeposition

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While it is evident that the nanocrystalline metals/alloys have superior room temperature mechanical properties compared to their microcrystalline counterparts, their corrosion behaviour is still under debate. From the classical thermodynamic point of view, one would expect that the nanocrystalline metals will relatively be more prone to corrosion due to the presence of high energy sites (grain boundaries, intercrystalline regions and triple junctions). However, studies on the corrosion behaviour of nanocrystalline metals have demonstrated highly conflicting results. Moreover, the corrosion behaviour of ultra-nanocrystalline (grain size <10 nm; in the inverse Hall-Petch regime) metals has not been studied yet.

The Ni-W coatings are potential candidates for hard chrome replacements and therefore have gained a lot of attention. The present work, therefore investigated the corrosion behaviour of pulse electrodeposited ultra-nanocrystalline Ni-W alloys (Ni16W, Ni23W and Ni27W) in 1M H_2SO_4 by Potentiodynamic polarization and electrochemical impedance spectroscopy. The corrosion and passive current density decreased initially up to 23 at% W and increased thereafter as shown in Fig. 1. The corrosion properties are correlated with the nature of the surface oxide film (composition by XPS depth profiling and semiconducting properties, porosity and defect density by Mott-Schottky tests) formed when exposed to the corrosion media to reveal the factors controlling corrosion. The crucial role of the nature of surface oxide film in determining the corrosion performance has been neglected in earlier studies. Based on the present results, a Hall-Petch type of relation between the grain size and corrosion rate has been proposed in nanocrystalline metals as depicted in Fig. 2. Therefore, it is believed that there exists a critical grain size (therefore a critical W-content in Ni-W alloys) below which the corrosion rate decreases with grain size while it increases above that. Such a behaviour is explained as follows: the electrochemical electron transfers and diffusion rates are higher in nanocrystalline metals compared to their bulk counterparts leading to an improved rates of passive oxide film formation resulting in lowering the corrosion current. On the other hand, high dissolution rates in near amorphous coatings [Fig.3] (d < 2 nm) is attributed to the formation of a discontinuous and defective oxide film as revealed by SEM analysis and Mott-Schottky tests. This study can help in designing novel nanocrystalline Ni-W coatings with optimal grain size (or W content) for superior corrosion resistance in harsh environments.

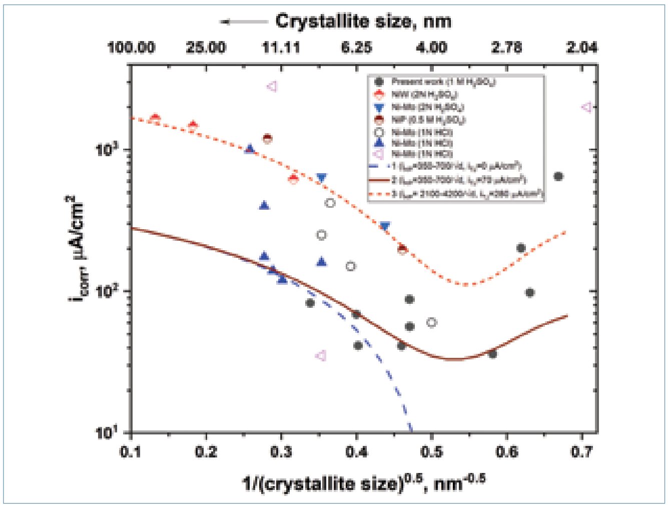

Fig. 2 Dependence of corrosion current on crystallite size along with literature data

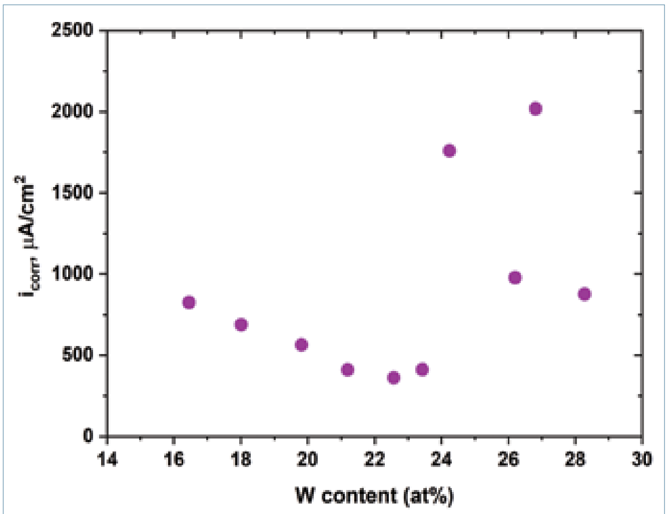

Fig. 1 Variation of corrosion current as a function of W content. The numbers indicate samples with different W content

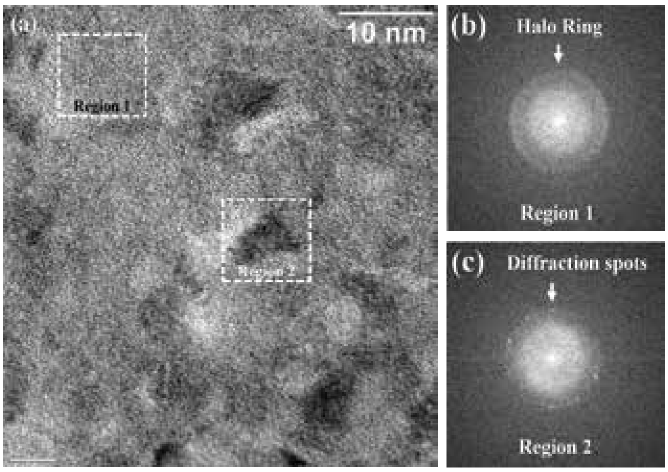

Fig. 3 High-resolution TEM image for Ni27 at% W (a) with along with corresponding Fast Fourier Transform (FFT) of region 1 (b) and region 2 (c) This leads to formation of discontinuous oxide film formation

Contributor: B. Lava Kumar

High Temperature Oxidization Resistance Coatings by Sol-Gel

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Metals when exposed to an oxidizing gas especially at elevated temperature, can undergo corrosion due to direct reaction with the gas, even in the absence of a liquid electrolyte. This type of corrosion is referred to as high–temperature oxidation, scaling or gaseous corrosion. Currently minimizing corrosion of metals due to the demand for emerging high temperature applications are gaining importance. This can be realized by either material modification (alloying) or changing the exposed atmosphere (inhibitors) or by creating the barrier (protective coatings) on component surface. Surface coating to protect the material from oxidation due to high temperature is gaining prominence due to its inherent advantages. Some of the examples are powder coatings employed to protect the mild steel furnace side walls, and stainless steel (SS) used in boiler systems at a temperature range of 300–500 °C because of their low cost and acceptable mechanical properties. It is well known that oxidation and hot corrosion are the main reasons for degradation of thermal power plant boilers and heat exchanger systems. In order to minimise the problem of corrosion, application of appropriate surface coating in the above–mentioned fields is considered to be the best option. Moreover, this kind of coating can also improve the durability in combination with the performance as seen in a number of day–to–day applications, such as, automotive engine exhaust parts, household heating systems, energy conversion systems (fossil power stations), petrochemical and chemical processing industries.

There are various high temperature oxidation protective coatings that are available for industrial usage such as nitrides, silicides or transition metal oxides, anti–fouling paint and aluminising, etc., Other than the above conventional protective coatings, attempts were also made for the above application by sol–gel coating technique. Sol-gel coating technique has many advantages over the other techniques due to composition control at molecular level, room temperature processing, uniformity of coating and relatively lower processing cost. However, inorganic sol-gel coatings have limitations in coatings thickness. The main requirement of high temperature oxidation resistance coatings on metallic surface is the formation of an impervious, inorganic physical barriers against the aggressive hot environments. Due to the above mentioned limitations, sol–gel thin film coating techniques were not studied for the high temperature oxidation protection of MS. The current study made an attempt to address the limitation of sol-gel for oxidization resistance coating on mild steel.

Single and multilayer titania–silica (TiO_2–SiO_2) naocomposite oxidation resistant dry gel film was applied on mild steel (MS) through sol–gel based dip coating technique. The coated samples were cured at an optimum condition of 410ºC for a period of 30 minutes. The coating film thickness was estimated using spectroscopic ellipsometry and was found to be in the range of 200–400 nm. Oxidation studies showed that the uncoated specimen exhibited a weight gain of 0.72 mg/cm^2, however, for coated specimens the weight gain was 6 times less for single and substantially less by 16 times for 3 layers of deposition. Further, oxidation kinetics study revealed the reduction of parabolic oxidization rate constant by 43 times (0.026 mg^2.cm^{-4}.h^{-1}) due to single layer of thin film coating and reduction by to 325 times (8×10^{-5} mg^2.cm^{-4}.h^{-1}) upon increasing the number of coating layers to 3, compared to bare MS exposed to identical conditions. Multilayer deposition provides an effective coverage of micro–cracks that may be induced due to thermal mismatch, which further enhances the oxidation resistance. Fig.1 shows the oxidization kinetics of the bare and coated samples. The present work demonstrates the application of TiO_2–SiO_2 thin film coating on MS through sol-gel technique forming an impervious layer to enhances the oxidation resistance substantially at elevated temperatures. Considering thermal expansion coefficient of base material, surface roughness and phase transformation behaviour of thin film material as a design parameter, there is a possibility to make such high temperature protective coating on any substrate.

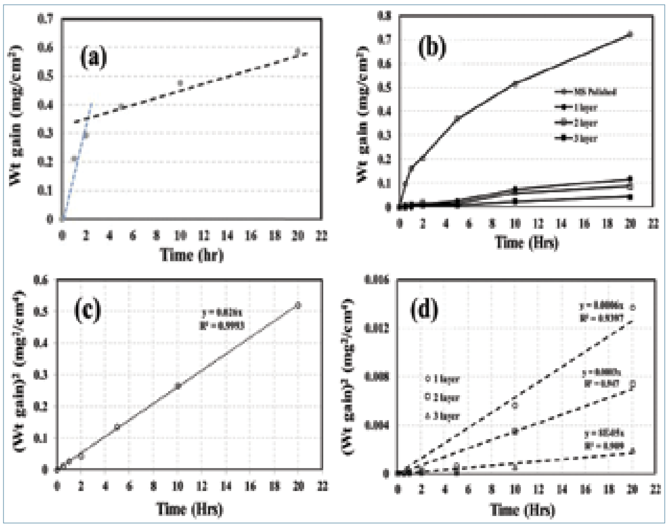

Fig. 1 Isothermal oxidation kinetics study on bare and TiO_2-SiO_2 coated MS at 400°C for 20 h (a) various size of bare MS (b) bare and coated MS (c) parabolic rate constant of bare MS and (d) parabolic rate constant of single and multi-layer coated MS

Contributors: Vijay Krishna, R. Padmapreetha, S. B. Chandrasekhar and Roy Johnson

Revisiting the Criterion for Minimum Spacing of Indents

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With the advances in instrumented indentation systems and testing methodologies, high speed indentation testing can now be performed with each indentation test taking less than a second. In addition, the advances in electronics have also enabled fast measurements without compromising the accuracy or noise even at depths as low as 50 nm. High speed nanoindentation testing opens up a significant opportunity to measure the local mechanical properties of multi-phase alloys and small volumes of materials with high throughput by large arrays of indents, which can serve as an effective characterization tool to significantly reduce design and production time. This then raises a very pertinent question that determines the resolution of the mechanical property mapping - What is the minimum spacing of indents? The currently accepted standard, proposed more than 50 years ago, was not developed from rigorous analysis. Hence, a systematic study of the minimum indent spacing, was undertaken.

The primary findings of such a work using the standard Berkovich indenter is summarized in Fig. 1, wherein, the hardness error, defined based on the deviation in hardness at a given spacing to that at very large spacing, is plotted as a function of the ratio of indent spacing to depth for a wide variety of materials. Similar plot for modulus is also shown. It can be observed that a minimum indent spacing of 10 times the indentation depth is sufficient to obtain accurate results for a Berkovich indenter. This is less than half of the commonly followed criteria of spacing the indents three times the lateral dimension (or 20 times the depth).

To understand this rather surprising experimental observation, Finite Element Analysis (FEA) was carried out on a wide range of materials and the key findings are summarized in Fig. 2, which shows the indent topography and cross-sectional plastic strain contours. It can be observed that the hardness error at a spacing to depth ratio (d/h) of 10 is less than 1 % in spite of the plastic zones overlapping. This contradicts the popular notion that the indents should be spaced such that their plastic zones do not overlap. This apparent contradiction can be explained from simple indentation energy calculations, wherein it was found that the majority of the work of indentation is expended within a hemispherical region bounded by the contact and the energy contribution outside that is minimal. This explains why the indents can be spaced much closer that the currently accepted criterion and opens up a tremendous opportunity for high-resolution and high-speed property mapping.

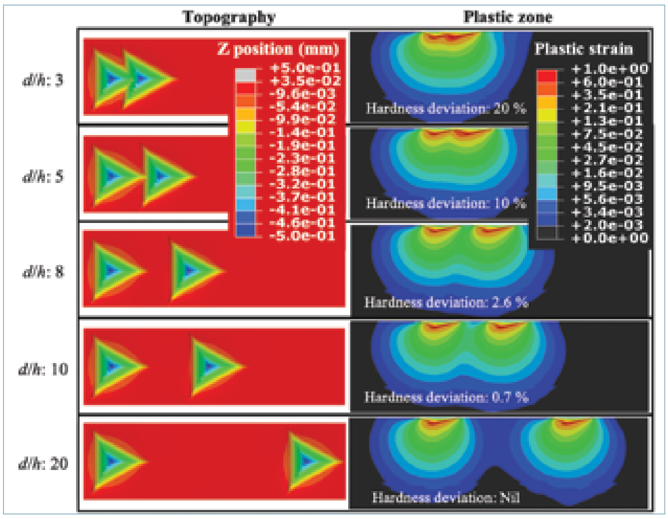

Fig. 2 FEA calculations of indent topography and the cross-sectional plastic strain contours at different ratio of indent spacing to depth (d/h) for a material with E/Y: 3000 and n: 0.5. Plastic strains below 0.2 % are grayed out to visualize the plastic zone boundary

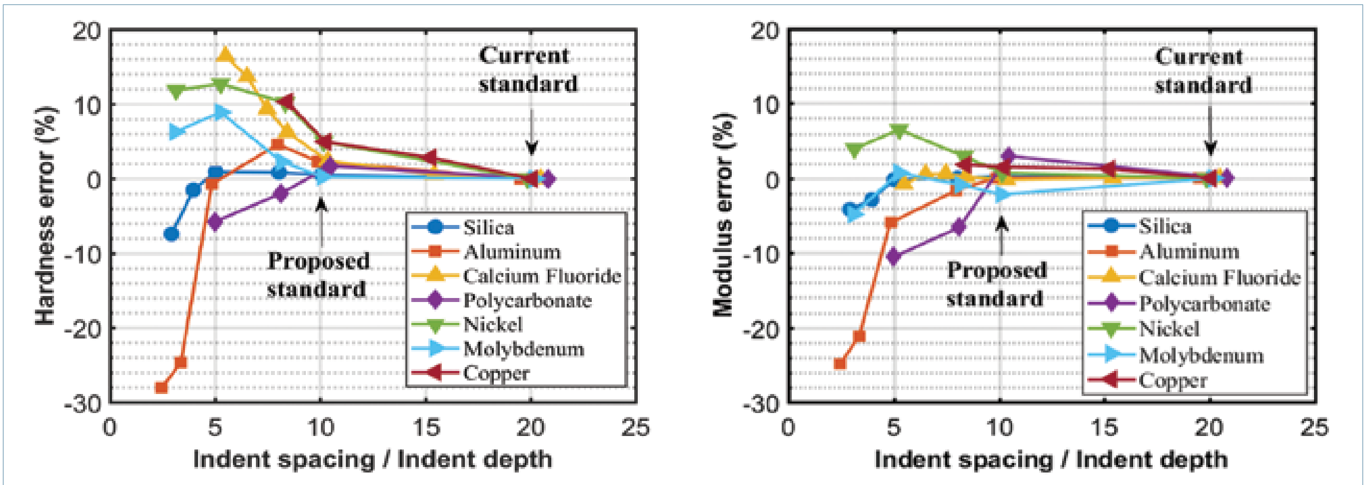

Fig. 1 Experimentally determined hardness and modulus error as a function of the ratio of indent spacing to depth for different materials

Contributor: D. Srinivasa Rao

New Continuous Stiffness Measurement (CSM) Based Indentation Method to Measure Hardness and Elastic Modulus of Materials with Improved Precision and Accuracy

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Over the years, there have been many improvements to the depth sensing indentation (DSI) or nanoindentation testing methodology and measurement electronics. These advancements provide opportunities to develop novel testing capabilities and also improve the reliability of the measurements. The precision and accuracy of a DSI test depends on several factors, including the testing instrumentation, test methodology and material response. The focus of this article is on the test methodology and material response aspects. Specifically, a continuous stiffness measurement (CSM) based indentation test, wherein a sinusoidal load is superimposed on the broadband load to obtain hardness and modulus continuously as a function of depth, is considered.

In this regard, a comprehensive model for simulating a constant indentation strain rate continuous stiffness measurement (CSM) test that includes the elastic-plastic response of the material and the response of the phase lock amplifier (PLA), is developed to understand the parameters affecting the precision and accuracy of the measurements. When the mean value of the load increases in each cycle of a CSM based indentation test, the resulting amplitude of the displacement oscillation is influenced by not just an elastic response but also the plastic response and gives rise to an error in the calculated elastic contact stiffness or compliance, which is commonly referred to as the plasticity error. The compliance error due to plasticity for a given material and test conditions depends on the non-dimensional parameter X=(P/P)(1/f)(P_DC/P_ACo), where (P/P) is proportional to the indentation strain, f is the oscillation frequency and (P_ACo/P_DC) is the ratio of the AC to DC parts of the load. The compliance error for a wide range of materials collapses onto a master curve when plotted against a parameter Y= $X^{-0.85}(e^{X}-1)\phi$ as shown in Fig. 1, which can then be used to correct the plasticity error.

In addition to a simple procedure to correct the plasticity error, a new test methodology that uses a fixed ratio of the amplitude of the sinusoidally varying portion of the instantaneous load to the load's mean value (AC to DC) during CSM testing is developed. Unlike the current method, the new test methodology does not require closed-loop feedback and can also reduce the plasticity error and improve the signal-to-noise ratio (SNR) in stiffness. Fig. 2, shows the significant improvement in SNR of S^2/P and phase angle for the new method compared to the current standard method in the case of indentation tests on fused silica.

In summary, the new test methodology that maintains a constant ratio of AC to DC load, coupled with the plasticity correction, results in improvements in the precision and accuracy of nanoindentation testing.

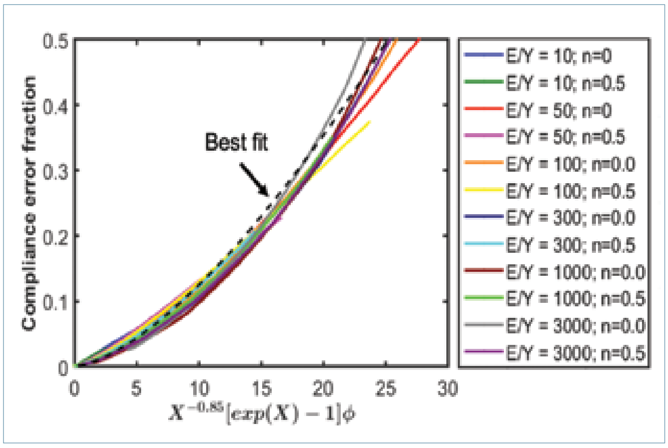

Fig. 1 Compliance error fraction calculated from simulations as a function of the parameter Y= X^(-0.85) (e^X-1)ϕ for materials with different ratio of elastic modulus to yield strength (E/Y) and strain hardening exponent (n).

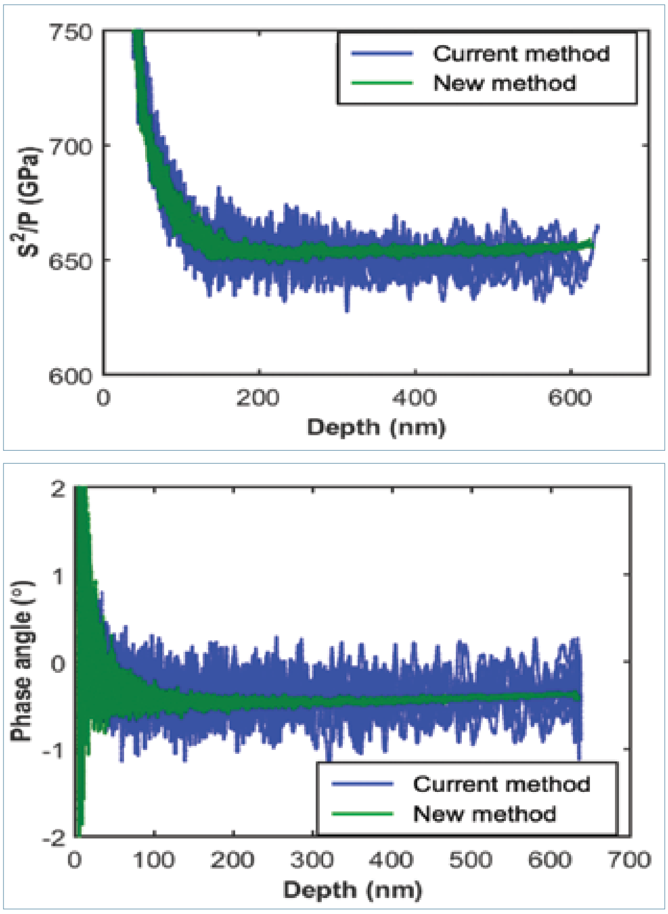

Fig. 2 Comparison of the experimental data from 10 repetitive tests on fused silica, between the current CSM method that uses a fixed 2 nm displacement oscillation and the new method that maintains a fixed dynamic load fraction of 0.2 for the case of S2/P and phase angle

Contributor: D. Srinivasa Rao

Development of Compositionally Modulated, Wear Resistant Al_2O_3-TiO_2 Ceramic Composite Coatings Through Detonation Spray Technique

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Thermally sprayed Al_2O_3 ceramic coatings have several industrial applications for creating notable wear, corrosion and oxidation resistant surfaces. These coatings have their applications in textile manufacturing components, marine, power industry, tooling, components for the chemical industry, etc. However, pure alumina coatings are very brittle and exhibit low grindability. Al_2O_3-TiO_2 composite coatings have certain advantages over pure Al_2O_3 coatings i.e. increase in toughness and presence of low melting TiO_2 results in dense coatings with good inter-splat bonding. TiO_2 content in the Al_2O_3 composite influences its microstructure and electrical conductivity. In addition, the TiO_2 content also influences its tribological properties. The influence of TiO_2 content up to 40% (AT-3: Al_2O_3-3 wt.% TiO_2, AT-13: Al_2O_3-13 wt.%TiO_2, AT-40: Al_2O_3-40 wt.%TiO_2) on the microstructure, phase content and wear properties of Al_2O_3 composite coatings is studied.

Detonation spray technique is a cyclic process and can deposit coatings like low melting oxides in addition to cermet and alloys coatings by proper selection of power flux (oxy/fuel ratio) to achieve suitable atmosphere. Al_2O_3 blended with TiO_2powders is used as the feedstock. Dense Al_2O_3-TiO_2 composite coatings with thickness about 300 µm are deposited on mild steel substrate. The coatings exhibited an increase in α-Al_2O_3 and Al_2TiO_5 phases with increase in TiO_2 in the coatings. Addition of TiO_2 to Al_2O_3 has shown impact on mechanical properties of coatings. The hardness decreases with increasing TiO_2 content in the coating from 1082 HV in 3 wt.% TiO_2 coating to 909 HV in 40 wt.% TiO_2 coating. These coatings have been subjected to tribological tests under pin-on-disc conditions. During sliding wear test, the pins were made to slide over rotating disc (WC-6Co) having hardness (1913 HV10) for a sliding distance of 1000 m in each lap, at a normal load of 30 N, and the results are presented as cumulative mass loss versus sliding distance in Fig. 1. It is well known that hardness has high impact on wear resistance of coatings, and it is reported that increase in hardness resulted in the improvement in the wear resistance of Alumina–Titania coatings Sliding wear of Al_2O_3-TiO_2 coatings followed the coating hardness trend in this study. It is observed that AT-13 coatings exhibited high friction (COF) of 0.68 as against 0.58 in AT-3, 0.57 in AT-40 coatings. From EDS analysis of worn surfaces, the elements of counterpart (W, Co) having hardness 1913 HV10 are attached on the tribo-layer formed during sliding of AT-13 coating, and these high-hard elements aid in the formation of stable and harder tribo-layer which has shown clear impact on COF values, and thus, AT-13 coating exhibited high COF compared to other two coatings. SEM images of worn surface regions (Fig. 2) revealed the formation of tribolayer on worn regions of AT-13 and AT-40 coatings. The tribo-layer formation is minimum in AT-3 coating, which may be due to low amount of TiO_2 in the coating. Absence of tribolayer & grinding type material removal on the surface layer is the main material removal mechanism noticed in AT-3 coatings. Adherent tribolayer in AT-13 coatings is noticed in the worn surface regions with removal of tribolayer in small patches. In case of AT-40 coatings, a tribolayer with cracking and removal of entire splat (delamination) is the main material removal mechanisms. The presence of adherent tribolayer resulted in higher COF in AT-13 coating than AT-3 and AT-40 coatings. Studies are in progress to evaluate the wear performance of Al_2O_3-TiO_2 composite coatings under abrasive and erosive wear conditions with more TiO_2 compositions in the coatings such that the suitable coating can be identified based on the type of wear the component will experience.

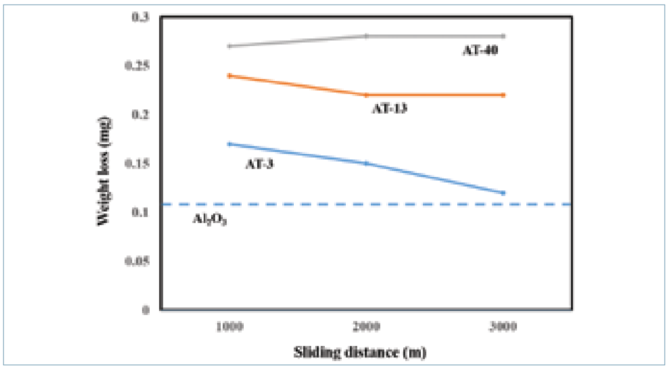

Fig.1 Cumulative weight loss of Al_2O_3-TiO_2 coatings under pin-on-disc wear deposited by detonation spray system. The dotted line shows the weight loss of pure Al_2O_3 coating

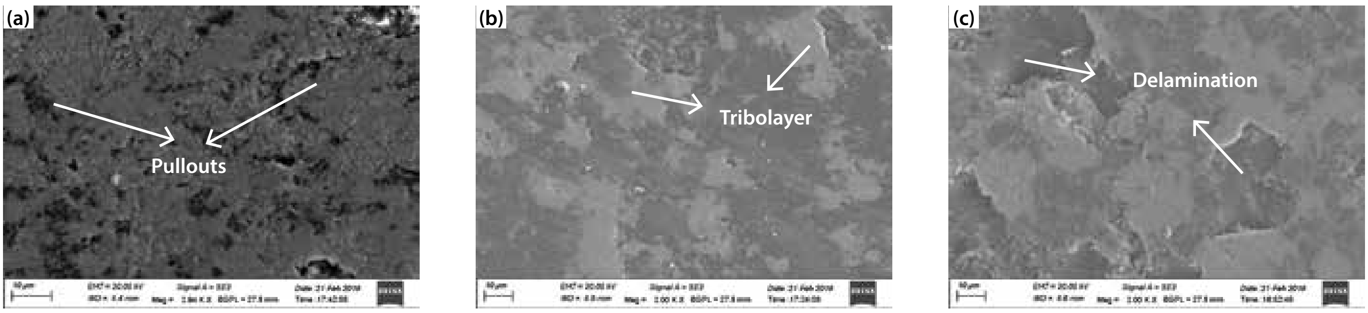

Fig.2 SEM images of Al_2O_3-TiO_2 coatings worn surface regions (a) AT-3 (b) AT-13 and (c) AT-40

Contributors: P. Uday Chandra Rao, L. Rama Krishna and D. Srinivasa Rao

Abrasive Wear-Resistant Coatings for Agricultural Sector: A Viable Solution for Life Enhancement of Briquetting Machine Components

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In the recent past during the switchover period from kharif to rabi season (only few days), due to the lack of viable methods for utilization of paddy straw most of the stubble were burnt on the fields itself. This stubble burning in Punjab, Haryana and Uttar Pradesh states in large quantities resulted in a devastating situation in places like Delhi by enormously increasing the air pollution. In order to minimize the air pollution, several attempts were made to convert paddy straw into a useable resource of energy. Among the available solutions, briquetting processes is one of the closely matched viable solution. Even though the briquetting process is a well known economic solution for forest wastes, the use of the same is not viable in case of paddy straw due to a low lignin content and high silicon oxide (SiO2) which can cause erosion/ abrasive problem and result in high wear and tear of briquetting machine components like: ram, piston, hammer (Fig. 1) and chopper blades, making paddy straw briquetting process un economical. Hence, in the present study an attempt is made to develop abrasive wear resistant coatings for briquetting machine components to make briquetting process more economical.

TiN, TiCrN and TiAlN coatings were developed on hardened D3 steel substrates using Cathodic Arc Physical Vapor Deposition (CA-PVD) with varying thickness and subjected to abrasive testing. The volume loss measurements indicate that the TiCrN coating with 4-micron thickness has better abrasion resistance. The detailed results are shown in figure 2. The higher toughness and minimal surface roughness are the key features for observed better abrasive properties. Further, as the component sizes are relatively large and coating them completely using PVD is not economically viable (as the component is made of simple D3 steel), a novel design with two parts: insert (wearing part) and tool (support/fixture) geometry was fabricated for real time field testing as shown in figure 3. Between the insert and tool geometry, only the insert needs to be coated and several of them can be coated at a time making it economically viable. The field performance evaluation studies of the redesigned tools with hard and wear resistant TiCrN coating has been initiated and is expected to be deployed by the end of coming kharif season.

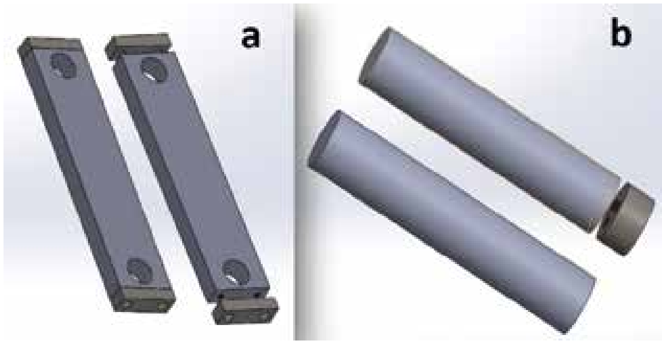

Fig. 2 The abrasive wear resistance of TiN, TiAlN & TiCrN coatings in terms of worn out time

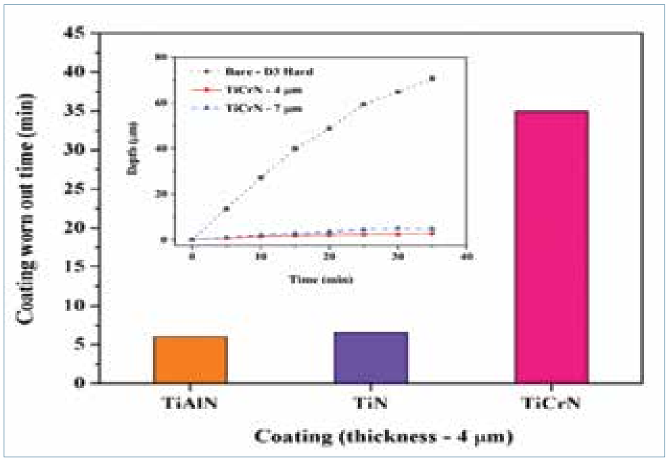

Fig. 3 Modified two component structure of briquetting machine components: a) hammer blade and b) die

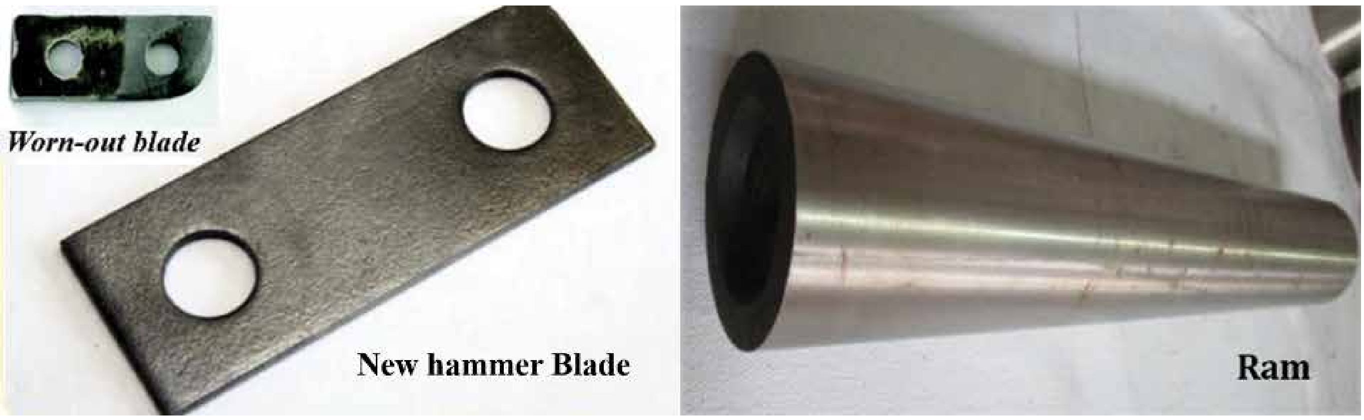

Fig. 1 Photographs of hammer blade and ram used in briquetting machine

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Wear and Corrosion Performance of Cold sprayed Cermet Coatings

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Cold spraying has emerged as one of the versatile variants of thermal spray techniques by which variety of engineering metals and alloys have been deposited targeting a range of industrial applications. Depositing cermets using conventional thermal spray techniques such as plasma spray and high velocity oxy-fuel spraying has limitations since very high process temperatures present in the process plume / jet accelerates the decarburization of functional carbides present in the cermet feedstock. Owing to the low processing temperature in cold spraying, this technique has a potential and is considered one of the very few techniques used to overcome the issues related to decarburization without affecting the feedstock chemistry which has a direct impact on the functional performance of the deposited layer.

Selecting a suitable feedstock is a key in depositing cermet coating through cold spraying. Conventional agglomerated sintered cermets are not suitable for cold spraying because of the fact that carbide and metal phases present in them shatters upon high velocity impact leading to poor or lack of deposition. A suitable alternative for cold spraying to overcome this issue is to synthesize cermet powders having carbides completely covered with binder such as in a core-shell structure (chemically cladded).

Dense coated 17Ni-83WC powders were deposited at 20 bar, 600 oC process conditions using in-house cold spray system to obtain the required coatings. Since the Nickel binder has very high thermal sensitivity, three different nozzles having different convergent lengths (20 mm, 40 mm and 80 mm) were utilized to deposit the coatings based on the fact that increasing convergent length of the nozzle enhances the thermal energy to the feedstock within the nozzle, thus greatly enhances the deposition behavior by increasing degree of plastic deformability of the binder and facilitates inter-splat bonding between Ni-Ni interfaces. As expected, the coatings deposited using longest convergent length show best deposition characteristics as confirmed through thickness, hardness and elastic modulus of the coatings. It is worth noting that the coatings deposited using different nozzles do not alter the carbide retainment but alters the deposition efficiency indicateing the role of enhanced plastic deformability.

Scanning Electron Micrsocope images (Fig. 1) of the coating cross section reveals that the coating is intact with the steel substrate with 52 MPa bond strength. Also, it was observed that the carbide percentage in the coatings was similar to that of feedstock suggesting that shattering phenomena upon impact can be avoided by careful selection of feedstock. Almost ~ 80% of carbides were retained in the coatings with a high thickness (~ 1 mm). The coatings were subjected to sliding wear and corrosion tests. Sliding wear rate of ~ 2x 10-5 mm3/m was achieved with very low friction coefficient (~0.15) for a sliding distance of 900 m. These results (Fig. 2) are comparable with the conventional coating results. The coatings were subjected to potentiodynamic polarization test immersed in 3.5 wt % NaCl solution. The results are shown in Fig. 3.

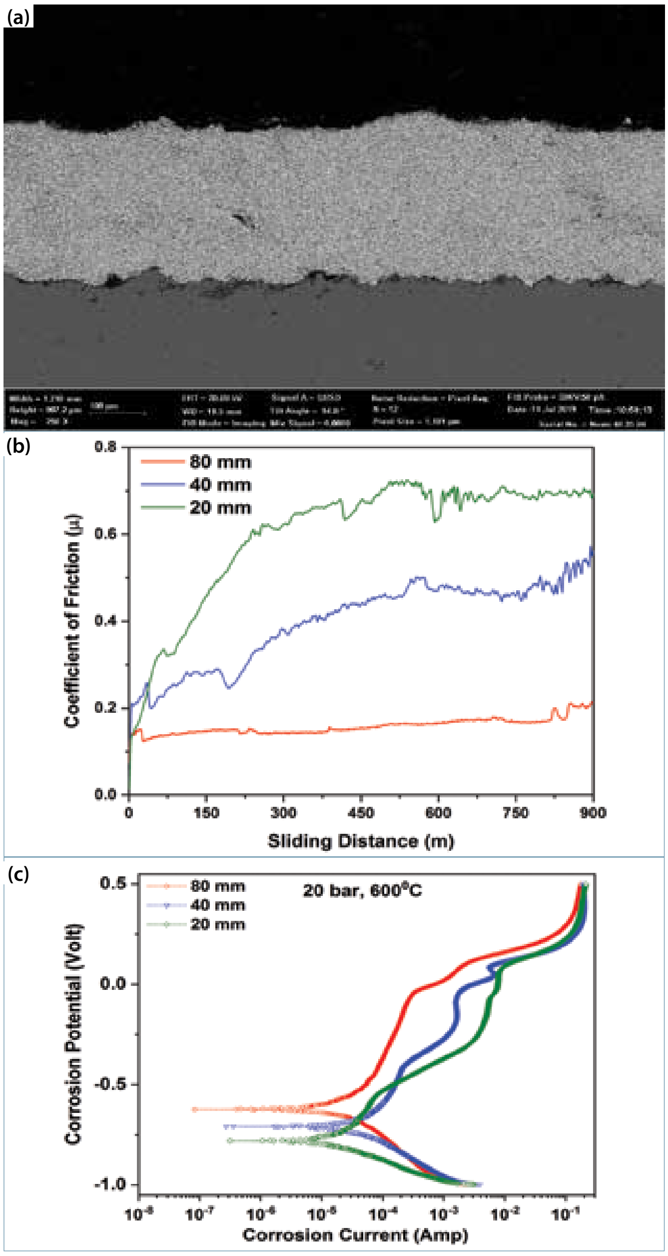


Fig. 1 (a) Scanning electron microscope image of cold sprayed Ni-WC coatings; (b) Sliding wear and (c) corrosion performance of the coatings deposited using different nozzles

Contributors: A. Sai Jagadeeswar and A. Jyothirmayi

Grain Refinement in Cu and Cu-Al Alloys-Influence of Cold Spray Conditions and Stacking Fault Energy (SFE) of the Feedstock

Naveen Manhar Chavan

Severe plastic deformation (SPD) of copper and copper alloys has attracted a lot of attention over the past few decades as a potential method to fabricate nanostructured materials. External deformation conditions such as strain, strain rate and temperature and composition of the starting material decides the extent of grain refinement. In this report, a high strain rate (~10^{10} s^{-1}) technique known as cold spray is used to deposit Cu, Cu2.2Al and Cu7.5Al that have significantly different SFE values (Cu~78 mJ/m^2, Cu2.2Al~ 28 mJ/m^2 and Cu7.5Al~6 mJ/m^2) in order to study the microstructure refinement with SFE. Cold spray is an established low temperature high velocity variant of thermal spray coating techniques which is used in repair and refurbishment of conventionally and additively manufactured components due to the low heat input. This technique involves impact, in solid state, of micron sized powder particles (10-50 µm) at high velocities (300-1000 m/s) thereby deforming them at a range of strain rates (10^5 s^{-1} to 10^{10} s^{-1}) and moderate to high strains.

Extent of grain refinement can be seen from Fig.1. wherein Fig.1a shows the grain size in the feedstock powder and Fig.1b shows the grain size in the coating (only Cu7.5Al is shown). Drastic grain refinement is seen, as marked by arrows, owing to the high strain and high strain rate nature of cold spray process aided further by the effect of SFE. Detailed TEM investigations revealed that the average grain size in the coatings is 110 nm, 45 nm and 30 nm for Cu, Cu2.2Al and Cu7.5Al respectively, which is two orders of magnitude finer than starting powders. In order to explain this refinement, it is pertinent to look at Fig.2. that shows grain size (d) normalized by Burger's vector (b) as a function of SFE (χ) normalized by shear modulus (G) and Burger's vector. Irrespective of the processing method, grain size reduces as SFE is reduced due to twin fragmentation induced grain refinement which is different from the traditional dislocation activity induced grain refinement. In this mode, as twinning stress becomes lower than that of slip, fine twins appear. These twins, in order to accommodate further strain, break or fragment into cuboidal grains leading to final grain sizes of the order of twin width(s) observed in the respective materials.

Based on the above findings, it can be concluded that cold spray can be used as a potential technique to consolidate powders and achieve coatings/freeforms that have grain sizes that are orders of magnitude lower than starting powders. The process parameters and powder size cuts can be varied to obtain free forms that have a combination of superior strength and ductility.

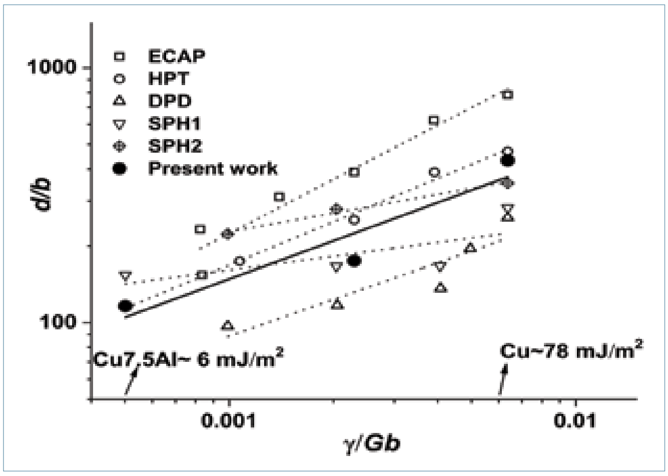


Fig.2 Normalised grain size as a function of normalized SFE (Literature data also plotted for comparison)

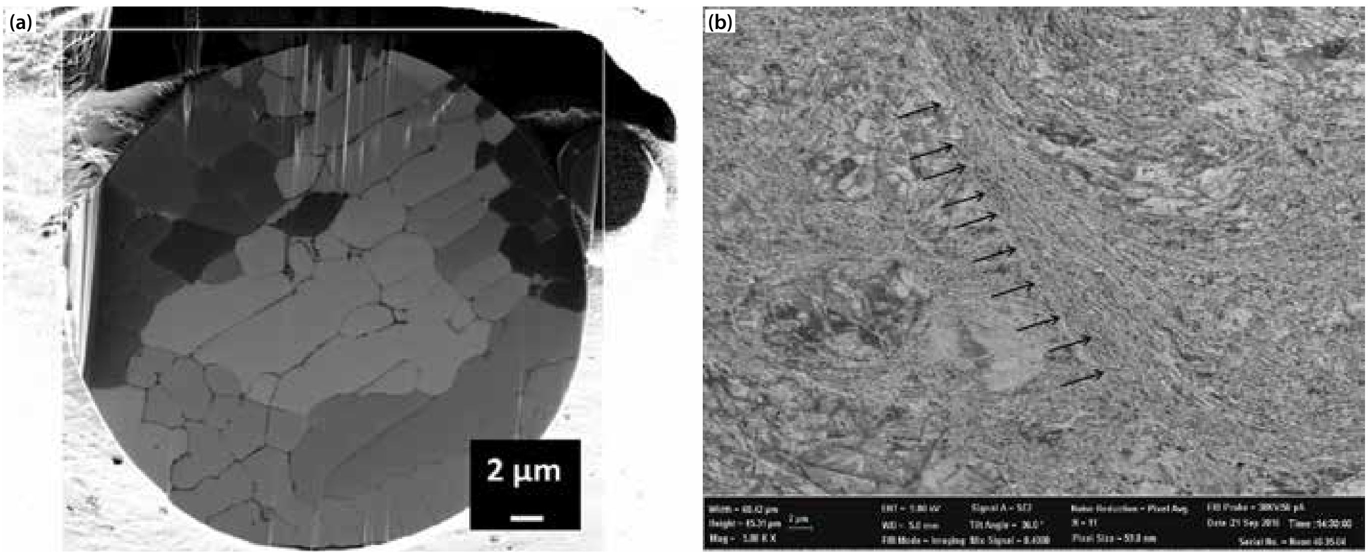


Fig.1 Grain size in Cu7.5 (a) powder and (b) coating (Note: similar observations made in other two materials)

Contributors: P. S. Phani, M. Ramakrishna, L. Venkatesh, Prita Pant and G. Sundararajan

Process Parameter Optimization and Performance Testing of Advanced DSC System

J Nagabhushana Chary

Thermal spray coatings have gained great attention since last two decades to protect the components from wear, corrosion, oxidative environments and to enhance their life even when subjected to harsh environment. Further, the coatings are also widely used to repair/refurbish various components in aerospace, power industry etc. to put them back in service without replacing them with new ones, which can be very expensive. Centre for engineered coatings at ARCI is equipped with various thermal spray systems and has been engaged in development of wide variety of coatings for various industrial applications. Detonation spray coating (DSC) system, one of the thermal spray variants has been successfully indigenized by the centre. Application development and demonstration of performance of various coatings on industrial components has been completed. Technology has also been transferred to Indian industry and the technology receivers have shown great progress over the years.

Detonation spray is a cyclic process running at three shots per second and the gas flow is controlled through rotameters and mechanical moving parts. ARCI has decided to initiate R&D activity to design a high frequency DSC system with increased shot frequency from 3 Hz to 6 Hz with solenoid valves and mass flow controllers by PLC based programing with all safety features for easy operation and enhanced productivity i.e. advanced detonation spray coating (Mark II). Towards meeting this objective, substantial R&D work and trials have been conducted. A prototype system (Fig.1) has been fabricated with all mechanical assemblies, bought out components, electronic hardware, MFCs, solenoid valves, PLC-HMI controllers etc.

In any thermal spray system, it is very important to optimise the process parameters to obtain dense coatings with good interface bonding. Major systems use feedstock in the form of powder to deposit coatings. Hence, a typical thermal spray coating exhibits lamellar structure with porosity at the splat boundaries, un-melted particles, oxides formed during

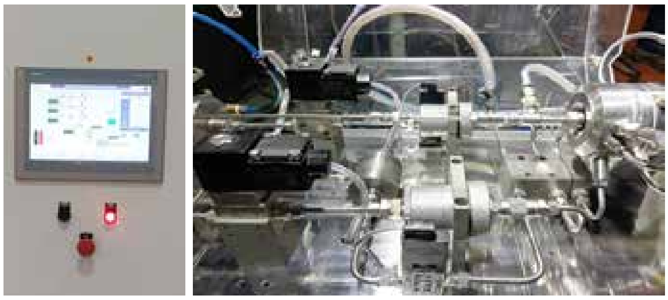


Fig.1 Advanced DSC system (Mark II) with HMI interface and electronic controllers

exposure to flame. A dense coating with low porosity and good inter-splat bonding performs better under the service conditions. In order to achieve such a dense coating, the process parameters have to be optimized for each type of coating. Heat flux (oxy-fuel volume ratio), standoff distance (distance between component to be coated and gun exit) and powder feed rate are the major parameters that influence the coating properties. The total integrated system (prototype system) was subjected to various tests for optimization of process parameters to deposit cermet and ceramic coatings, followed by coating characterization. The process parameters were optimized for oxide (Al2O3), composite (Al2O3-TiO2), carbide (WC-Co, CrC-NiCr) and alloy (Ni-Cr) coatings. The cross-sectional images of coatings deposited at optimum process parameters at 3Hz and 6Hz are shown Fig.2 show dense coating with good interface bonding. Further, the system performance has been checked by various other measurements like the coating thickness per shot, deposition efficiency and gas consumption. In addition, the system was run continuously for 10000 shots (around 30 minutes) at 6 Hz using oxide powder to check its performance similar to coating shop floor conditions. The system performed well in the longer duration tests. The system has been checked for other processing difficulties and fine-tuned for routine operation.

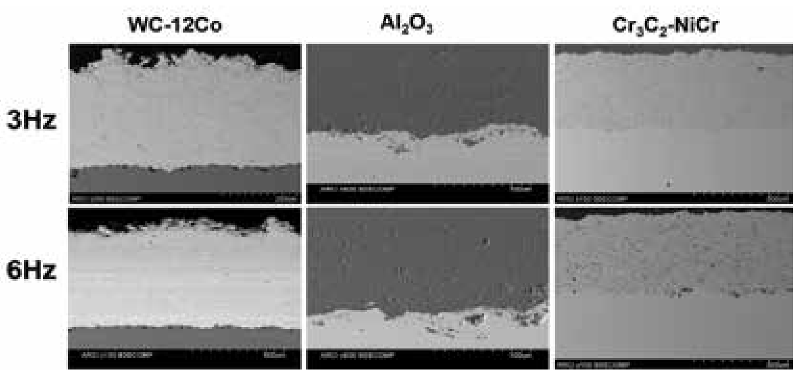


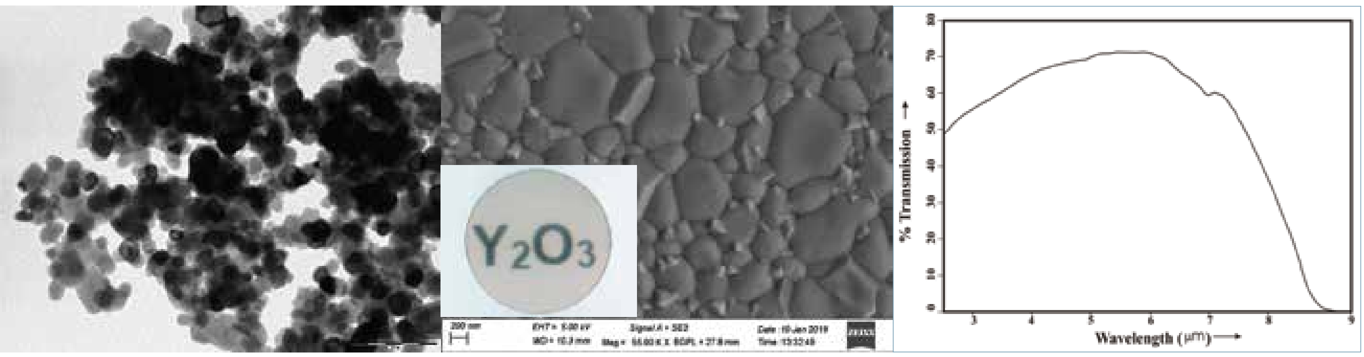
Fig. 2 Cross-sectional SEM images various coatings deposited by advanced DSC system at 3 Hz and 6 Hz frequencies

Contributors: Advanced Detonation Spray Coatings (ADSC) System Team

Centre for Ceramic Processing

Centre for Ceramic Processing is geared up to take new challenges in the pursuit of shouldering the needs of the time, has entered in to new areas through different consortium efforts. As a continuation of transparent ceramic activity, the Centre has ventured into a new area of glass ceramics. The Centre is envisaged to establish a melt quenching facility to establish a process for producing the high-quality glass materials. Technology for producing the glass ceramic materials is currently not available in the country and requirements are met by imports. The Centre is also prepared a road map for scale-up and commercialization jointly with private stake holders as per the mandate of ARCI. Centre has taken initiation in establishing a pilot scale facility on solid oxide fuel cell (SOFC) based on CSIR- CGCRI know – how (TRL-4) for the generation of power through ecofriendly process. A consortium of SOFC stake holders has been formed for the contribution towards filling-up of the technological gaps, if any, and also for hand holding to analyze and address the various aspects related to techno-commercial viability issues for commercializing the SOFC modules.

In the area of optical fabrication, Centre has also initiated ultra-precision finishing technique of magnetorheological finishing (MRF) due to its inherent advantages of diversity in applications with respect to materials ranging from glasses to hard optical ceramics and capability finish complex shapes. As part of international collaborations, ARCI and AVLHMTI, Belarus have demonstrated MRF polishing of glass ceramics to a surface finish (Ra) of 1.6 Ao. Apart from the above, ARCI is also continuing the ongoing activities on transparent ceramics, cellular ceramics and 3D printing of ceramics meeting the commitments of various projects. 'Green Dispo', an ecofriendly sanitary napkin incinerator jointly developed by ARCI-CSIR-NEERI-Sowbal has crossed more than 300 installations as a part of market seeding and sensitization. 'Green Dispo', with its innovative features, user-friendly and eco-friendly attributes, is expected to have a large market potential that will benefit the country at large in sanitary waste management.



TEM of the Nano Yttria powder along with sintered transparent disc and close packed microstructure

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Comparative Evaluation of the Properties of Conventional and Pressure Slip Cast Sintered Alumina

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Pressure slip casting technique has been recently considered for shaping of advanced ceramics owing to its superior features like, enhanced green density, high homogeneity, low rejections and high productivity in place of conventional slip casting technique. The issue of obtaining interlocking of particles in spite of having a stable slurry with non-plastic advanced ceramics in order to get higher green densities is expected to be answered in the pressure slip casting process.

A study has been taken up with using two different particle size Alumina powders and caste the stable slurries by both conventional and pressure slip casting techniques. A PoP mould is used for conventional while a SAMA make (PCM-100 N model) pressure slip casting machine is used for the casting under pressure.

Alumina powders of average particle size 1 µm and 7 µm (MR-01 & HIM-10, Hindalco) were employed in the ratios 50:50, 40:60, 30:70 to prepare slurries having solid loading in the range 70-80 wt% using Darvan as dispersant. Among all, 30:70 ratio mix is observed to exhibit better particle interlocking while slurry with 75-80 wt% solid loading is seen to be stable resulting in higher green densities. The stable slurry thus prepared has displayed the desired shear thinning behavior clearly showing a uniform increase in the permeability of solid particles into the cast as viscosity decreases from 400 MPa.sec with shear rate of 100 per sec.

The conventional casting was conducted with slurries of different solid loading while the pressure slip casting trials under various pressures were performed using the stabilized slurry with solid loading >75 wt%. From the results of green density measurements it can be concluded that with a given solid loading the pressure slip casting technique yields definitely 5% higher green density and finally as high as 65%.

All the green bodies were fired at about 1600oC and the properties determined like density, flexural strength, compression strength and the results are presented in Table.1 Sintered samples were cut into 3×4×45 mm for flexural strength and 20 mm cubes for compression strength measurements.

FESEM photographs of sintered Alumina samples prepared under pressure and pressure-less conditions presented in Fig.1, clearly brings out the close packing, smaller grain size achieved in pressure slip cast samples.

Pressure slip casting technique is proven to yield up to 65% green and >98.5% sintered densities in Alumina bodies with improved mechanical properties when compared with those produced by conventional casting method. The results shows the suitability of pressure slip casting to produce Alumina products for better yields, enhanced mechanical properties with lower rates of rejection.

Table 1 Mechanical properties of alumina by conventional slip casting and Pressure slip casting

	Density		Mechanical Properties		
	Green Density (g/cc)	Relative Density (% TD)	Flexural Strength (MPa)	Fracture Toughness (MPa $m^{1/2}$)	Compression Strength (MPa)
Conventional Slip Casting	2.29	3.873 (97%)	242.70	3.73	394.80
Pressure Slip Casting	2.55	3.931 (98.6%)	294.40	4.03	1341.10

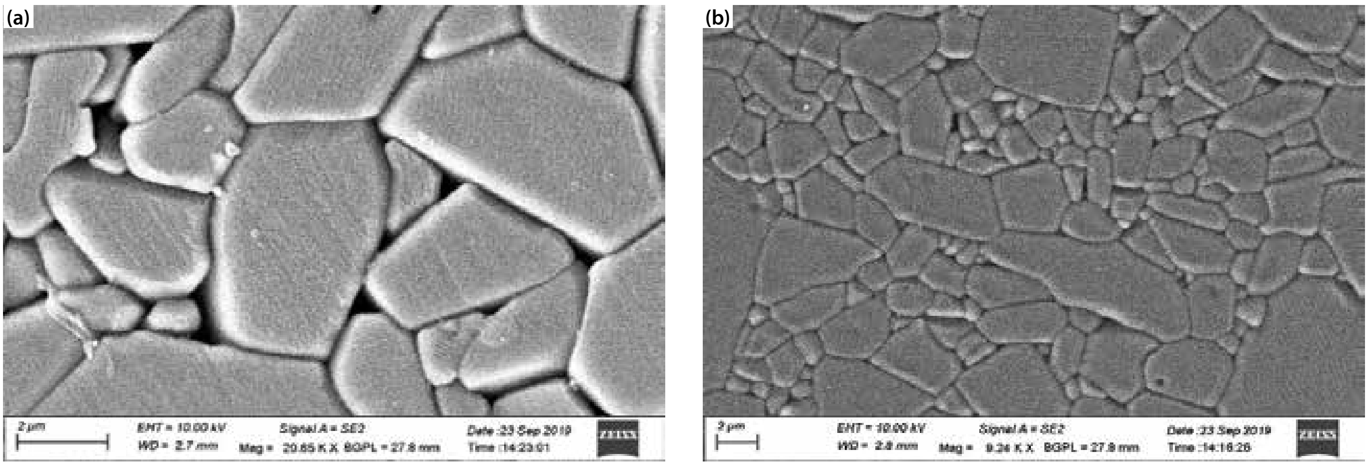

Fig.1 Micro-structure of sintered alumina prepared by (a) Slip casting (b) Pressure slip casting

Contributors: P. Raju and Roy Johnson

Studies on 8YSZ Electrolyte Coating and Co-firing of Anode Supported SOFC Half Cells

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Solid Oxide Fuel Cell (SOFC) is an emerging power generation and relatively clean technology for meeting future global energy requirements. High efficiency due to high operating temperatures, flexibility in use of fuels and low emissions are the major advantages of SOFCs. SOFCs can be applicable from microsystems to medium -and large -scale systems and currently commercial modules of 10s & 100s of kW are being made by global players are readily available. SOFCs have generally fabricated in three configurations such as electrolyte supported, anode supported and cathode supported. Though the electrolyte supported SOFCs are widely used and commercialized anode supported SOFCs are gaining prominence due to several advantages.

Anode supported SOFCs have the advantage of higher power density, low ohmic loss due to thin electrolyte membrane (10-20 μm) and lower cell degradation. Additionally, this design has a thin cathode layer that provides an opportunity for tailoring the cathode material formulation to enhance the performance of oxygen reduction and provide chemical resistance for various applications. Processing of anode supported SOFCs proceeds through conventional ceramic processing as in the case of electrolyte supported configuration through tape casting, lamination and uniaxial pressing etc. However, there are several issues with co-firing of the configuration due to the differential sintering of tapes leading to warpage and delamination of the half cell.

In order to address the above issues, a wet chemical-based scheme to coat 8YSZ on sintered anode was evolved as shown in Figure-1. 8YSZ electrolyte pastes with different solid loadings suitable for screen-printing were prepared using μ-Terpineol as mixing medium and Ethyl Cellulose/ Polyvinylpyrrolidone as binder. The mixed suspension is stirred and ultrasonicated for de-agglomeration. The pastes of different solid loadings were prepared for experimentation and it was observed that a solid loading of 65% is optimum for paste-1 and 50% for paste-2. The resultant 8YSZ pastes were manually screen-printed on the NiO-8YSZ anode supports, dried after every print and finally fired at 1400°C for 2 hours to form an anode-electrolyte bilayer. Figure 2 shows the microstructure of 8YSZ film of thickness 15 μm. It is evident that the combination of two layers printing with different solid loadings has resulted into dense microstructure with an average grain size of 1-2 μm though there are evidence of presence of pores. Further, trials are in progress to eliminate the porosity and to obtain fully densified electrolyte through the evolved scheme.

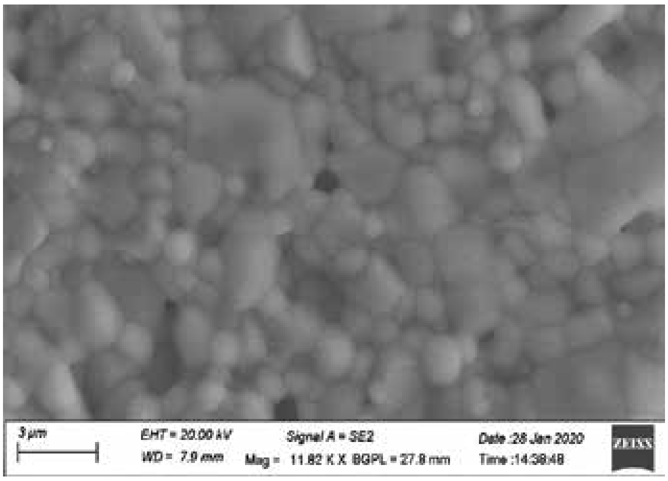

Fig. 2 SEM Image of screen printed 8YSZ film

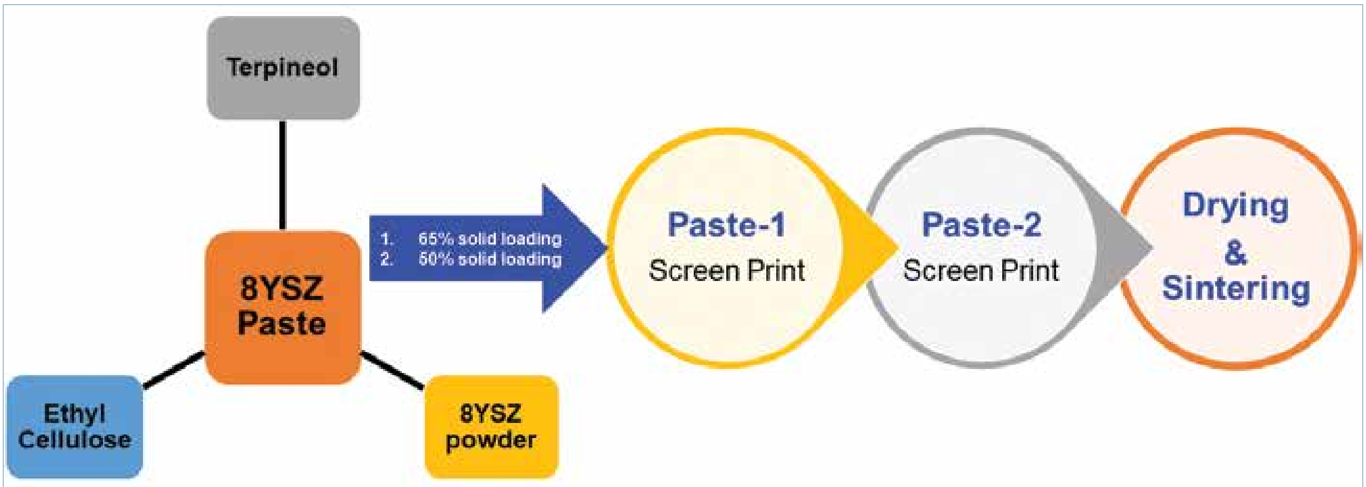

Fig.1 Process flow chart for the preparation of 8YSZ electrolyte paste

Contributors: Amit Das, Y. S. Rao and Roy Johnson

Investigations on 3D Printed Ceramic Honeycombs as Substrates for Phytorid Applications

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Sewage is the contaminated water originating from toilets, kitchens, farming etc. containing constituents such as organic wastes, suspended solids and pathogenic micro-organisms which pollutes the primary source of water. Sewage is generally treated by physical, biological and sometimes chemical or combined processes to convert into water suitable for disposal or reuse. Among the advanced technologies to treat the sewage, patented Phytorid technology developed by CSIR-NEERI (National Environmental Engineering Research Institute) which mimics the natural wetland ecosystem is gaining prominence. Stone/aggregates immobilise the micro-organisms that consumes the organic wastes through the metabolic activities. Substrates with optimum surface to volume ratio is highly depended on effective sewage treatment and provides the scope for light weight along with high mass transfer offering flexibility to design the bio-reactors on economic scale.

In the current study, additive manufacturing (AM), also known as 3D printing or rapid prototyping, is used for the fabrication of naturally occurring clay-based substrates. As the process generates part from the virtual model directly, it offers prototyping of substrates with various configurations and cellular parameters to achieve varying surface to volume ratio. Clay based ceramic formulation were printed using a ram type 3D printer fitted with a nozzle. Though the clay exhibit plasticity with addition of 38% by weight of water as a medium in order to derive optimum pseudo-plastic behaviour the flow properties required to be modified using organic additives. These additives such as polyethylene glycol 0.75% by weight promotes the flow under shear while 3D printing and 0.2% by weight methyl cellulose as a binder aids to retain the shape after shear forces are removed. The paste with has clearly indicated a shear thinning behavior with respect to shear rate. The type and concentration of additives are optimized based on several experiments in our laboratory Further shear rate exponent (n) was calculated and is found to be 0.77 signifying shear thinning behavior which can be attributed to the optimum additives concentrations added during the paste preparation.

Honeycomb substrates has cellular parameters such as unit cell length (l) 3.49-6.09 mm (l for square cell: 3.49 mm, hexagonal cell: 4.06 mm and triangular cell: 6.09 mm) and wall thickness (t) 1 mm for square, hexagonal and triangular configurations. In an attempt to evaluate the performance of 3D printed substrates a reactor was fabricated with 3D printed substrates as shown in Fig. 1.

Sewage mix is treated with a space velocity of 0.041 hr-1. Performance markers such as pH, TSS, BOD and COD were comparatively evaluated. All the parameters such as pH, TSS, BOD and COD were found to be within the stipulated values as shown in Fig. 2. Use of honeycombs as substrates has demonstrated substantial reduction in the weight by half in comparison to the stone-based reactors. Additionally, due to its inherent configurations low-pressure drop in combination with high mass transport can be achieved.

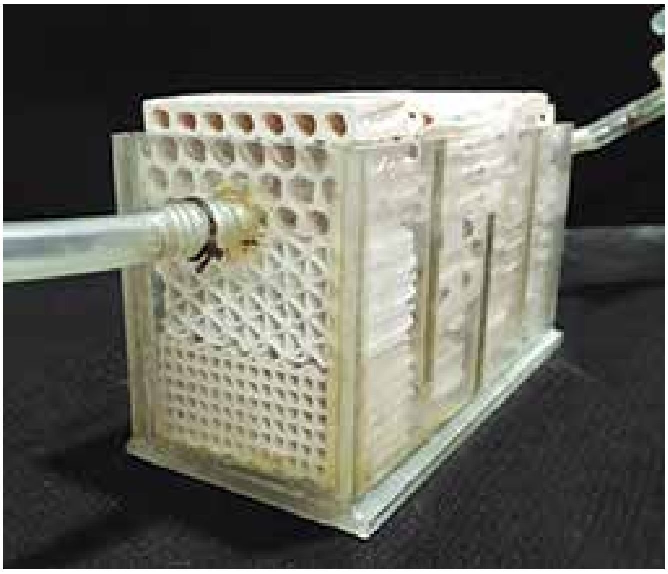

Fig. 1 Phytorid reactor with 3D printed honeycomb substrates

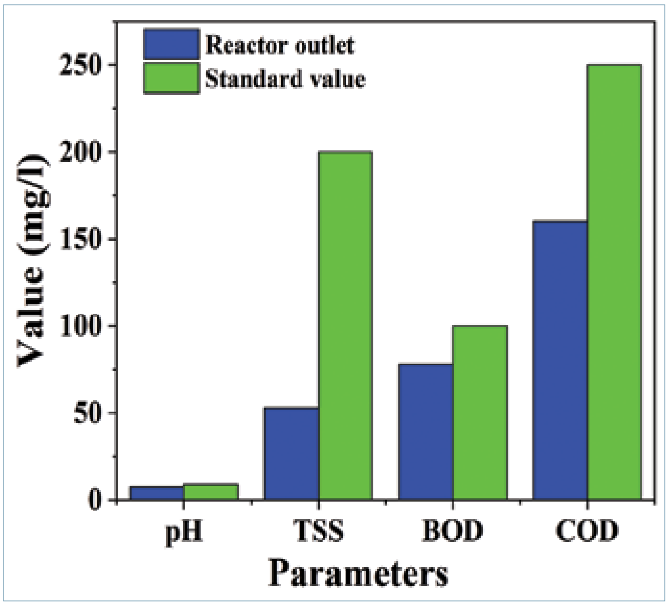

Fig. 2 Performance marker of treated water

Contributors: S. Mamatha, Y. S. Rao and Roy Johnson

Processing of Transparent Y_2O_3 Ceramics using Sol-Gel Derived Nano Powders

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Polycrystalline yttrium oxide ceramics are cubic and optically isotropic material. It exhibit superior resistance to corrosion, high refractoriness and transmit electromagnetic radiations in the wavelength region between 0.25 and 8 μm. Due to such excellent chemical, thermal and optical properties, it is useful for various applications such as host material for high power lasers and scintillators, envelops for high-intensity-discharge lamps, IR transparent domes and windows.

Fabrication of transparent grade ceramic materials involve various processing steps comprising appropriate selection of ultra-pure, highly reactive starting powders, fabrication of homogeneous, defect free green bodies, sintering the shaped components with high degree of densification and elimination of last 0.01% of porosity from the sintered bodies. Presently, researchers are focusing to achieve densification of transparent ceramic materials at temperatures around 1400°C to control the final sintered grain sizes in the submicron regions and obtain improved mechanical properties.

In this context, the present study is focused to synthesize highly reactive nano yttria powders and selection of additives to lower the sintering temperature and to retain the finer grains. The samples compacted out of powders synthesized thorough sol gel based process in this study have shown high degree of densification (97-98% of theoretical) at temperatures as low as 1325°C. The sintered samples were further pressed hot isostatically at 1300°C and argon pressure of 190 MPa for achieving transparency. Figure 1 show the transparent yttria sample produced at ARCI and Fig. 2 shows the IR transmission data in the 3 – 5 μm wavelength regions. The sample exhibited transmissions up to 70% in the above said regions.

Fig. 3 shows the microstructure of yttria samples produced from sol-gel produced powders. It is evident that the grain sizes retained in submicron ranges due to low sintering temperatures. Further effective pinning of grains along the grain boundary is also visible by the additives. The sintered samples exhibited knoop hardness of 900 kg/mm^2 under 200 g loading conditions, which can be attributed to the finer grain structure.

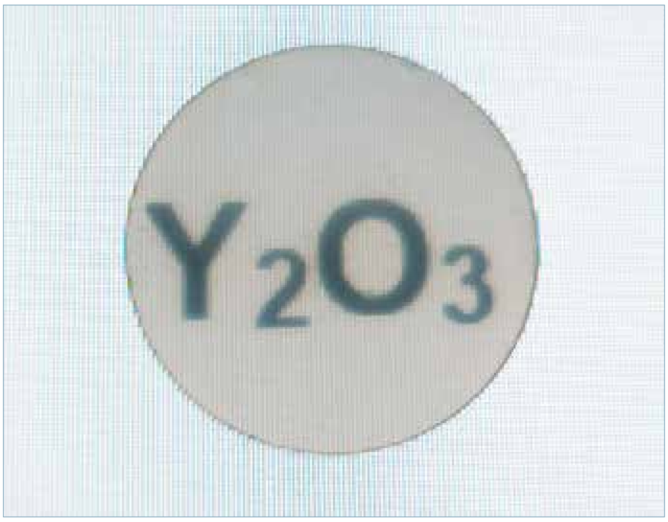

Fig. 1 Transparent Yttria

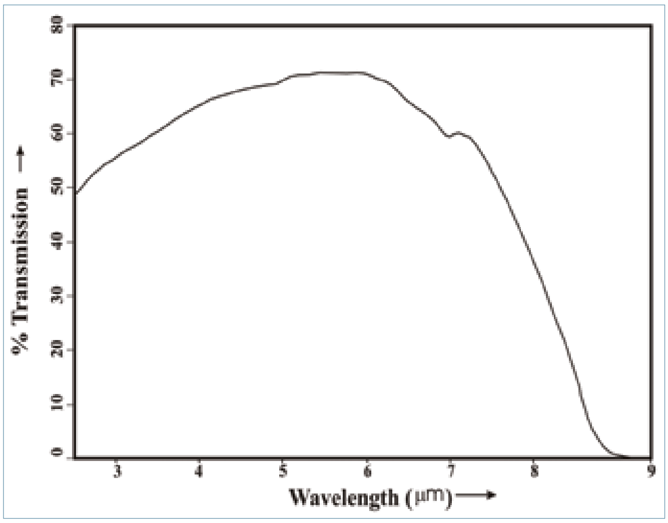

Fig. 2 IR transmission

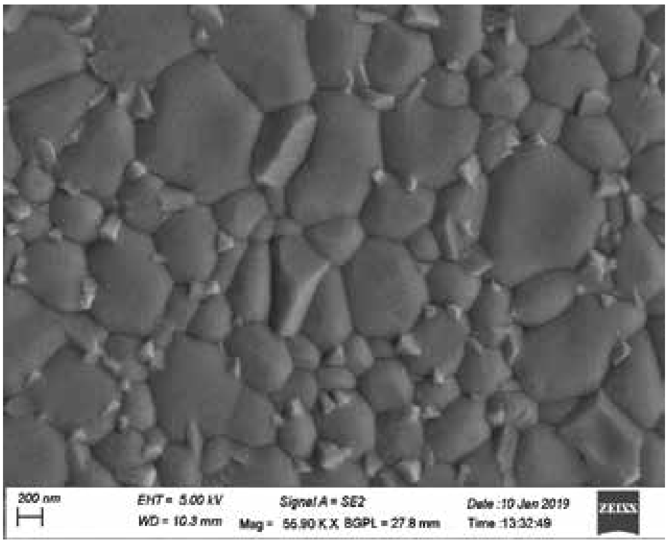

Fig. 3 SEM image of sintered microstructure of yttria ceramics

Contributors: Y. S. Rao and Roy Johnson

Spray Granulation of Silicon Carbide Powders

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Flow properties of the ceramic powders is a function of collective forces on individual particles such as Van der walls and electrostatic forces as well as frictional properties of the powder which in turn determine the acceptable flow for shaping. The hollow granules produced by spray drying process with spherical morphology has several advantages for engineered flow and also can be pressed into simple and complex parts with uniform densities. In the current study silicon carbide powder (SiC) was spray granulated to achieve the spherical granules under optimum instrumental and slurry parameters.

Granulation of commercial grade SiC powder (average particle size, d50, 0.62 μm shown in Fig. 1) was carried out through spray drying of SiC slurries in aqueous medium. Solid-loading in the slurries was varied in the range of 20-25 vol.% in the presence of N, N, N, N-tetra methyl ammonium hydroxide (TMAH) dispersant to enhance the dispersion behaviour of SiC particles in aqueous medium. In addition, poly vinyl alcohol (PVA), polyethylene glycol (EPG) and 1-octanol were used as the binder, plasticizer and antifoaming agent, respectively. Detailed study showed that the slurries with above formulations exhibited pseudoplastic flow characteristics.

A laboratory spray drier (BUCHI B 290/295, model) employed in this study consists of a peristaltic pump that feeds the slurry into the nozzle which is located at the top of the drying chamber and produces a fine spray. The hot air entry was made in counter current with the slurry feed. Granules are collected at the bottom of the chamber and further separated by the cyclone separators. Operating parameters entry air temperatures are varied from 190-220°C and accordingly the exit temperatures at equilibrium are found to vary from 110 to 120°C . Two fluid atomization nozzle design with a nozzle diameter of 1.4 mm and slurry feed rate of 15 ml/minute.

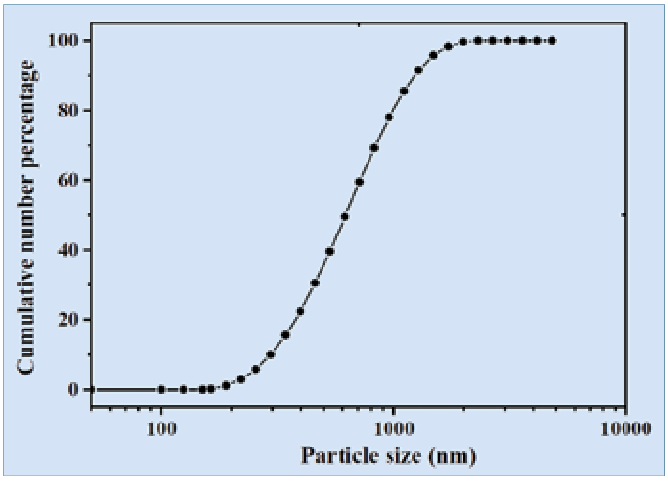

Fig. 1. Cumulative number percentage particle size distribution (PSD) of raw SiC powder

SEM micrographs of raw SiC powder and SiC granules are shown in Fig. 2(a) and (b). It is evident that as procured powder (Fig. 2(a)) as shown an irregular morphology with the particle size in the range of 0.62 μm. Scanning electron micrographs of all spray dried granules with an average granule size is 10-25μm as shown in Fig. 2(b) and also display spherical particles with a smooth surface exhibiting the suitability of spray drying parameters. The moister content of the SiC granules are also found to be < 2% due to the internal water migration after granule formation to the surface by slow diffusion followed by evaporation from the crust. The granules were compacted and compacts were shown the green density of 1.78 g/cc (relative density of 55.4%) with negligible variation from compact to compact.

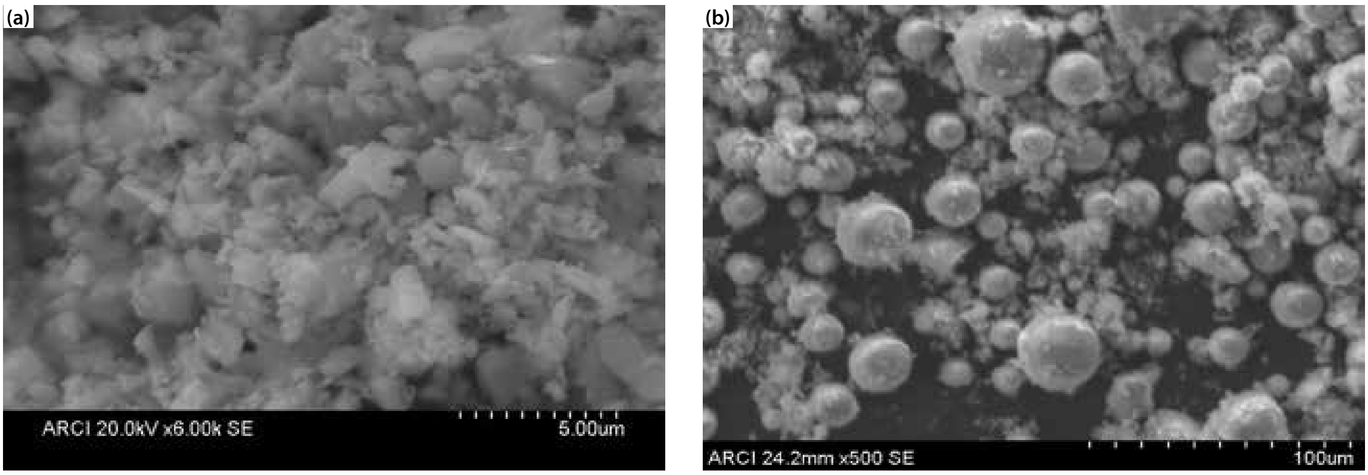

Fig. 2 SEM micrographs of (a) Raw SiC Powder and (b) Spray dried SiC granules

Contributors: Dulal Chandra Jana, Y. S. Rao and Roy Johnson

Lithium Aluminium Silicate Glass Ceramics: Correlation of Crystal Structure and Thermal Expansion Behaviour

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Lithium aluminosilicate glass-ceramics (Li_2O-Al_2O_3-$2SiO_2$, LAS) due to their inherent near zero thermal expansion with moderate mechanical properties is a material of choice for space mirrors, telescopes and also high-end consumer products such as cooktop, cookware, fireplace windows etc. Precursor LAS is prepared by the melt quenching technique and further converted into glass–ceramics through controlled crystallization process using suitable heat treatment protocols depending on the desired properties. Flow chart (typical) generally followed for the preparation of glass ceramics is shown in Fig. 1. Hence, by engineering the heat treatment protocols and additive chemistry, it is possible to achieve LAS with desired thermal expansion values by controlling the extent of crystallisation and orientation of crystals. A typical thermal expansion curve recorded for out-sourced LAS is shown in Fig. 2 and the corresponding X-Ray Diffraction pattern shown in Fig 3.

It is evident from the dilatometric curve that the thermal expansion of LAS is close to zero at room temperature and however, exhibit a linear increase in thermal expansion with respect to the increase in temperature. Coefficient of thermal expansion value was estimated 0.05 x 10^{-6}/K in the temperature range of 20-100°C. X-ray diffraction pattern in Fig. 3 have shown characteristic peaks for the β-spodumene phase with hexagonal crystal structure and glass phase though in minor quantity. In the LAS glass structure, Al^{3+} substitutes the Si^{4+} and the charge is compensated by the addition of Li^+ ions. Hence, LAS exhibits two-dimensional sheets which contain ionic bond of Li-O, and strong covalent bonds of Si-O and Al-O. On increasing the temperature, the rotation of the bods in clockwise and anti-clockwise direction in alternate layers perpendicular to c-axis occurs in the framework and is associated with the change in bond angles contributing towards lower expansion. Additionally, the formation of voids in the structure per unit cell parallel to the c-axis of the crystal results in a negative expansion along the c-axis and a positive thermal expansion along the other axes causing thermal anisotropy. Heat treatment schedules dictate the orientation of the crystals has key role to play in determining the thermal expansion values of LAS.

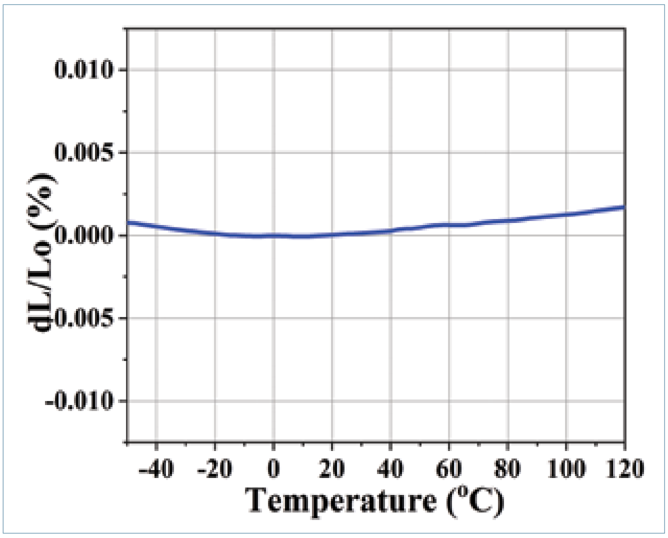


Fig. 2 Thermal expansion curve recorded for the LAS glass-ceramics

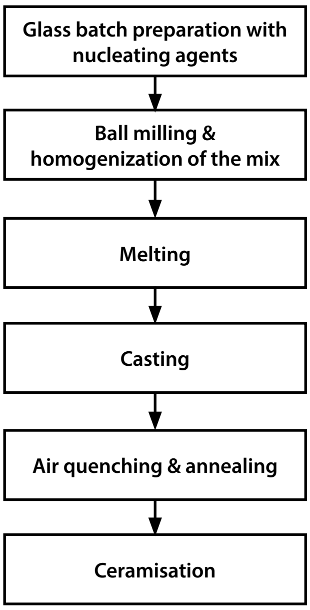


Fig. 1 Flow chart (typical) for preparation of glass ceramics

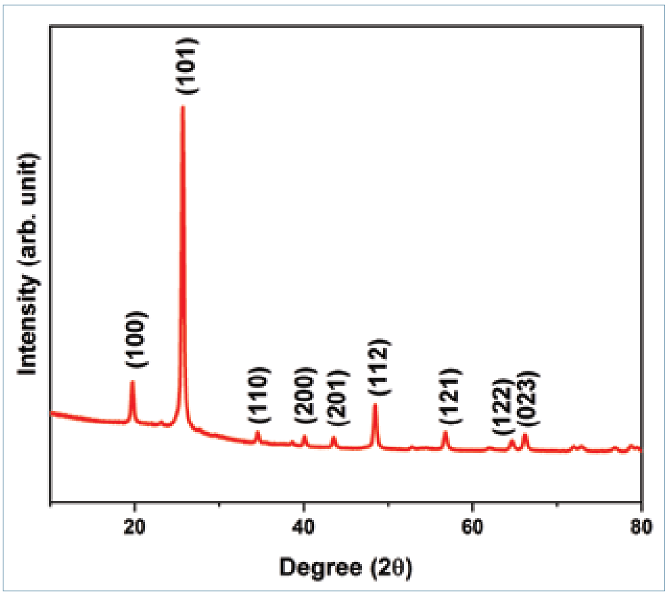


Fig. 3 X-Ray Diffraction pattern of the LAS glass-ceramics

Contributors: P. Biswas, Y. S. Rao and Roy Johnson

Centre for Laser Processing of Materials

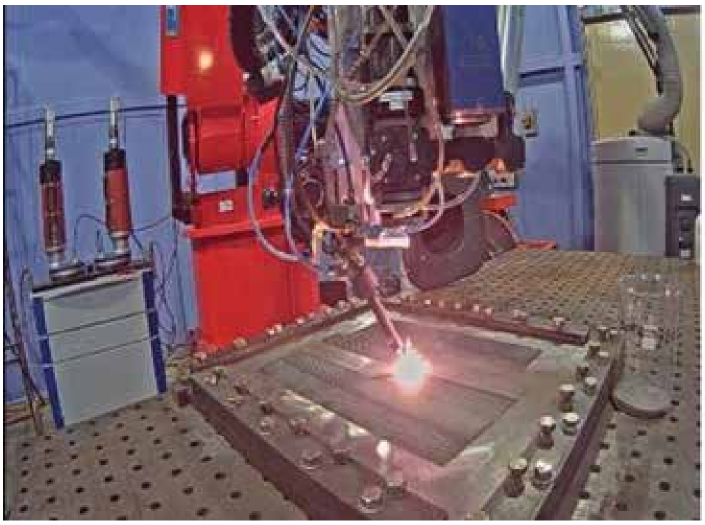
The centre is a unique R&D facility in the country based on high-power industrial lasers. The center's main objective is to promote and provide laser-based materials processing technologies for industrial applications. The centre has been conducting R&D in the areas of laser processing of materials such as metal additive manufacturing, micromachining, surface engineering, repair & refurbishment, materials joining, and drilling with the help of various laser processing systems available at the centre.

Several applications were attempted using laser-based additive manufacturing during the last year, such as (a) Microchannel disc, (b) Valve Block, (c) Brackets, and (d) Gearbox with different alloys. Core pin, with conformal cooling channels, was successfully build for pressure die casting and field demonstrated for improved quality of the cast parts.

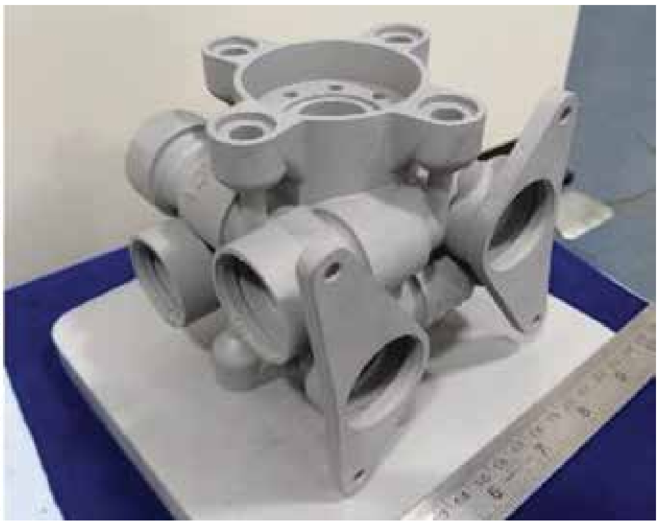
Laser assisted surface engineering was one of the major continued activities. Micro surface textured piston rings and cylinder liners was carried out using ultrafast laser processing and engine tests on with these components improved fuel efficiency of internal combustion engines. Novel methods of laser hardening were developed for treating small bearing components for increased capacity and performance. Laser clad deposition technology was demonstrated for the repair of aerospace components. Laser cladding technology was further investigated to improve the process efficiency and economics to enable industry-friendly adoption. The feasibility of laser and laser-arc hybrid welding of thick sections for power plant applications in plate-plate and plate-tube configurations has been demonstrated.

Major new initiative was launched in the area of laser-assisted machining to address challenges of machining different hard-to-machine materials, ranging from superalloys to ceramics.

Several industry tie-ups and collaborations with academic institutions through national and international collaboration programs have been pursued. Our goal is to exploit laser material processing potential even further - in close cooperation with our customers and partners.



Laser Cladding of Burner Tip Plates



AM built Direction Control Valve

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Additive Manufacturing of AlSi10Mg alloy

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Additive manufacturing technology offers several advantages over conventional manufacturing in terms design freedom, reduced material wastage, shorter development cycle of a given component, light weighting etc. Possibility to additively manufacture components from aluminium alloys has great application potential. Detailed investigation on additively manufactured AlSi10Mg alloy blocks using powder bed laser melting process was carried out. Through optimisation of build parameters, a density of 99.5% of theoretical density was achieved indicating negligible porosity. Microstructural investigation showed ultrafine grains and metastable phases. The Electron Back Scatter Diffraction (EBSD) study revealed that the microstructure (Fig. 1) comprised of elongated grains along the build direction. The average grain size is found to 4.2 µm and 5.6 µm across and along the build direction, respectively. The grain size reported is calculated from the diameter of the area of the equivalent circle of every grain from the EBSD result. The TEM studies indicated presence of high density of dislocation at the grain boundaries as well as presence of Mg_2Si precipitates as well. Tensile tests recorded a UTS, YS and elongation of 450±10 MPa, 265±5 MPa and 8% respectively. Fine microstructure with grain formation of precipitates resulted in superior properties. In view of the promising results an attempt was made to additively manufacture actual components with intricate geometrical features in the size range of 200 microns (Fig. 2). Feasibility of producing a range of geometries with close tolerances was successfully demonstrated.

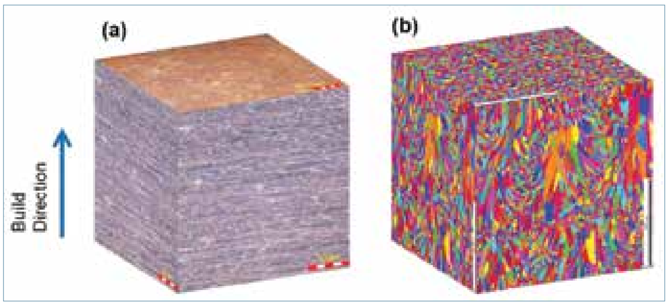

Fig. 1 (a) Optical cross-sectional micrographs and (b) EBSD image showing grain structure for AM built AlSi10Mg block

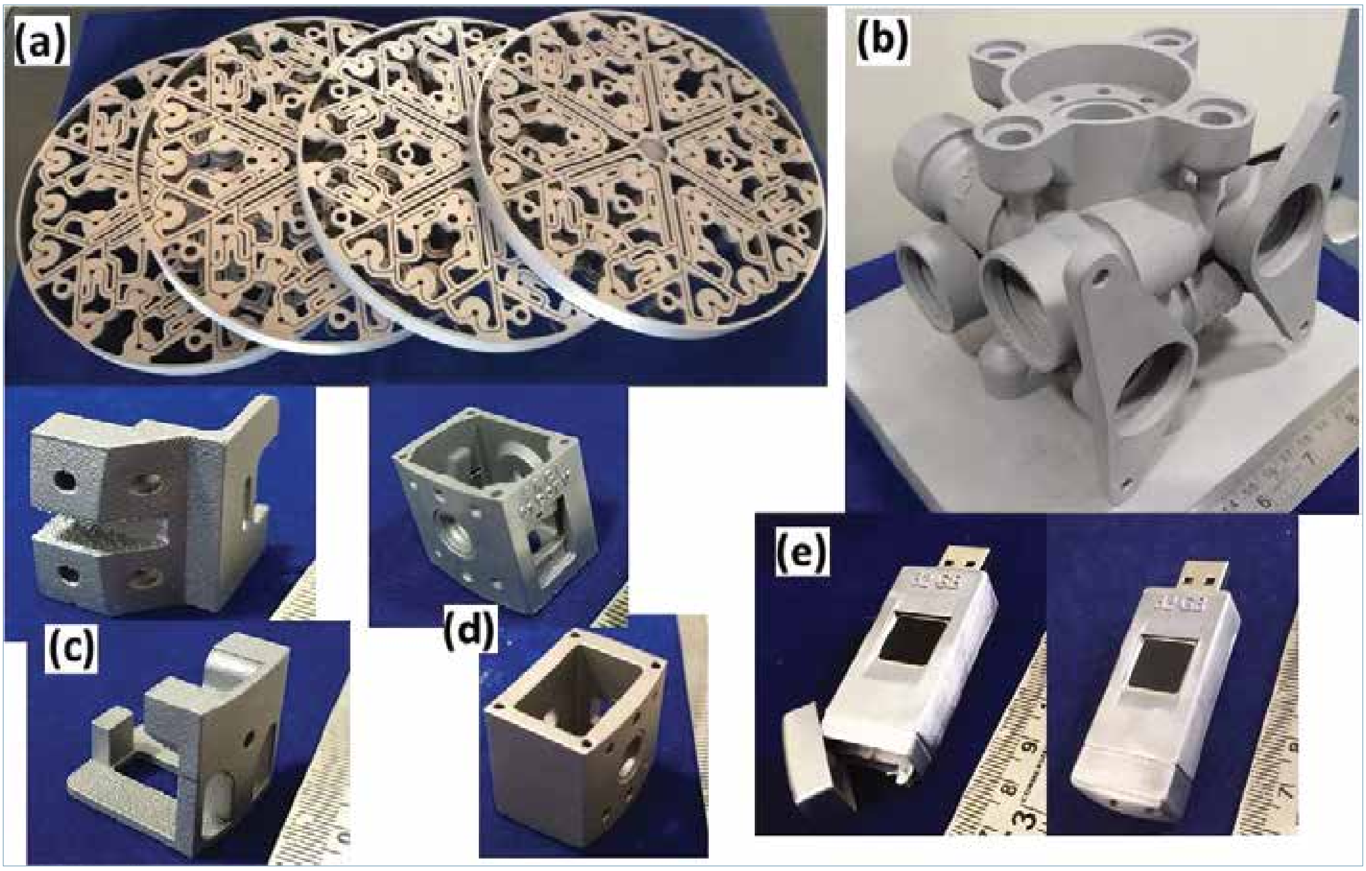

Fig. 2 Photographs showing AM built AlSi10Mg components (a) Micro channel disc; (b) Valve Block; (c) Brackets; (d) Gear box and (e) Pen drive cover with dielectric coating

Contributors: D. M. Santhoshsarang, N. Venkata Rao, Gururaj Telasang and G. Padmanabham

Improved pressure die casting (PDC) tool with conformal cooling channels by Selective Laser Melting

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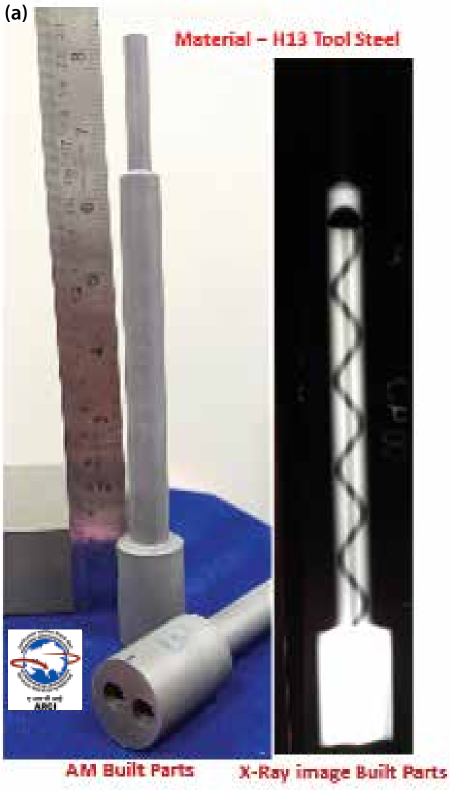
One of the major advantages of additive manufacturing technology is the possibility to incorporate intricate internal features in the components. In this context provision of conformal cooling in the dies and tools for PDC would improve thermal management during the process leading to reduced cycle times due to active cooling, increased production, minimized rejection, improved cast quality, and customized water line designs. In collaboration with a PDC industry, ARCI took up a case study to demonstrate and validate AM's concept of a conformal channel. A core pin, with 196 mm height with varying diameter from 23 mm to 7.5 mm, was identified for this validation process. The selected core pin is a critical component of a die assembly, creating a variable internal diameter bore in the cast part, which has a very high functional role, which was being used without any cooling arrangements leading to less service life and affecting the cast part quality. The conformal channel of 2.5 mm diameter is designed for the selected core pin and built using AM facility (SLM 280 HL) at Center for Laser Processing of Material, ARCI in AISI H13 tool steel alloy powder. The AM built component was subsequently subjected to sand blasting, heat treatment and required post-machining. The core pins were tested for dimensional accuracy, surface defects through dye penetrant test and internal soundness through X-ray radiography and found to be sound and acceptable.

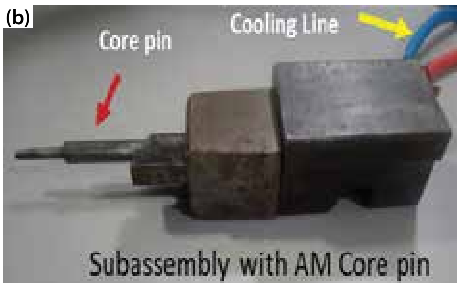
The necessary new assembly for the cooling water connection for this core pin for real-time validation in PDC production was designed and arranged with the help of the industrial partner. Following are the validation test results:

1. Monitoring of Die temperature: Die thermal mapping of the core pin recorded a 15 to 20% reduction in the die temperature.
2. Surface porosity of the cast component using the core pin: Surface porosity is reduced in size and numbers, thereby reducing the number of rejections. The soldering behaviour of the core pin with conformal cooling channel has improved.
3. Cycle time: It has been confirmed that the cycle time has reduced by two seconds which results in increase of productivity.
4. Service life: Because of effective cooling the service life of the core pin has also increased as compared to the core pin without conformal cooling channel.

(a)



(b)



Core Pin Temperature (°C) recorded after casting cycles		
Without conformal channel	With Conformal Channel	Reduction in Temperature
123	100	23
122	96	26
122	10	20
124	103	21
122	98	24

(c)

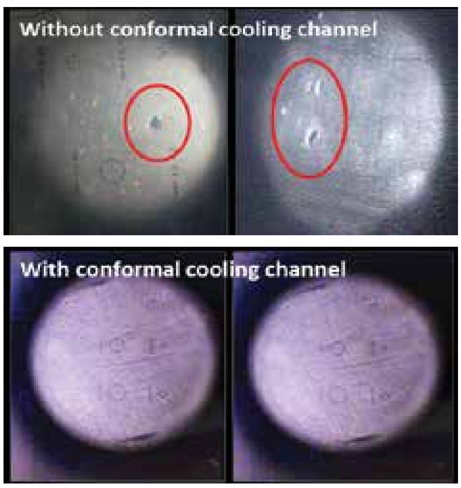


Fig. 1 (a) Photographs of AM built core pin with conformal channel and X-ray radiography; (b) Photographs showing the validated core pin assembly and table with core pin surface temperature measured during PDC process and

Contributors: D. M. Santhoshsarang, N. Venkata Rao, K. Divya and G. Padmanabham

Laser Assisted Machining for Improved Machinability of Hard to Machine Materials

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The demand for higher strength and heat resistant materials is increasing, notably in power and aerospace applications. However, these materials are considered as difficult to machine due to excessive tool wear and poor surface finish. As the flow-stress and strain-hardening rate of materials normally decreases with increasing temperature due to thermal softening, thermally assisted machining (TAM) becomes a possibility when machining hard-to-machine materials. It has been reported that an increase in temperature reduces the mechanical strength of hard to machine materials. As a result of heating, the yield strength, hardness, and strain hardening of the workpiece reduces and deformation behavior of the hard-to-machine materials changes from brittle to ductile. In Laser-Assisted Machining (LAM), the material is locally heated and softened by an intense laser source before material removal, without melting or sublimating the workpiece which enables more efficient machining and with low machine power consumption, which leads to an increase in material removal rate and productivity.

The Laser-Assisted Machining (LAM) set up was established by integrating an existing lathe machine with a 6 kW diode laser. The laser optics were mounted on a tool holder's platform using a five axes universal fixture that can facilitate positioning the laser spot with respect to the tool. A piezo-electric dynamometer was integrated with the system to record the forces on the tool while carrying out the LAM operation. The setup was used in demonstrating the feasibility of LAM for Ni-based alloy 625, hardened steels, and Silicon Nitride ceramics. Detailed LAM investigations were carried out on hardened En24 and En36C steels, which are commonly used steels in the aerospace industry. While the machinability of these steels is limited due to their higher strength and hardness, the results indicated that careful selection of parameters and experimental conditions could significantly improve tool wear.

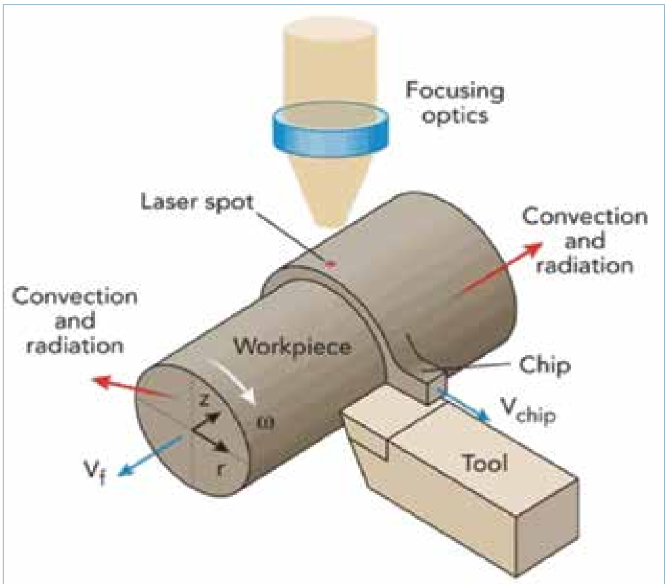

Fig. 1 Illustration of laser assisted machining (Source: Industrial Laser Solutions)

Fig. 2 Laser Assisted Machining setup at ARCI

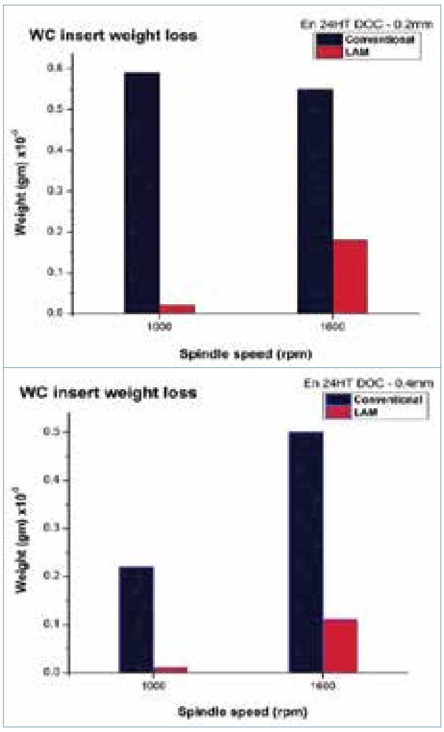

Fig. 3 Tool wear in conventional and LAM with different spindle speed and depth of cut

Contributors: B. Amarendhar Rao, Ravi Bathe and G. Padmanabham

Ultrafast laser surface micro-texturing of piston rings

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Laser surface micro-texturing, which offers precise control of the size, shape, and density of micro-surface texture features, has gained momentum as a way to control friction and wear. In this technology, a pulsating laser beam creates periodic micro-dimples or grooves on the surface of the material in a controlled manner. These surface micro-texture patterns generate additional hydrodynamic pressure, thereby increasing the load-carrying capacity of the surfaces. Such textures also act as lubrication reservoirs that can directly deliver the lubricant into the contact zone in starved oil lubrication. The surface texturing is also useful for trapping wear particles because the elimination of wear particles from the sliding contact interface reduces friction and wear in both lubricated and dry sliding regimes. In order to control the friction, it is crucial to understand the mechanisms which occur during the conformal or non-conformal contact in dry and lubricated conditions. Ultrafast lasers make micro/nano features without vacuum conditions and smaller than the diffraction-limited focal spot diameter-a unique property of ultrashort duration laser-matter interaction. The process is a thermal, and pulse durations are orders of magnitude lower than the thermal diffusion time.

The texture surfaces were created on automotive internal combustion engine components such as piston rings (coated and un-coated) and cylinder liners using an ultrafast laser with a pulse duration of 100 fs and wavelength of 800 nm. The effect of a range of process parameters such as pulse energy, scan velocity, textured density on the performance characteristics of laser textured samples was investigated. The laser surface textures were examined using an Opto-digital 3D microscope. The friction and the wear test were performed using a ball-on-disk tribometer, and all the tests were performed under dry contact and lubrication conditions. Based on the results on the test coupon, the micro dimples of 20-30 μm diameter and ~5 μm depth with the regular pattern were created on the piston rings (shown in Fig. 1). The engine testbed (at Amrita University) was used to evaluate the effect of laser surface texturing on fuel consumption when the texture is applied to the top and second piston rings. The created textures were tested under different speeds and different temperatures of coolant and lubrication oil. It is observed that there is a 16% reduction in the lube oil consumption with the use of texture on the piston rings. The 10-hour lube oil consumption test shows that the blowby substantially reduced with textured rings (Fig. 2).

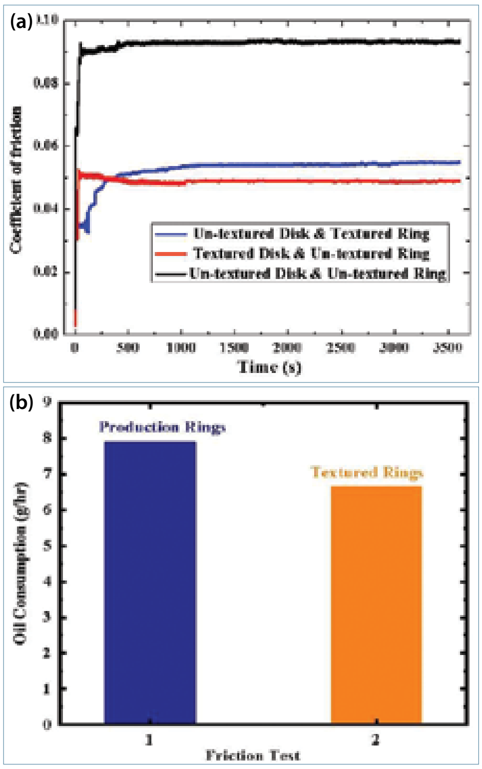

Fig. 2 (a) Ball-on-disk test of different textured samples and (b) Engine test of textured piston rings

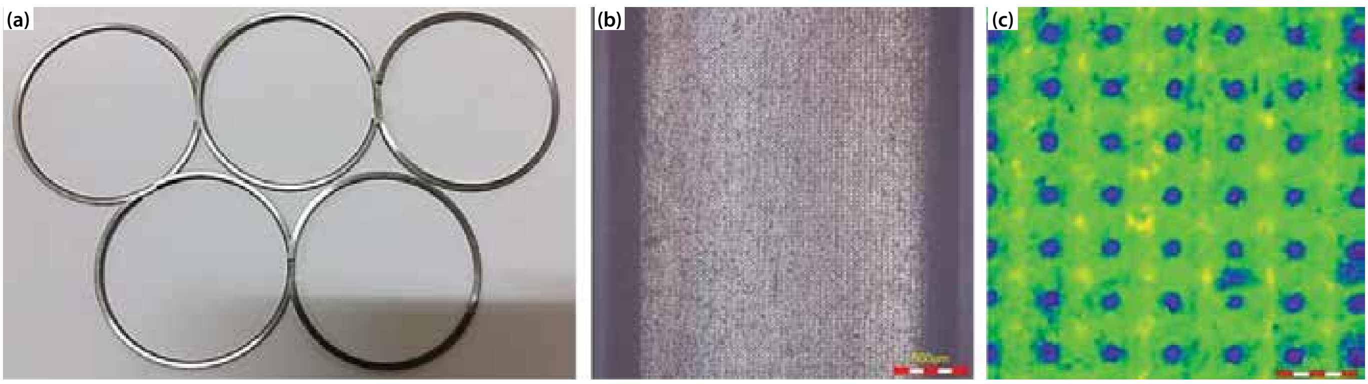

Fig. 1 Femtosecond laser surface texturing (a) piston rings, (b) micro-dimples on ring surface, and (c) textured ring surface at high magnification

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Cost-effective laser-clad coating technology for burner-tip nozzle for thermal power plants

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Further to the already developed laser-clad coating technology (patented and successfully tested) for baffle plates used in burner-tip nozzles of thermal power plants, ARCI modified this technology with newer developments to improve the process efficiency and reduce costs to enable industry-friendly adoption. The technology improvement elements involved right from design modification of baffle plate to elimination of distortion effects due to cladding heat-input with the improvised fixating setup to processing pattern design to improved post-process machining and welding assembly. The new improvement in technology for reducing the processing cost involved modification in optic-nozzle setup. This resulted in doubling the cladding speed with a vast reduction in process time (reduced by half) and high powder deposition efficiency (doubled as compared to previous development) and complete elimination of re-work. The clad-overlapping effects were reduced by half by adopting a wider laser spot with improved powder-feeding nozzle setup.

The economics of the process was improved in terms of processing cost by a vast reduction in powder wastage as well as by reducing the thickness of the coating (20% reduction) that can provide similar life. The developed coating with the above modifications was comprehensively characterized for coating profile, metallurgical bonding analysis, microstructure, and hardness distribution to match that of previously qualified and tested one. The modified coating has also been successfully tested for its qualification by subjecting to laboratory-scale high-temperature erosion testing (at 600°C) as per ASTM standards. The result showed vast improvement with doubling of wear resistance as compared to that of uncoated and weld-surfaced counterparts. Baffle plates developed with these modifications were assembled in the actual nozzle tips and fitted at different stage levels of the boiler assembly of the 200 MW thermal power plant of NTPC Farakka for practical performance assessment and life.

The adoption of these technological modifications for industrial adoption with ARCI technology receiver (private entrepreneur) is also underway.

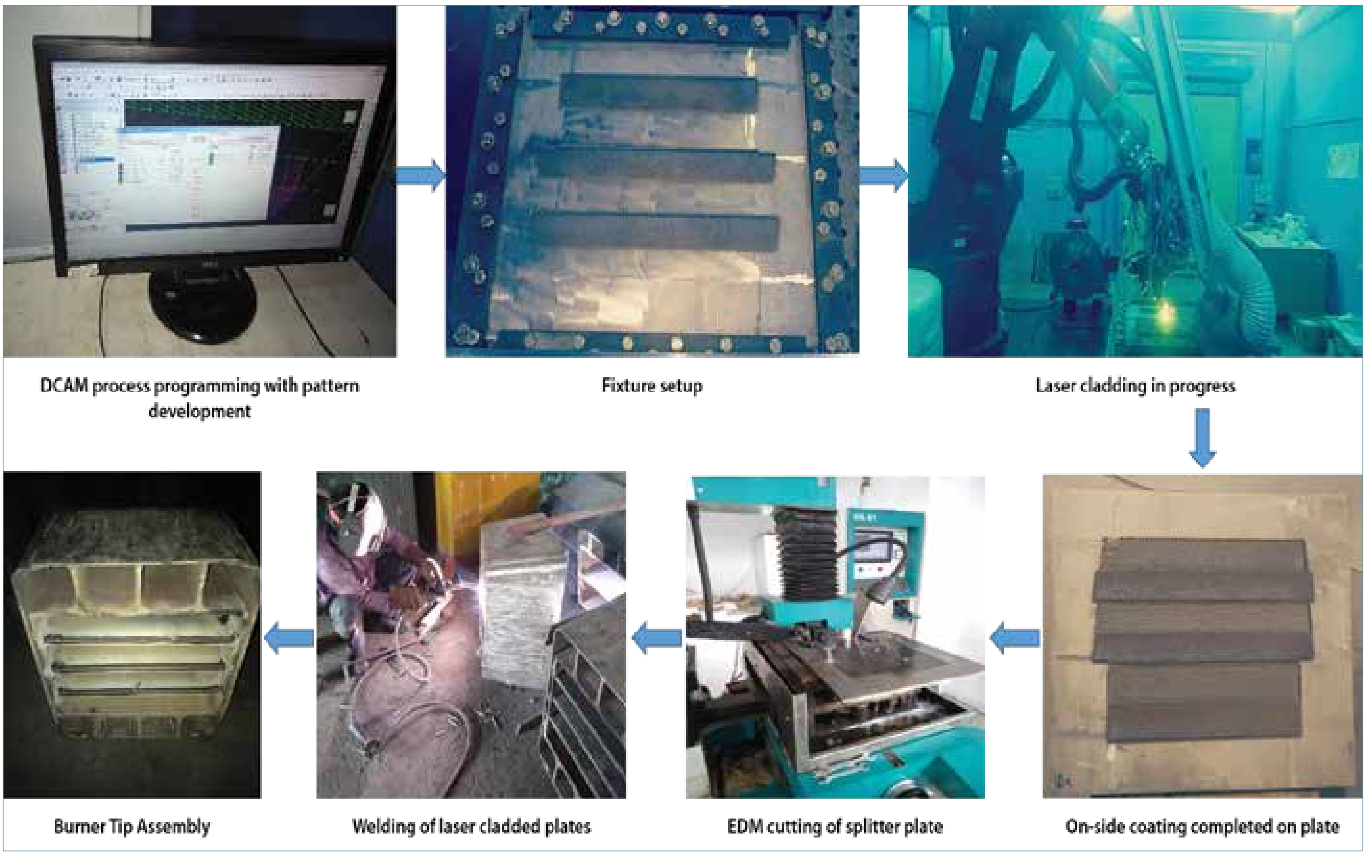

Fig. 1 Manufacturing process cycle for laser-coated baffle plate and its assembly in burner-tip nozzle of 200 MW thermal power plant

Contributors: J. Shyam Rao, Manish Tak and G. Padmanabham

Centre for Fuel Cell Technology

Clean energy technologies are gaining momentum worldwide in the light of environmental impacts and energy security issues related with the conventional fossil fuel based energy sources. Hydrogen based clean energy systems are revolutionizing the energy scenario and touted as the energy for sustainable future. Capitalizing on enormous potential of hydrogen energy, Centre for Fuel Cell Technology (CFCT), has been working on the development of clean energy technologies encompassing the various aspects of hydrogen economy. CFCT is one of the Technology Groups on PEMFC (Proton Exchange Membrane Fuel Cell) development in the country which demonstrated capability on process know how of its various components, testing and the viable applications.

CFCT is functioning at IIT Madras Research Park, Taramani, Chennai, with state-of-the-art facilities established for various operations required for PEMFC technology development in terms of components development, characterization, testing, analysis etc. The major accomplishments realized at the Centre are, fuel cell stack development up to 10 kW, system development up to 20 kW for stationary application and 5 kW system for transport application, with cost reduction for various Fuel cell components. It has demonstrated Hydrogen generation of 2.5 Nm^3 capacity and also executing various R & D activities related to Fuel cell technology.

The Centre continues to be at the forefront of PEMFC technology development in the country and has attracted several industries to forge many partnerships. During 2019-2020, the centre has made significant efforts in identifying User Agencies for field trials of PEMFC technology applications for both stationary and transport applications and demonstration is in progress at various levels of testing. Noteworthy is the recent demonstrations at Tamil Nadu Disaster Management centre, Chennai and Bhabha Atomic Research Centre, Mumbai in which a complete PEMFC system has been installed at the site and the data has been collected.

The Centre conducted "One Day Workshop on Hydrogen and Fuel Cell for Sustainable Future" consecutively for the second year to celebrate "National Hydrogen and Fuel Cell Day" on October 18, 2019, and to create awareness on clean technologies based on hydrogen and fuel cells for sustainable future. This workshop has brought together Industries, Academicians and the Research Scholars to critically discuss the future of Hydrogen and PEMFC applications in India.

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PEMFC System Demonstrations – Field Trials

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The world which is witnessing a dramatic change in the energy economy is inching closer toward hydrogen. At the centre of this transformation is the hydrogen fuel cell, the most efficient way to turn a variety of fuels into useable power with greatly reduced emissions. Centre for Fuel Cell Technology (CFCT), ARCI have for long acted as the forerunner in ushering this technology for Indian scenario. CFCT has developed Polymer Electrolyte Membrane Fuel Cell holistically. These developed PEMFC have the advantage of operational capability at low-temperatures with applications in decentralized power generation systems. Through intense R&D efforts in the area of fuel cell technologies, ARCI has developed in-house PEMFC systems in the power range of 1 to 20 kiloWatt (kW) and demonstrated the same in stationary (1-20 kW) and transport applications (1.5-5 kW). In the period 2019-2020, CFCT has been intensely demonstrating the prowess of PEMFC at a number of establishments sourcing hydrogen as well as a portable energy source during disasters. Field trials at different sites for varied stationary purposes were one of the milestones in this period. Firstly, The PEMFC system was integrated with onsite hydrogen production system at BARC and was successfully demonstrated for DC power production. Next, the PEMFC systems along with various home appliances were packed into a truck and were demonstrated as a possible alternative to diesel generators during time of disasters at the Tamil Nadu Disaster Management Authority, Government of Tamil Nadu Head Quarters.

At Bhabha Atomic Research Centre (BARC), which produces significant amount of pure hydrogen gas produced by electrolysis process, identified Fuel Cells as thrust area of R & D in utilizing the generated hydrogen at some of their chemical plants to generate power for useful applications. In this context fuel cells will be ideal to convert the hydrogen to electrical power without much pollution and higher efficiency. The project demonstration of 5kW fuel cell system at BARC for stationary application was considered to be useful in critical evaluation of the fuel cell components and the stack. The project would further help in development of next generation improved stacks to improve the efficiency. As fuel cell generates "GREEN" electricity it would also help the company in generating carbon credits. The second demonstration was carried out at the Emergency Operation Centre at Tamil Nadu Disaster Management Authority, Chennai. The Government of Tamil Nadu is keen in developing a robust disaster management system. In this regard, the disaster management authorities would like are in the process of convertng the existing Control Rooms to Emergency Operation Centres (EOC). EOCs respond immediately during an emergency situation with State-of-the-Art communication systems. This helps in providing immediate support during the Golden Hour of the disaster.

Hence, the State Government decided to look at the prospect of converting the existing Control Room to EOC backed with 10 kW system along with fuel cell stack, air moving subsystems, power control devices and control and monitoring system. Fuel cell systems offer a potential benefit in terms of providing sustainable electricity using hydrogen gas without the need of grid power as required by conventional battery backup systems. Having the aforementioned motto, ARCI demonstrated the feasibility of providing power to EOCs. PEMFC stack with a capacity of 5kW has been installed on the mobile truck and demonstrated on December 5, 2019, at Tamil Nadu State Disaster Management Authority (TNSDMA). Dr J. Radhakrishnan, Commissioner, Revenue Administration, and Disaster Management, witnessed the demo and appreciated the prowess of PEMFC technology.

As part of the demonstration for use of PEMFC system as an alternative for diesel generators during disasters, a 5 kW fuel cell stack along with its Balance of Plant Components, Power Conditioners and various domestic appliances like lights, fan, water pumps and LED display were projected under working condition. The FC system was highlighted also for its ease of transportation by loading all the aforementioned system on to a medium sized truck, which is essential during emergency situations.

Fig. 1 The PEMFC system along with its balance of Plant components deployed at BARC

Fig. 2 Schematic representation of the project outcome at Tamil Nadu Disaster Management Authority

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Evaluation of metallic flow field plates for PEM Fuel Cell application

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PEMFC stack challenges for commercialization arises from the materials cost and the difficulty in manufacturing. One such component is flow field plates which takes about 50% of the cost and 75% of the weight and volume. Hence, many fuel cell companies are trying to simplify the process of manufacturing by using alternative materials which are amenable for mass production as well increase the power density. Most of the automobile companies who are investing in Fuel cell based vehicles have started to use metallic flow field plates made of SS which are likely to reduce the weight and volume by more than 50% as they can be made thinner unlike the graphite / carbon composite plates. The major challenge in developing the metal flow field plate lies in forming a complex flow field design on both sides of the plate for the supply of reactants and bond them together for proper sealing in case of multiple cells.

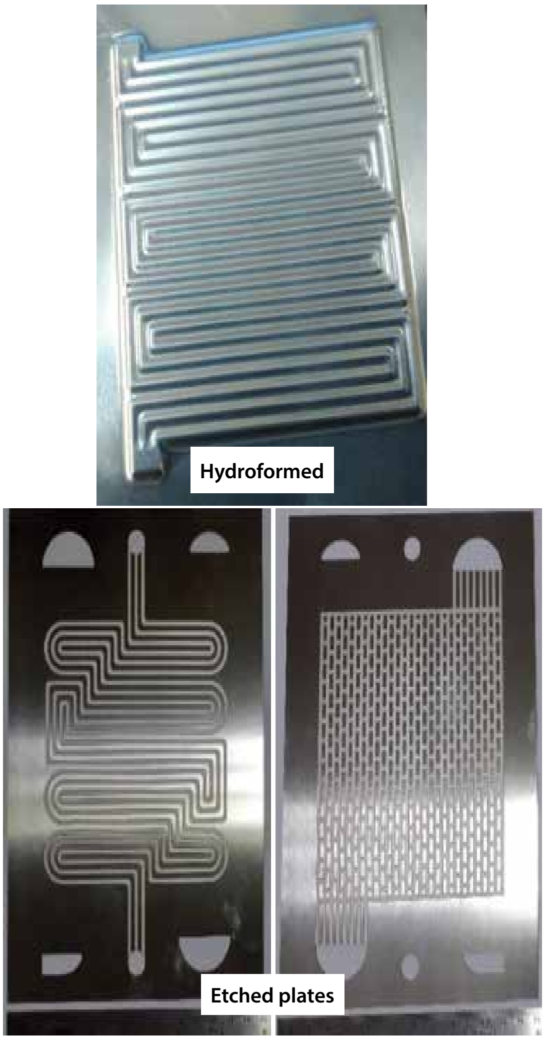

Fig. 1 Metallic flow field plate fabricated by various techniques

Hydroforming, is a forming process in which complex flow design can be formed on thin metallic sheets by forcing high pressurized liquid on one face of the die. By meticulous design modification and plate design, the need for welding of the plates can be done away with. An important advantage of going for Hydroforming process is the production volume of metallic flow field plate is comparatively high to other conventional techniques like milling. Also, instead of one set of Die in stamping, there is only a single Die in Hydroforming process, thus bringing down the tooling cost and eventually the plate cost. All leading automobile manufacturers whose customer base are in millions will benefit from this technology, where weight of the engine/drive train of the vehicle affects the price of the vehicle and running cost.

The flow field lines/design were validated with flow analysis software and this design is incorporated in suitable Die. Formability is better in comparison with conventional stamping. Minor modifications in the designs for better performance are being attempted.

In addition, CFCT is looking an alternative method for making such plates. Chemical etching of metals to form metallic bipolar plates does not require die tools and helps in design validation to address the stack characteristics by forming planar plates for evaluation. The other advantages include absence of burrs and stress on cutting edges. The etched plates can be formed with high geometric complexity with high precision in the tolerances. ARCI has developed a short stack of 75W using bipolar plates formed through etching technique using 316 stainless steel. The stack has been run for more than 100 hrs. intermittently. Corrosion concerns on the bare metallic plates are being addressed by a variety of coating studies at the centre. CrN coated SS plates have been formed and a 1kW stack development is already in progress.

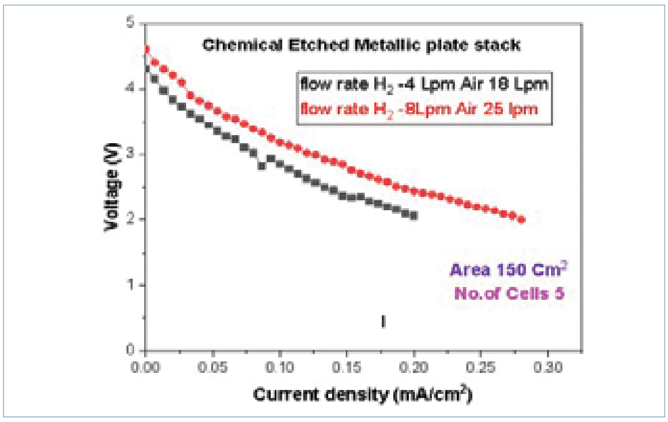

Fig. 2 Performance of short PEMFC stack fabricated using etched metallic flow field plate

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Noble and Non noble electrocatalysts for fuel cells

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The Platinum (Pt) supported on carbon is the conventionally used electrocatalyst in proton exchange membrane fuel cells (PEMFC). Nevertheless, the stability and durability of conventional catalyst carbon support is still a challenging issue in the transport application of PEMFC. Alternative non-carbonaceous support materials like oxides, carbides and nitrides are being researched and reported. However, these materials possess lower electrical conductivity when compared to carbonaceous materials. Graphene and carbon nanotubes are proved to be very promising supports with improved durability. Yet, their synthetic procedures are complex and expensive.

Carbon blacks like Vulcan carbon (VC), acetylene black (AB) and ketjan black (KB) are simpler to synthesize on a large scale. Hence, to improve the performance and durability of these carbon blacks, we chemically modified them by adding functional groups on their surface. These carbons were functionalized using a well-known acid functionalization method with the strong mineral acid mixture to introduce functional groups like hydroxyl, carbonyl and carboxylic groups. These functionalized carbons as electrocatalyst support immobilized the Pt-based active species effectively. The Pt electrocatalysts were tested for its electrochemical activity and durability. The Pt/AB and Pt/f-AB electrocatalysts exhibited remarkable durability with 6% and 16% ECSA loss after the start-up and shut down protocol, which was less than 40% and satisfying the set DoE targets for 2020. Thus, the durability of the Pt electrocatalyst supported on AB and f-AB is improved compared to VC and KB supported Pt electrocatalysts. Hence, Pt/f-Ab can be an ideal electrocatalyst for PEMFC cathodes with enhanced electrochemical activity and durability. Figure 1 shows the schematic of the synthesis of Pt electrocatalysts on functionalized carbons and their electrochemical surface area losses calculated after the start-up and shut down protocol.

Further, to accelerate the deployment EVs, the research in the field of PEMFC and SC is majorly focused on the development of Pt free catalysts and electrode materials with high charge storage capacity or energy density, respectively. CFCT is also working on the development of cost-effective multifunctional electrocatalytic materials derived from zeolitic imidazolate frameworks (ZIFs) for energy storage and conversion devices. Bifunctional, cost-effective cobalt embedded nitrogen doped carbon (Co/NC) nanocomposite electrocatalytic material was prepared via single step, direct carbonization of dual ZIF precursors, Zn-ZIF and Co-ZIF. The practical applicability of the Co/NC nanocomposite for PEMFC and SC applications was assessed in acidic medium (0.5 M H_2SO_4) and a conventional two electrode (symmetric) aqueous (6 M KOH) system, respectively.

The catalyst also demonstrated remarkable durability with loss of only 6% of electroactive surface area after 30,000 cycles of accelerated durability test. The enhanced ORR activity and durability is attributed to optimal balance of Co-Nx active sites along with appropriate N contents and graphitic carbon framework. The practical applicability of Co/NC as cathode catalyst for PEMFC was evaluated in single cell level and generated maximum current density of 200 mA cm^{-2} (at 0.112 V) at 70°C. Though the obtained performance is lower as compared to state-of-art Pt catalysts, considering the usage of non-noble and cost-effective Co/NC cathode catalyst the results are encouraging and the further efforts in performance enhancement of Co/NC cathode catalyst to achieve higher PEMFC is in progress.

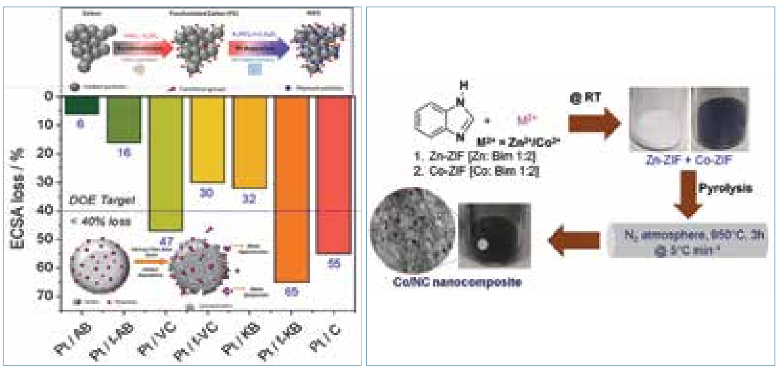

Fig. 1 (a) Loss of ECSA of Pt/f-AB electrocatalyst after the start-up and shut down protocol. (b) Schematic representation of preparation of Co/NC nanocomposite

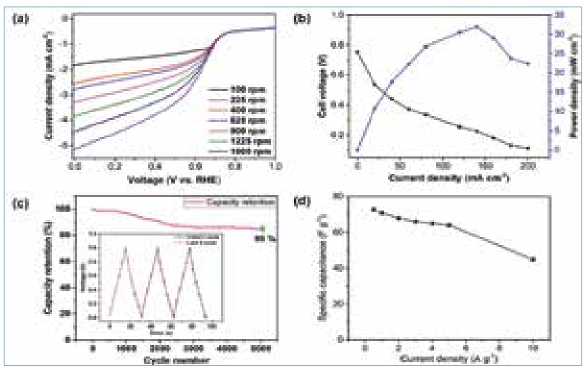

Fig. 2 (a) LSV curves recorded in 0.5 M H_2SO_4 at scan rate of 10 mV s^{-1}, (b) Single cell PEMFC polarization curves at cell temperature of 70°C, (c) Cycling performance of at 2 A g^{-1}, and (d) Ragone plot showing energy density and power density of bifunctional Co/NC nanocomposite

Contributors: Abha Bharati, N. Rajalakshmi and Prithi Jayaraj

Development of integrated PEM based Electrochemical Methanol Reformer for 2.5 Nm^3/hr hydrogen production capacity

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The objective of developing integrated PEM based ECMR system was achieved by integrating the developed GEN-2 electrolyser stack with major BoP components such as power supply, reactant feed system, gas conditioning system, control and monitoring system. The ECMR system delivered hydrogen at the rate of 2.5 Nm3/h with the average cell voltage of 0.6 V and the total energy consumption was about 1.4 kWhr/Nm3. Further testing, for longer duration was carried out to confirm the durability and reliability of the system. The electrolyser unit can also deliver hydrogen at variable production rate ranging from 0.25 -2.5 Nm3/hr. The various operating parameters such as stack current, voltage, temperature and production rate can be controlled and monitored. The produced hydrogen has about 98 % RH and passed through the gas conditioning system to reduce its humidity and temperature. Further, it has been stored at ambient condition in the steel cylinder. The produced hydrogen has 99.9% purity and efforts towards storing the hydrogen at pressurised condition (< 5bar) using low cost and efficient compressor is underway. In addition, with the view to integrate the PEM based ECMR system with renewable energy source like PV power, industrial partner has been identified and signed MoU for the joint development and demonstration of PV integrated PEM based hydrogen generator for on-site application.

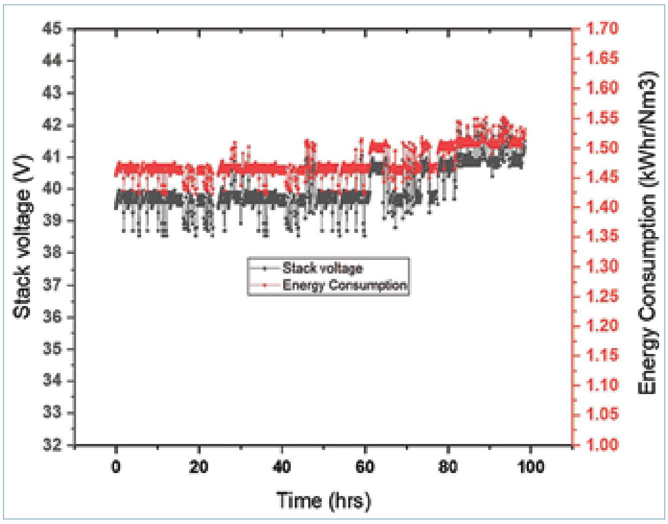

Fig. 2 Durability of developed ECMR system

Fig. 1 Integrated ECMR unit of 2.5 Nm^3/hr hydrogen production capacity with storage tank

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Development of 50Wh Zn-air battery module

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Zn- air batteries are being developed as energy storage batteries for various applications from microgrids to utility scale power plants due to their high energy density (1084Wh/Kg), rugged, long life, flat discharge potential and pollution free characteristics. The production costs of these batteries are expected to be very low as their chemistry is based on the redox reaction between air and zinc metal (one of the abundant metal on earth's crust). A bifunctional catalyst integrated air electrode, zinc electrode and cell architecture are important research parameters that determine the performance of Zn-air batteries. Zn anode gets oxidized to zincate and zinc oxide during discharge while the air from atmosphere undergoes reduction at the cathode. During recharge air electrode degrades due to oxygen evolution and corrosion while dendritic Zn growth occurs at the anode. These issues are critical factors that limit the cycle life of rechargeable batteries.

Carbon based air electrodes are conventionally used in metal-air batteries due its high specific surface area, porosity and high electrical conductivity. However, the highly oxidative environment of metal-air batteries during charging corrodes the carbon air electrodes which lead to poor cyclic stability. A hybrid air electrode with a nickel interlayer between carbon and electrocatalyst has been recently attempted. This approach protects the carbon from corrosion and also provides low resistant pathway for electron conduction through metallic nickel interlayer and improves the electrocatalytic activity of silver electrocatalyst deposited on nickel layer. The electrochemical performances of the electrodes were investigated to study the stability during cycling. The C-Ni-Ag electrode demonstrated a round efficiency of 55%, a ΔV around 0.9 V over the entire cycle life more than 1300 cycles over 345 hrs. of operation with capacity retention of 98.6%.

A 50Wh rechargeable Zn-air prototype cell has been fabricated and is currently being tested. Various lighting and inductive load are currently being tested. The battery can be discharged at 12V. It could be used to power a fan or LED display or Led lights. The electrode area used in the cells is about 150 cm^2. The cell can be operated in flow mode. The cell has been tested for about 40 cycles and further testing is in progress.

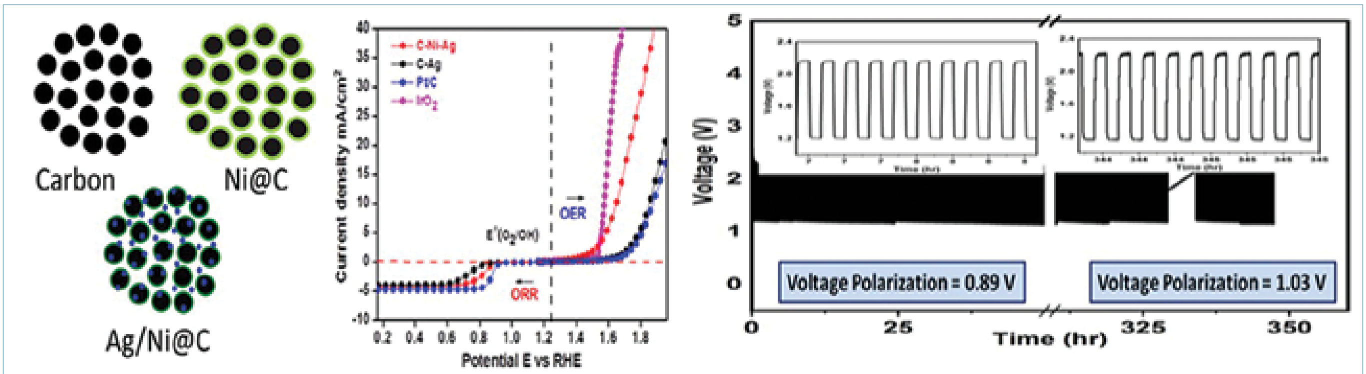

Fig. 1 Modified carbon structure and its electrochemical performance in Zn-air cell

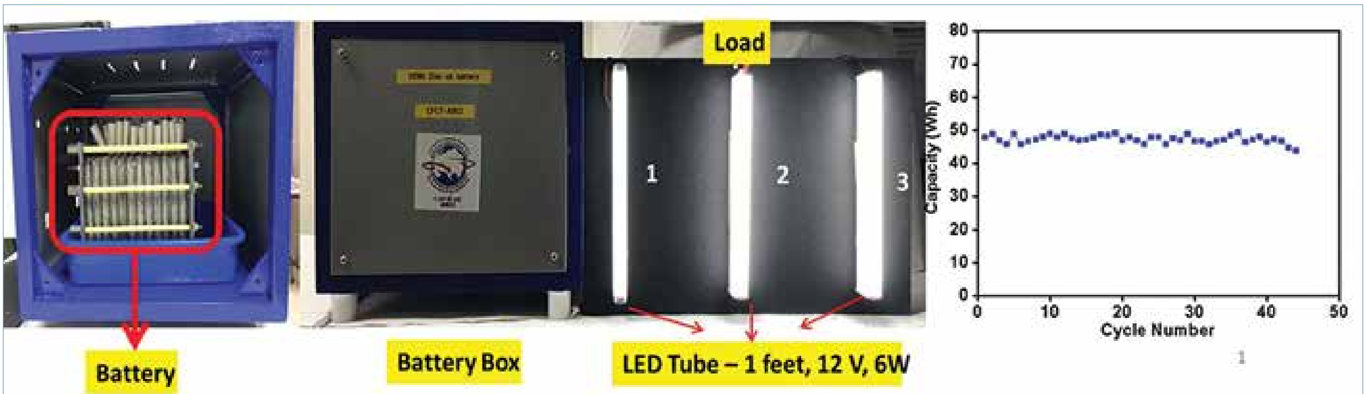

Fig. 2 50Wh Zn-air prototype module and its performance

Contributors: Imran, Arvind, Sudalaiandi and N. Rajalakshmi

Recovery and reuse of Pt catalysts from end-of-life membrane electrode assembly of proton exchange membrane fuel cell

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Pt based catalysts and nafion membrane forms the expensive components of membrane electrode assemblies (MEAs), the core of proton exchange membrane fuel cell (PEMFC) stack. Effective recycling of these precious components from end of life (EoL) MEA presents sustainable waste management of fuel cell components as well as development of cost-effective alternative technologies with the recycled components. Traditionally, noble Pt is recycled through multi-step hydrometallurgical and pyro metallurgical processes which are not only energy intensive, corrosive to the environment but also result in complete loss of the other expensive component, nafion membrane. Hence, development of a simple and environmental benign route for recycling of both Pt catalysts and Nafion membrane is imperative for development of a sustainable recovery centre. CFCT has been working on the development of recovery of precious components of EoL MEA through a simple and environmentally friendly route. One of the recovery strategies involve low temperature hydrothermal treatment of the EoL MEA in 50:50 v/v of water and isopropanol solution as presented in Figure 1. This results in the dissolution of membrane and subsequently Pt based catalysts were recovered through a simple vacuum filtration method. The Nafion membrane was recovered in the form of ionomer powder after evaporation of the solvent of the filtrate.

The X-ray diffractogram of the recovered materials confirmed the presence of Pt and perfluorosulfonic acid ionomer powder. The catalytic activity of the recycled Pt/C (Pt/C-R) was evaluated through cyclic voltammetric studies in half cell mode with 0.5 M H_2SO_4 and compared with fresh, commercial Pt/C catalyst (Pt/C-C). Electrochemical surface area (ECSA) calculated from cyclic voltammograms forms a critical attribute of electrochemical catalytic activity. Figure 2 (a) shows the CV plots of Pt/C-R and Pt/C-C catalysts. Pt/C-R retained 46% ECSA of Pt/C-C (0.1799 cm^2 vs. 0.3896 cm^2) indicating the potential of the recovered catalyst for reusage in alternative applications. The stability of Pt/C-R was also evaluated through CV to investigate the life-time characteristic of the recovered catalyst and is presented in Figure 2 (b) After 5000 cycles of accelerated durability test, Pt/C-R retained 94.7% ECSA revealing remarkable stability.

Fig. 1 Schematic representation of the recovery process of EoL MEA

The recovered Pt/C catalyst was further treated to obtain chloroplatinic acid (H_2PtCl_6) for the preparation of fresh Pt based catalysts. The usage of H_2PtCl_6 as the Pt precursor in the synthesis of new Pt based catalysts offers the advantage of tunability of Pt size, distribution and morphology which are critical parameters controlling the catalytic activity. In the process of attainment of H_2PtCl_6, first the recovered Pt/C was calcined at a temperature of 600°C to completely oxidise the carbon support to yield Pt powder. Thus, obtained Pt powder was dissolved in concentrated hydrochloric acid (HCl) and chlorine environment which was created by mixing trichloro isocyanuric acid ($C_3Cl_3N_3O_3$) in water. This resulted in complete dissolution of Pt powder leading to formation of orangish tinge solution indicating the formation of H_2PtCl_6. Work is in progress to prepare fresh catalysts with the in-house prepared H_2PtCl_6 from recovered Pt/C and evaluate its efficacy for various catalytic processes.

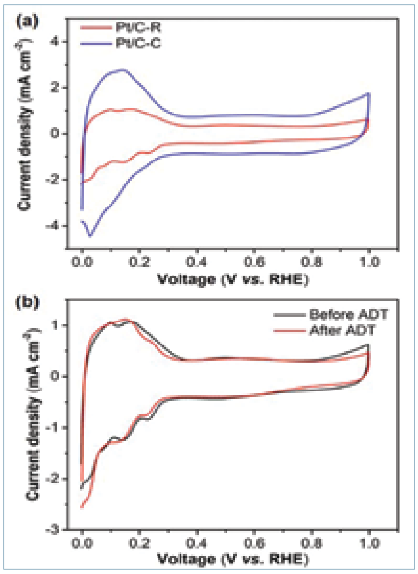

Fig. 2 (a) CV plots of Pt/C-R and Pt/C-C at scan rate of 50 mV s^{-1} in 0.5 M H_2SO_4, (b) CV plots of Pt/C-R at scan rate of 50 mV s^{-1} in 0.5 M H_2SO_4 before and after 5000 cycles of ADT

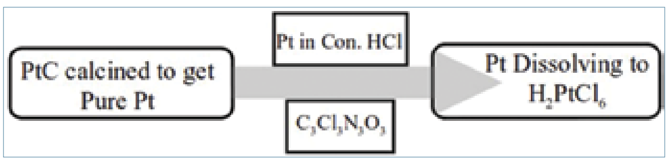

Fig. 3 Schematic representation of the Pt dissolution to chloroplatinic acid

Contributors: Raman Vedarajan, Abha Bharati, Sriraj and N. Rajalakshmi

Centre for Non-Oxide Ceramics

Centre for Non-Oxide Ceramics (CNOC) has been actively pursuing R&D activities in the area of various non-oxide ceramics, their coatings and composites for wide range of applications. The centre is equipped with the state-of-the-art forming, heat treatment and machining facilities for the processing of wide range of ceramic components. In the recent past, the centre has demonstrated its core competence in executing several sponsored programmes for producing large size non-oxide ceramic parts for application in demanding environments. During the period of this report, in addition to other programme, CNOC was actively engaged to produce complex shaped products using cold isostatic pressing using in-house designed mould, mandrel and flexible rubber bag. Also, the centre has taken initiatives for developing corrosion, wear and abrasion resistant SiC nozzles and seals. Ongoing R&D activities of the centre also include the development of various non-oxide based ready-to-press granules adopting spray-freeze drying techniques, carbon nano-fibre (CNF) and carbon nano-tube (CNT) reinforced SiC composites, SiAlON sleeves for molten metal handling purposes, SiC-based thin walled tubes and foams. The centre has been concurrently establishing processing-microstructure-property relationship for the materials (under development stage) as part of fundamental research activity. This centre is also working on the development of near-net shape components adopting various colloidal forming methods, wear and impact resistant parts, and silicon nitride based ceramics with favourable dielectric and mechanical properties.

Complex shape non-oxide ceramic product

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Effect of porosity on the mechanical behaviour of SiC foams processed through aqueous gelcasting

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The unique properties of silicon carbide (SiC) foams such as light-weight, high permeability, high mechanical and thermal properties in combination with the excellent high-temperature stability and long life in severe environments makes it suitable in wide range of applications including hot gas/molten metal filtration, heat exchangers, volumetric solar radiation absorbers, catalyst supports, ion exchange, metal-ceramic composites etc. Mechanical properties of the foams e.g., elastic modulus, mechanical strength, fracture toughness etc. play the crucial roles in many of the above applications. The study highlights the effect of porosity on the Young's modulus and compressive strength of solid-state sintered SiC foams processed through direct foaming followed by gelcasting and sintering.

SiC foams were prepared by foaming of SiC slurries using cetyl tri-methyl ammonium bromide (CTMAB) as the surfactant by tumbling in a roll mill. Subsequently, foamed slurries were cast in aluminium moulds, gelled at normal temperature and dried in a humidity controlled drier followed by binder removal at 500°C and sintering at 2150°C. SiC foams with relative density (RD) ranging between 0.12 and 0.34 were prepared through optimized gelcasting parameters including surfactant concentration, slurry viscosity and solid loading.

The Young's modulus of SiC foams as a function of RD in log-log scale is shown in Fig. 1. According to literature reports, Ashby model for cellular solids is the most realistic approach for explaining the mechanical properties of ceramics foams. The relationship between Young's modulus and RD of foams as per the Ashby model is given by:

$$E = C_1 E_s \left(\frac{\rho}{\rho_s} \right)^n \qquad \text{... (1)}$$

where C1 is a proportionality constant that depends on the pore geometry, (ρ/ρ_s) is RD, determined from the ratio of bulk density of foam (ρ) and density of strut material (ρ_s), E and E_s are the Young's modulus of porous body and strut, respectively and n is relative density exponent and it depends on cells morphology in the foam, n=2 for foams with open cells and n=3 for foams with closed cells. The linear fitting of relative Young's modulus (E/E_S) versus RD yielded n = 2.3 which is in close agreement with the Ashby model for open cell foams. The lack of exact fit of Young's modulus with the Ashby's model could be attributed to the presence certain amount of closed cell and non-uniform cell size distribution. Fig. 2 shows gradual decrease in compressive strength (σ) of SiC foams with RD. Whereas, the variation of σ with RD as per Ashby's model is as follows:

$$\sigma = C_2 \sigma_s \left(\frac{\rho}{\rho_s} \right)^m \qquad \text{... (2)}$$

where σ_s is the strength of strut, C_2 is a constant and m is the exponent which depends on the cell morphology. According to Ashby's model for interconnected foams m = 2.0 compared to the 2.93 in our study. The deviation of the exponent m from ideal Ashby's model could be associated with processing defects in the struts of SiC foams. The exponent m in the range of 1.5 and 3.0 for open cell foams are reported in the literature.

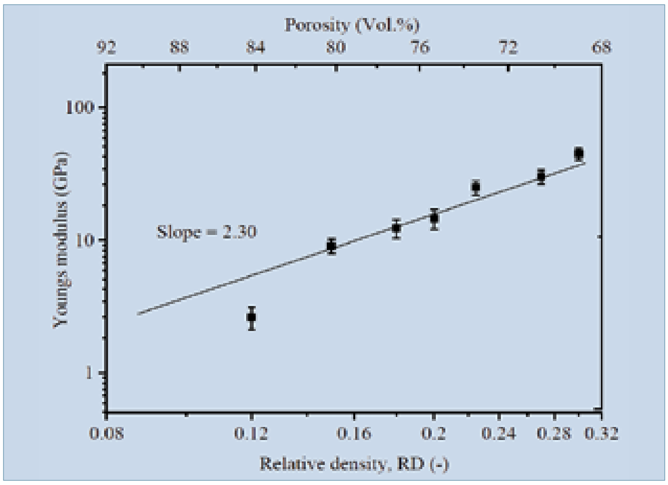

Fig. 1 The changes in Young's modulus of SiC foams with its relative density (RD)

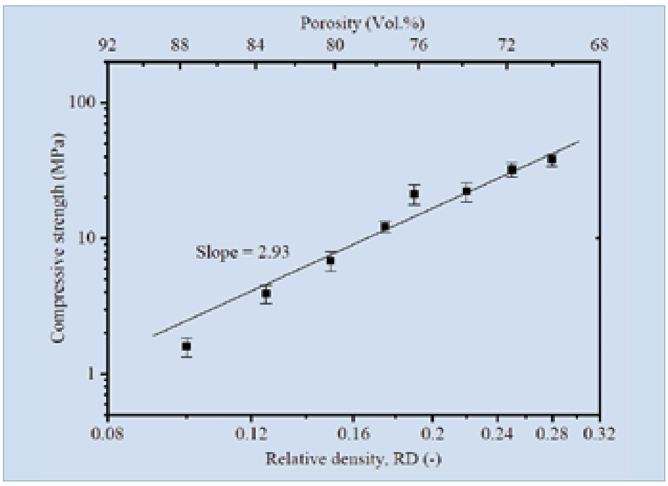

Fig. 2 Relative density (RD) dependent compressive strength of gelcast SiC foams

Contributor: B. P. Saha

Effect of boron nitride addition on dielectric and thermal properties of β-SiAlON ceramic

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The β-SiAlON is an excellent structural ceramic because of its unique combination of high Young's modulus (≈ 270-275 GPa), moderate hardness (15-17 GPa), high fracture toughness (6-8 MPa.√m), moderate thermal conductivity ≈ 15-20 W/m.k. Thus, SiAlON finds numerous applications such as cutting tools, wave transparent window, molten metal handling crucible, immersion heater tube in non-ferrous metallurgical industry. But, high di-electric constant (≈ 8) of SiAlON reduce electromagnetic wave transparency, which, in turn, limits SiAlON's application in some areas like substrate holder for microwave enhanced plasma chemical vapour deposition (CVD) reactor. In addition to this, higher thermal conductivity is generally preferred for such applications for rapid heat transmission from the component during operation. Thus, reduction in di-electric constant and improvement in thermal conductivity of β-SiAlON is of paramount importance for certain applications without comprising desired mechanical properties.

In this current study, an investigation has been carried out to study the influence of hexagonal boron nitride (h-BN) addition on dielectric constant and thermal conductivity of β-SiAlON ceramic with an objective to improve its dielectric and thermal properties. β-SiAlON with Z=2 (Z indicates the replacement of Si-N bonds by Al-O bonds) was prepared with the help of pressureless sintering technique at the temperature of 1750-1800°C for 4 h dwelling under nitrogen atmosphere, using the compact of Si_3N_4, AlN, Al_2O_3 and Y_2O_3 (sintering additive) powders of appropriate ratio.

Figure 1 shows the relative permittivity or dielectric constant (εr) of pristine SiAlON (SLN) and 5 wt% h-BN added SiAlON (SLN-5BN). It is observed that incorporation of 5 wt% h-BN in SiAlON decreases the dielectric constant from ≈ 8.4 to ≈ 7. Such outcome can be attributed to the combined effect of : (i) low dielectric constant of h-BN itself (static di-electric constant for bulk h-BN ≈ 3.76 (in-plane) - 6.93 (out-of-plane), and (ii) due to the formation of pores in the matrix as there is a reduction in density by 8.70% in case of SLN-5BN (density ≈ 3.22g/cm^3) compared to SLN (density ≈ 2.94 g/cm^3). It is to be noted that addition of h-BN inhibit the densification of SiAlON, which is in tune with many studies. The di-electric constant of air is provided in Figure 1 for reference purpose as the relative permittivity or dielectric constant of sample is calculated with respect to air.

The thermal conductivity (kth) for SLN and SLN+ 5BN samples decreases with the increase in temperature (shown in Figure 2) which is due to gradual reduction in mean free path of phonon movement due to their increased scattering with the increase in temperature. It is also noticed that with the incorporation of 5 wt% h-BN, the thermal conductivity of SLN-5BN increases significantly compared to that of SLN, depicted in Figure 2. Such phenomenon can be attributed to higher kth of h-BN which is ≈ 30 compared to that of β-SiAlON (Z = 2) which is ≈ 8.5.

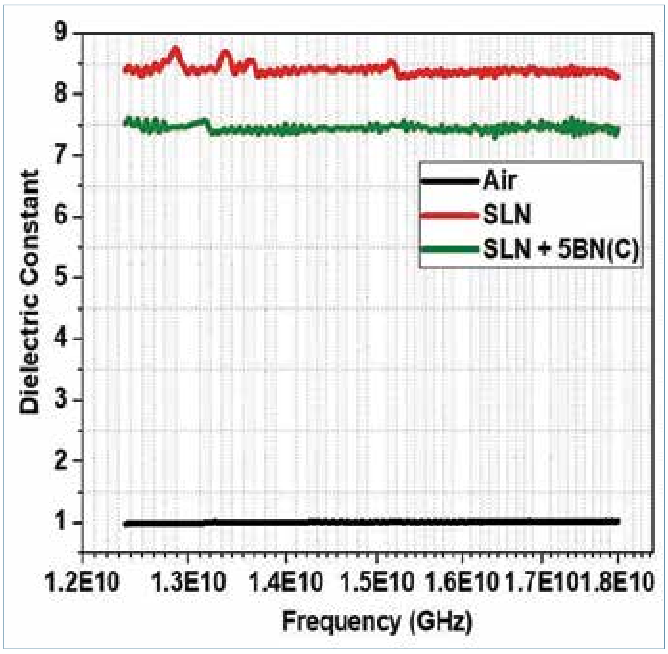

Fig.1 Room temperature dielectric constant versus frequency

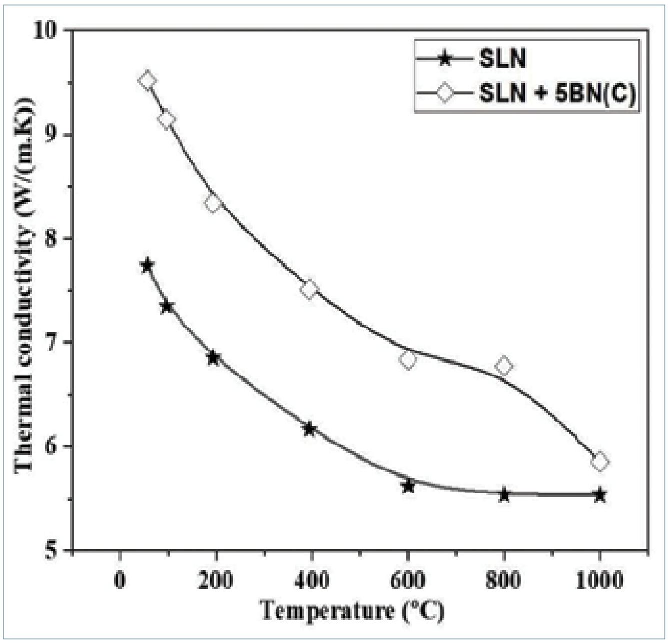

Fig. 2 Thermal conductivity as a function of temperature

Contributors: B. V. Shalini, R. Anbarasu and B. P. Saha

An innovative approach for easy powder filling during complex shape fabrication in cold isostatic pressing

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Conventional route of ceramic processing like uniaxial die pressing followed by sintering is commonly adopted for simple shaped small parts. It is to be noted that the die wall friction during uniaxial pressing creates non-uniform density in the compacted product particularly when the components are complex shaped and large. Cold isostatic pressing (CIP-ing) is one of the best technique which can be employed to overcome this issue and is used extensively in powder metallurgy, as well as in ceramic industries. The component produced by this process show consistent density throughout their cross sections as compared to those produced by conventional route.

Cold isostatic pressing is carried out by isostatically pressing loose or binder added granulated powder in a flexible rubber mould in hydraulic medium to form the shape of component. The fluid pressure acts uniformly in all direction of the rubber mould. During the CIP-ing process, the geometrical dimension tolerance, green density and surface roughness of ceramic part mainly depend on processing parameters like powder characteristics, powder packing in the mould, pressing pressure and time. The present work describes a novel innovative process of powder filling technique to form complex shaped large conical parts.

A practical difficulty is encountered during filling of powder at the spacing between metallic mandrel and flexible rubber bag to fabricate complex shape component (particularly conical shape) by cold isostatic pressing. Prior to compaction, the bag in unstretched condition should sit on metallic mandrel to maintain leak proof sealing between metallic mandrel and rubber bag. A gap in between the bag and mandrel will impede in achieving a leak proof sealing (which is very important) during CIP-ing. As there is no gap in between the bag and mandrel at the beginning, an innovative technique has been developed for filling the gap with powder uniformly to achieve uniform green density. In this approach, a hard shell is placed around the flexible rubber bag prior to placing the metallic mandrel inside the rubber bag in such a manner that the axis of both bag and the mandrel coincide with each other. The heavy metallic mandrel is perpendicularly hold by means of a separate mechanical fixture. Then, the vacuum sealing is ensured between flexible rubber bag and hard shell. A suction pump is connected through a flexible rubber hose at the bottom of the annular region in between the hard shell and rubber bag. During suctioning, vacuum is generated between bag and hard shell. As a result, the rubber bag expands laterally due to its high elasticity towards the inner surface of vacuum chamber and exactly sits on the hard shell. Thus, a uniform gap is formed between rubber bag and mandrel. Thereafter, it is very easy to pour the powder at this gap and uniform thickness of the green component is achieved with the help of this technique. After filling the powder, the suctioning is withdrawn and vacuum is released slowly. The rubber bag is sealed at the flat surface of metal mandrel. The whole assembly is then placed inside CIP chamber for isostatic compaction. The schematic drawing describing the CIP-ing mechanism is shown in Figure.

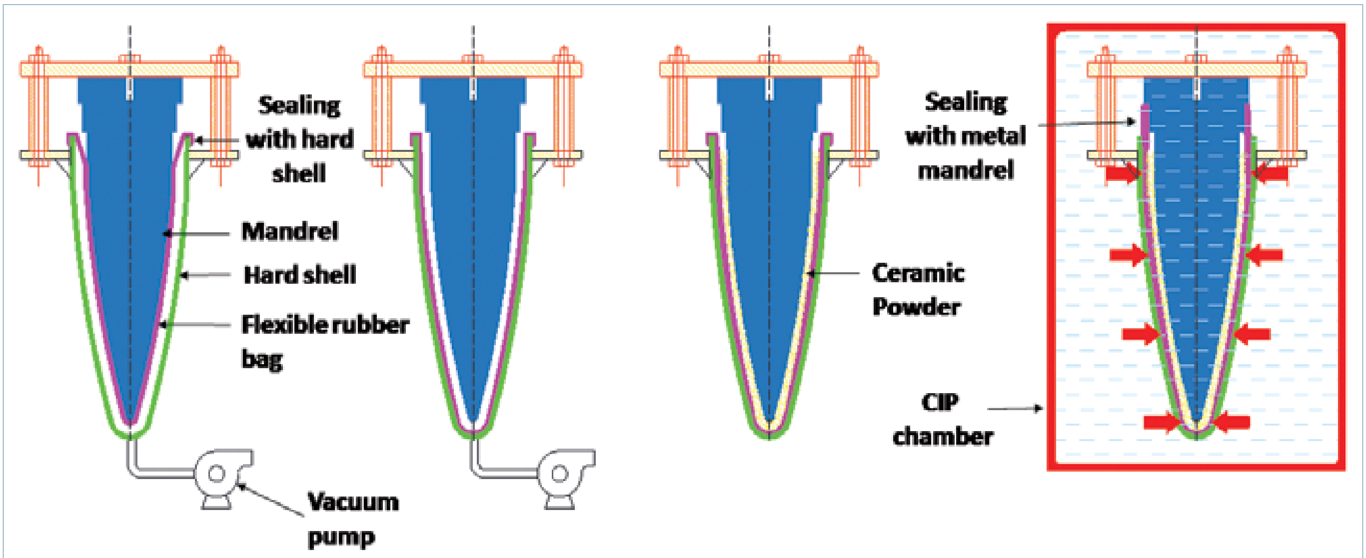


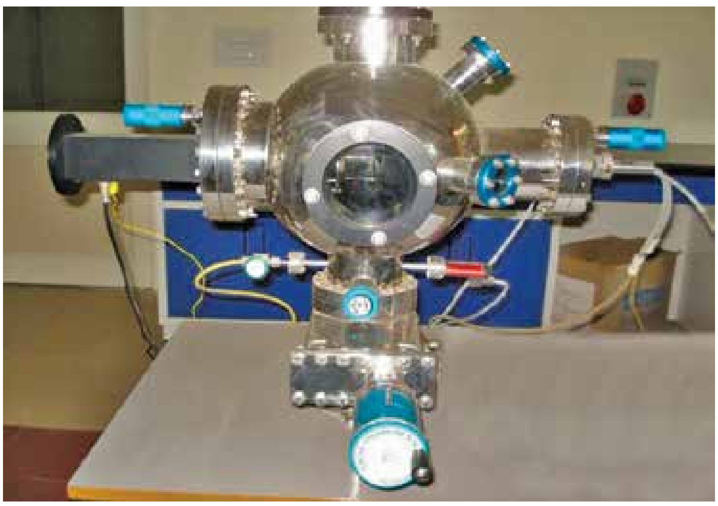
Fig. 1 Cold isostatic pressing arrangement

Contributors: B. V. Shalini, P. Barick and B. P. Saha

Centre for Carbon Materials

Carbon is an extraordinary element and of great importance to the scientist as well as to the technologist. Its unique characteristics made it versatile for many applications areas ranging from house holds as well as major industries on one hand in high tech aerospace, defence, nuclear energy and new energy source program on the other hand. Nanocarbon technologies deal with many forms of carbon (balls, tubes, sheets, diamonds, graphenes, etc.), among which nanotubes and graphene / nanoplates are most widely used. Graphene offers the unique set of thermal, mechanical physical and electronic properties, which makes it the ideal material for various engineering and technological applications. These unique and fascinating properties have resulted in many potential applications for high volume as well as for the nich areas. The energy sector is one such sector where many research groups are attempting to develop a super-capacitor with high energy density and power density.

Carbon nanomaterials based composite materials that synergistically integrate electric double layer capacitance of multi walled carbon nanotubes (MWCNT) with fast and highly reversible pseudo-capacitance properties. Transition metal oxides or conductive polymers are essential candidates for achieving such pseudo-capacitive behaviour in these composites. Porous and high surface area carbon materials are emerging as the electrode materials for supercapacitor applications. MWCNTs also find applications in Lithium ion battery applications as they increase the reversible capacity, enhance the rate capability and improve the cyclability. Carbon nano materials are highly anisotropic in nature and the properties are dependent on processing route as well as the processing conditions. Optimization of processing parameters and controlling the structure are the key factors for such application, and therefore efforts in the centre to get the better carbon nanomaterials are being persuaded. Keeping these emerging applications of carbon nanomaterials in view, Centre for Carbon Materials has initiated the efforts in the electrode development for supercapacitor and batteries applications. Nanocarbons, especially graphene due to its self-lubricating property, attracted a lot of interest for lubricant applications. Graphene, as a nano-additive in lubricant oils, theoretically improves its lubricating properties and thermal properties as well. Graphene, with its various forms (monolayer, few layer and multi-layer), is a potential replacement of multiple additives being used presently. The transition from conventional additives to carbon Nano-additives will lead to a big leap towards an efficient lubricant also pursued in the centre. Considerable research is going on at the center on PCM based thermal management technology and large scale production of graphite nanoplates as a filler material in various composites.



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Graphene nanoplatelets/eutectic phase change materials hybrid based heat sink for thermal management system

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Critically devastating environmental conditions enforced us to use electric vehicles (EV) to reduce the dependency on fossil fuels for sustainable development. Interestingly, energy storage devices (batteries and supercapacitor) are the crucial components of the EV system. The efficient energy storage devices are tremendously stimulating because of population explosion and depletion of fossil fuels hand-in-hand with rapid development in the economy worldwide. In recent years, Li-ion batteries (LIB) are considered as promising components of advancement in compact electronic and communication devices, and automobile industries. Remarkably, LIB has a high specific energy density and low auto-discharge. However, it can present a security risk in the case of leakage and overheating. During the drive, the continuous usage of Li-ion battery for longer duration generates a tremendous amount of heat energy, which consequently degrades the cell performance, and may cause severe explosion along with fire. Fortunately, overheating could be mitigated through adapting the passive cooling system to dissipate extra heat generated beyond the normal range.

As a consequence, use of phase change materials (PCM) to absorb/release heat during the melting/solidification process to delay the peak temperature rise inside the battery cells, thereby mitigating the risk of overheating. Consequently, the PCM sink is the right candidate to provide an appropriate solution for the thermal runaway of the battery by controlling the temperature in the range of 45-50°C. Thermal runaway is often due to exothermic reactions during improper charge and discharge (series of chemical reactions), and short circuit. The as-generated thermal energy must appropriately dissipated to create suitable operational conditions for the battery system.

Mostly, the materials with higher thermal conductivity could dissipate heat energy by increasing the heat transfer rate. However, PCM possesses a lower thermal conductivity. To enhance the thermal conductivity of PCM, the nanoadditives with high thermal conductivity are loaded to improve thermophysical and thermal properties as the fabrication of nanocomposites are among the most appealing approaches to achieve improved thermal conductivity. Graphene platelets (GP), the wondrous carbon allotrope with 2D structure possess excellent thermal conductivity around 5000 W/m.k which could find an alternative for a group of nanoadditives. To address the management of heat in a LIB system, GP loaded PCM composite was developed to suppress the thermal runaway through increasing the thermal conductivity.

Firstly, GP was produced by solvent-phase exfoliation of microwave-assisted exfoliated graphite through fluid dynamics-mediated intense turbulence-driven shear fragmentation using a co-solvent. The blades of the mixer are capable of producing very high shear rate beyond critical shear rate to sustain a continuous process for fragmentation as well as exfoliation. Then, eutectic PCM based on a mixture of myristic acid (MA) and stearic acid (SA) loaded with GP were prepared through the melt-mixing process.

Figure 1 shows differential scanning calorimetry (DSC) curves of eutectic MA-SA mixture and the raw fatty acids in which the phase transition temperature of eutectic is lower than MA and SA. The suitable melting point of eutectic for application could be tailored to the required transition temperature by introducing the fatty acid with lower temperature (MA) to higher temperature fatty acid (SA). Additionally, introducing SA into MA decreases the melting point of MA and vice versa. However, at the eutectic point, both of the fatty acids melt simultaneously at 47.37°C.

The addition of 3 wt.% GP to eutectic MASA exhibited a decrease in latent heat storage and significant increase in thermal conductivity as indicated in Table1. Such a eutectic system with phase transition in the range of 45-50°C temperature and excellent heat transfer could open a new avenue for heat management in battery-operated EV system.

Table 1 Thermal properties of MA, SA and eutectic MA-SA mixture

Sample	Phase transition (°C)	Latent heat (kJ/kg)	Thermal conductivity (W/m.k)
MA	55.80	195.0	-
SA	61.30	199.8	-
MASA	47.37	183.1	0.168
MASA-3GP	46.82	179.2	0.531

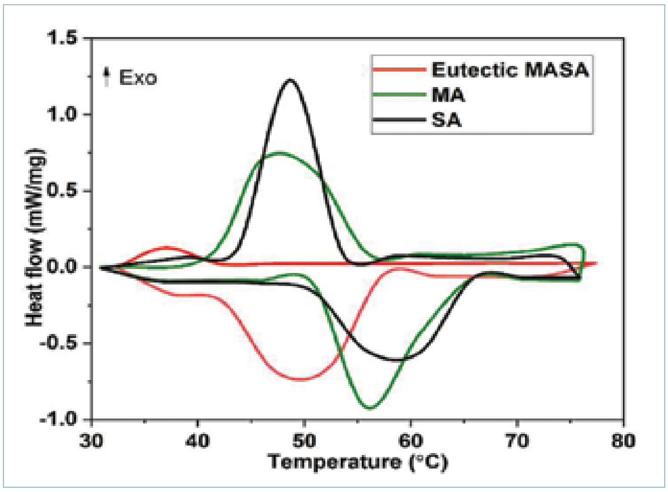

Fig. 1 DSC curves of MA, SA and eutectic MA-SA with heating and cooling

Contributors: Akshay Kumar and P. K. Jain

Development of nanocarbon composites for metal ion batteries (Lithium/Sodium batteries)

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Rechargeable lithium ion batteries are undergoing rapid development and providing power to many modern portable electronic devices due to their high energy density and lightweight as compared to other rechargeable batteries. The electrochemical performances of the rechargeable batteries depend on the properties of the anode materials. Currently, graphitic carbon is widely used as anode material because of its low and smooth charge/discharge potential and low cost, but relatively low specific capacity (~372 $mAhg^{-1}$) is the disadvantages of graphite. In order to improve the capacity of such batteries for the heavy duty and large scale storage applications like in electric vehicles and grid storage, there is an urgent need to identify and develop electrodes possessing still greater capacities, rate capabilities and improved safety aspects; but without compromising on the cycle life.

With respect to negative electrode materials, metallic materials (e.g., Sn, Al, Sb) are expected to replace the presently used graphitic carbon based anode materials for Li-ion batteries on accounts of their higher Li-capacities and improved safety aspects. However, the metallic anode materials undergo huge volume changes during lithiation/delithiation which leads to the development of stresses that result in severe mechanical degradation and concomitant drastic capacity fade. Conversion reaction-based transition metal oxide nanomaterials (TMOs) are found to be potential candidates to replace graphite as anode material in lithium-ion batteries due to their high specific gravimetric and volumetric capacity values and excellent safety characteristics. However, these TMO electrodes suffer from drawbacks that hinder their applications. Low electronic conductivity, volume expansion during electrochemical cycling, and voltage hysteresis are the three main issues plaguing TMO materials. The low electronic conductivity limits the transfer of electrons and hinders improvement of the rate capability, Li insertion/extraction at high current rate, of the electrode. Volume expansion damages the structures of the active materials, resulting in decayed capacity and inferior cycling stability.

$CuFe_2O_4$ with inverse spinel structure considered to be one of the most promising anode materials for lithium ion batteries. It exhibits high theoretical capacity, 895 $mAhg^{-1}$ where commercial graphite exhibits 372 $mAhg^{-1}$ when compared. $CuFe_2O_4$ material was synthesized by hydrothermal method. $CuFe_2O_4$/rGO/CNT composite material was prepared by hydrothermal method. Electrochemical behaviour of $CuFe_2O_4$ and its composite performed with lithium.

Surface morphology of $CuFe_2O_4$ material was observed by FESEM and it was flake like morphology with spinel layered structured. The average particle size of the each sheet is ~120nm.The electrochemical behavior of $CuFe_2O_4$electrode was investigated by the cyclic voltammetry (CV) taken at a scanning rate of 0.1mV s^{-1} in the voltage range of 0.01-3.0V, and the CV curves of the first three cycles are displayed in Fig. x. As can be seen, in the first discharge reaction, there was a spiky cathodic peak at 0.7V with an onset at 1.25 V. The peak could be ascribed to the decomposition of $CuFe_2O_4$ material and formation of metallic Fe and Cu nanoparticles in an amorphous matrix of Li_2O, as well as the decomposition of electrolyte and formation of solid electrolyte interphase (SEI) when the electrode potential decreased to 0.01V. In the first charge process, a broad anodic peak was presented at about 1.68 V, which corresponded to the oxidation of both metallic Fe and Cu nanoparticles to Fe_2O_3 and CuO, respectively, as well as the decomposition of SEI. The specific capacity of $CuFe_2O_4$electrode was recorded to be ~ 250 mAh/g at the current density of 200 mA/g after 100 electrochemical cycles against lithium whereas the capacity of CFO/rGO/fCNTs composite electrode was recorded to be ~763 $mAhg^{-1}$ at the current rate of 200 mAg^{-1} after 80 cycles.

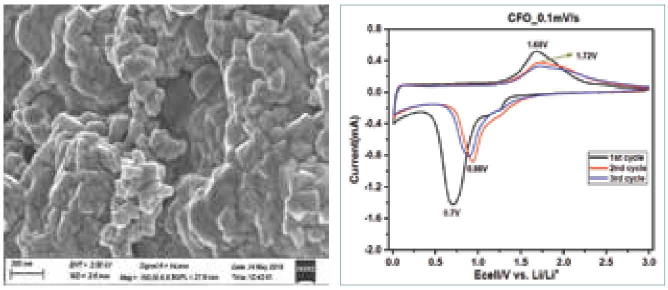


Fig. 1 (a) FESEM image of $CuFe_2O_4$ and (b) Cyclic voltammetry of $CuFe_2O_4$ at scan rate of 0.1mV/s

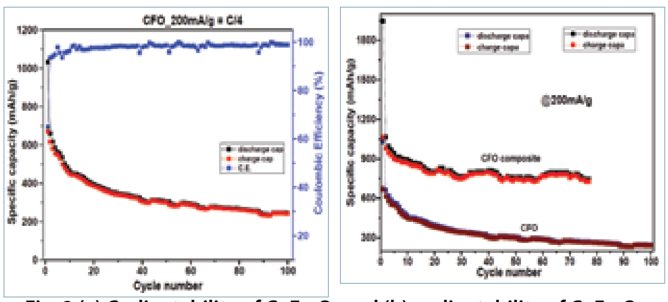


Fig. 2 (a) Cyclic stability of $CuFe_2O_4$ and (b) cyclic stability of $CuFe_2O_4$ and $CuFe_2O_4$ composite

Contributors: M. Shanti and P. K. Jain

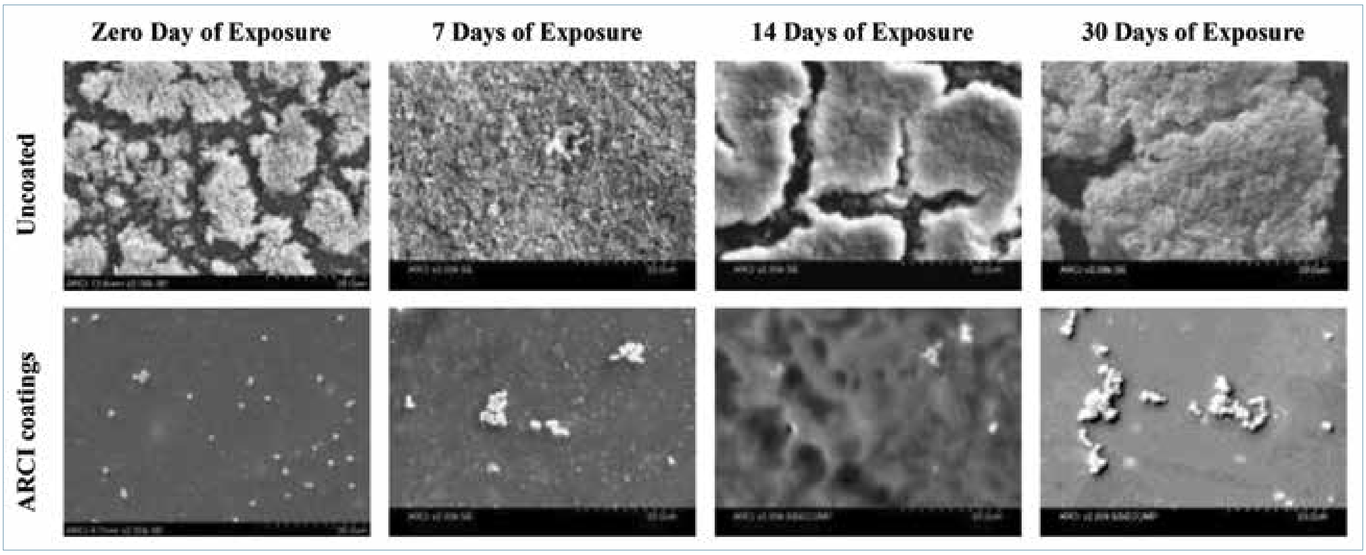
Centre for Sol-gel Coatings

Centre for Sol-Gel Coatings has been meticulously working along with industrial partners for commercialization of the sol-based nanocomposite coatings for a wide variety of applications. The distinct advantages of using sol-gel coatings on any substrate are the good adhesion due to chemical bonding of the sol with the substrate and possibility of generating multifunctional coatings. During the last year, the Centre has been focusing on the following applications:

1. *Anti-bacterial coatings on non-woven fabrics*
2. *Anti-biofilm coatings for eye care products and for preventing surgical site infections*
3. *Corrosion protection coatings on steel sheets for automotive applications*

Anti-bacterial coatings by using an environment friendly bactericidal material immobilized in a sol-gel matrix was promising to be used on non-woven fabrics. Coatings without any active material, but which could exhibit antibiofilm forming ability merely due to the hydrophobicity of the coatings were explored and were found to be promising. The feasibility of applying these coatings on sutures used in surgery is being investigated.

Protective coatings on steels and galvanized iron that are formable, weldable, ready-to-paint and which can obviate phosphating are being developed. Promising preliminary results on galvanized iron sheets have been obtained.



Scanning electron micrograph of un-coated coupons (above) and ARCI anti-biofilm forming coated contact eye lens case (below) that were soaked in Bio-true multipurpose solution for 7, 14 and 30 days and then treated with gram-positive bacteria, showing the durability of ARCI coatings for antibacterial and anti-biofilm forming ability

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Release rates of corrosion inhibitors in nanocontainer-based self-healing corrosion protection coatings on Mg alloy AZ91D

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Magnesium alloys are considered as ideal materials for the production of weight-sensitive components such as gear boxes, air-bag channels, engine blocks, steering wheels, suspension arms etc., in aircraft, automobile and electronics industries due to their lightweight characteristics (35 % lighter than aluminum and 78 % lighter than steel), better strength-to-weight ratio, high conductivity, good machining ability and wide availability. However, Mg alloys are very much prone to corrosion. Sol-gel nanocomposite coatings provide very good corrosion protection and are promising for use on Mg alloys. In order to improve and prolong the corrosion resistance of the coatings, in our earlier studies, corrosion inhibitors such as 8-hydroxyquinoline (8-HQ), Ce^{3+}-Zr^{4+} and mercaptobenzothiazole (MBT) were encapsulated into nanocontainers like halloysite clay nanotubes (HNT) and introduced into the sol-gel matrix to provide an autonomous self-healing effect. The lumen of the HNT was etched using conc. H_2SO_4 to increase the amount of loading of the inhibitors. The inhibitor loaded HNTs were dispersed into a hybrid silica sol-gel matrix and coatings were generated on Mg alloy AZ91D substrates by dip coating technique. The corrosion resistance of the coatings was investigated by potentiodynamic polarization studies by exposing the coated substrates in 3.5% NaCl solution for 120 h, and the results are shown in Fig 1.

The inhibitors 8-HQ and Ce/Zr were found to provide better corrosion protection (lower io values) when compared to MBT. Hence, the release rates of the corrosion inhibitors from the HNT nanocontainers were studied for only 8-HQ and Ce/Zr as a function of pH. For this purpose, the inhibitor loaded etched HNTs were dispersed in 3.5 wt % NaCl solution of pH values 3, 7, 8.5 and 10.2 and the solution was kept under constant stirring conditions to provide an external trigger for release of the corrosion inhibitor. The release behaviour was investigated by measuring the absorbance of athe solution at 209 nm (for Ce^{3+}-Zr^{4+}) and at 249 nm (for HQ) after specific intervals of time. Fig 2 depicts the percentage release of Ce^{3+}-Zr^{4+} and 8-HQ as a function of time at different pH values.

It can be seen that the percentage release of 8-HQ is higher than Ce/Zr at all pH values and at pH 7, it is least but slowly increasing with time. For a self-healing release based coating, it is always desirable that the release of the inhibitor is slow and steady which persists over a long time. The pH of a 3.5% NaCl solution is 7. Hence, the 8-HQ has shown the least corrosion current in the potentiodynamic polarization studies, confirming better self-healing effect for HQ when loaded in etched HNT, whereas in case of Ce/Zr, the release is very high and fast at pH 7 and less at pH 3. This study gives information on which inhibitor can be loaded into the lumen of etched HNTs and which can exhibit a better self-healing effect, depending on the pH of the service environment of the substrate Mg alloy AZ91D.

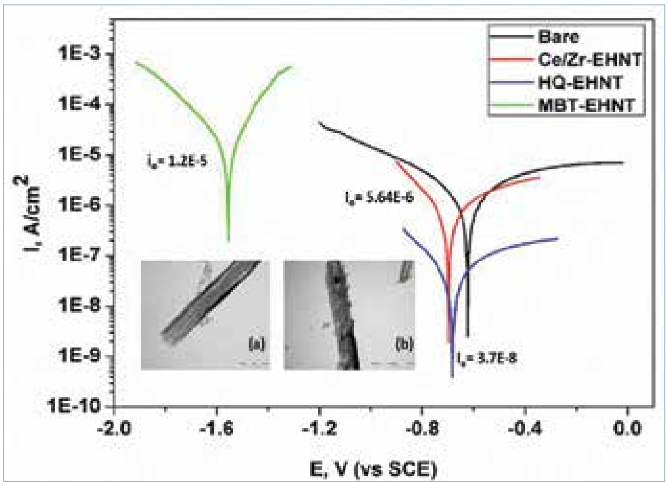

Fig. 1 Potentiodynamic polarization data for coatings generated using inhibitor loaded etched HNTs after exposure to 3.5% NaCl for 120 h

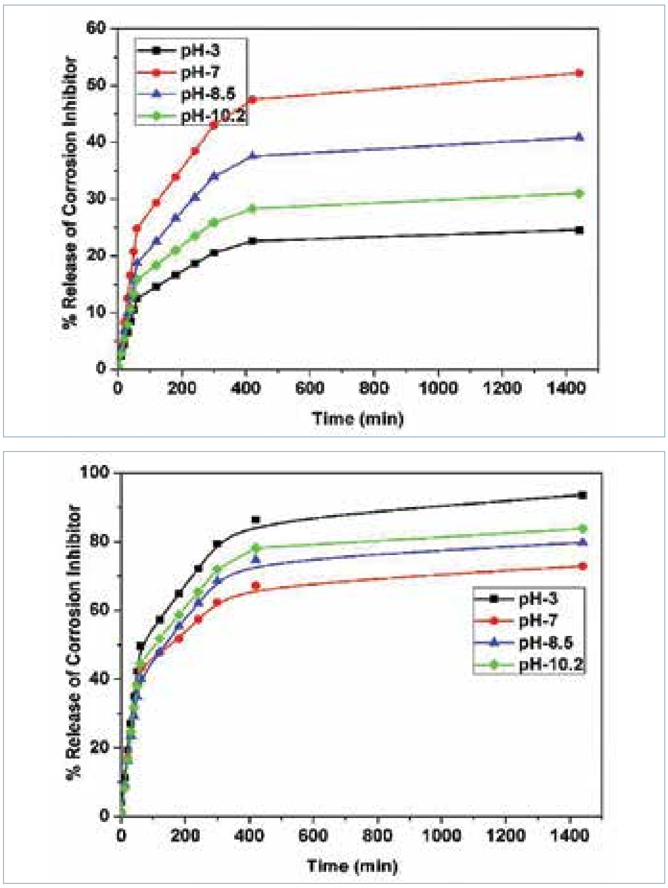

Fig. 2 Release profiles of inhibitors (a) Ce^{3+}/Zr^{4+} and (b) 8-HQ as a function of time at different pH values of 3.5% NaCl solution

Contributor: Swapnil H. Adsul

Sol-gel based anti-bacterial coatings for non-woven fabrics

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Sanitation has been a big factor for improvement of overall health and well being of humans. Modern kitchens, bathrooms and office cubicles are signature areas to our habits, living style and have high potential to act as microbial incubators irrespective of social progress of any nation. As per a recent publication by Karim Hassan et.al (J. Pure and Appl Microbiology 11 (2017) 1687-1693), our kitchen platform cleaning wipe or a scrub pad has been demonstrated to have highly contaminated with pathogens and can easily risk cross contamination. Pathogens are disease causing microorganism such as fungus, bacteria, virus and other parasites. Among these, bacteria release toxins and virus damages our cells. Typical size of virus is 20 to 400 nm, bacteria is 0.5 to 5 μm long, while fungus is 2-10 μm in diameter to few cm long. Bacteria are characterized as gram positive and gram negative. Gram positive bacteria have thick peptidoglycan layer that is responsible for take up and retaining colour of the crystal violet stain and have no outer lipid membrane and hence are named as gram positive. Gram negative bacteria have a thin peptidoglycan layer due to which they cannot take-up and retain the crystal violet stain due to which they are named as gram negative and also have an outer lipid membrane. Staphylococcus aureus is an example of gram positive and Klebsiella pneumonia and Escherichia coli are examples of gram negative bacteria. These pathogens adhere to any inanimate surface and they are the source of infections when they enter a human body. Healthcare associated infections are of growing concern since they are the main source of antimicrobial resistance. Non-woven fabric is an engineered product that is resilient, stretchable, washable, provide cushioning, thermal insulation and used to prepare products of single use or limited use products such as surgical gowns, caps, surgical masks, diaper stock etc. in health care industry. An important need of the hour is to impart antibacterial resistance to the personal protective equipment (PPE) used by healthcare personnel to prevent bacterial infections.

Organic-inorganic hybrid nano composite sol-gel coating can be used to improve the hygiene of products made from non-woven fabrics by incorporating suitable antibacterial agents. Sol-gel matrices are very good host matrices for immobilizing the anti-bacterial agents. Inorganic materials such as nanoparticles of gold, silver, copper, magnesium & iron metals, metal oxides of aluminium, cobalt, zinc, titanium, cerium, bismuth and organic agents such as triclosan, neem oil, tea tree oil, aloevera and grape fruit seed extract are some of the well-known antimicrobial agents. For the present investigation, a two component eco-friendly antimicrobial agent and an aqueous hybrid silica sol system was used at different mix ratios to spray coat on non-woven fabric substrates. Coatings were then cured at room temperature (RT) drying for 2 h and flash curing at high temperature (HT). Concentration of antibacterial material was optimized to make the product commercially viable while it actively inhibits growth of E. Coli, S. Aureus and K. Pneumoniae bacteria. Abrasion test was used to assess the durability of the coating. Efficacy of the antimicrobial activity was assessed with log reduction test as per ASTM 2149-E standard method and zone of inhibition as per AATCC 147 test method respectively.

As shown in the fig. ( ) optimized sol-gel coating composition and curing conditions could result in lowest abrasion wear of sol-gel coated non-woven fabric while maintaining excellent antimicrobial activity with more than 97% log reduction of all the three bacteria and more than 6.3 mm zone of inhibition with S. Aureus and K. Pneumoniae bacteria and no zone of inhibition with E.coli. Results ascertain eco-friendly green antibacterial coatings derived from a hybrid sol could be successfully developed on non-woven fabric.

Table 1 Table: Antimicrobial test results of sol-gel coated non-woven-fabric against different bacteria

Test organism	Percentage Reduction of Bacteria		Antibacterial Activity		Conclusion	
	Inoculated treated sample at 1 hr	Inoculated treated sample at 24 hr	Zone of inhibition	Growth under specimen	Diffusible antibacterial activity	Pass/ Fail
Staphylococcus aureus	79.16	99.79	6.3 mm	No growth	Diffusible antibacterial activity	Pass
Klebsiella pneumoniae	73.95	99.73	6.4 mm	No growth		
Escherichia coli	66.50	97.70	No zone	No growth		

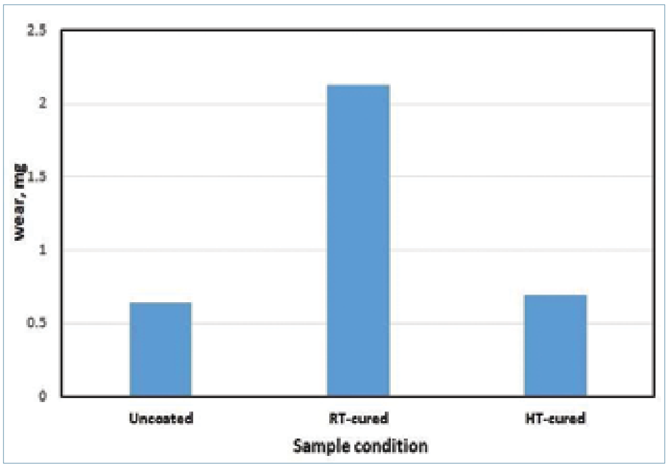

Fig. 1 Abrasion wear test results of non-woven-fabric in uncoated and sol-gel coated and cured with different temperature conditions

Contributors: D. Sreenivas Reddy and R. Subasri

Development of abrasion resistant sol-gel nanocomposite coatings on electro deposited mild steel panels as hard chrome replacement

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Abrasion resistant coatings have been widely used to reduce or eliminate wear, thereby extending the lifetime of the products. In most working conditions, wear is minimized by applying lubrication to improve surface mechanical properties. However, in some situations, oil or grease lubrication alone are not sufficient to meet wear resistance requirements. Abrasive resistant coatings may be the only feasible option to protect the product surface. Conventionally, manufacturing Industries adopt hard chrome coatings for providing abrasion resistance on mild steel. Since, hexavalent chrome which is used in the chrome plating process is very toxic and a hazardous air pollutant, the use of chrome is heavily regulated by most of the countries including India. To replace the hazardous hard chrome plating, slowly industries are switching over to cathodic electro deposition (CED) of acrylic/epoxy based coatings on mild steel.

Cathodic epoxy electrocoat is a popular primer technology because of its superior adhesion and corrosion protection properties, as well as its compatibility with a wide range of liquid and powder topcoat materials. Since this technology has good appearance properties, it can also be used for single-coat applications where resistance to the ultraviolet (UV) rays from sunlight is not needed. Today's cathodic epoxy e-coat materials are environmentally friendly and suited to parts with possible cure temperature above 200°C. However, since the abrasion resistance of ED coating is poor, there is need to further improve its abrasion resistance properties. For this purpose, an organic-inorganic hybrid silica-zirconia nanocomposite sol was developed for use as a top coat on the cathodic electrodeposited coatings on mild steel panels. This sol was deposited on electro deposited mild steel panels by a manual spray process and heat treated at 150°C for 2 hrs. The coated samples were characterized for taber abrasion, scratch hardness, tape adhesion tests as per ASTM standards. Taber abrasion test was carried out with CS 17 abrading wheels for 1000 cycles with a load of 1 kg and results are presented in the Table 1. It can be seen that the abrasion resistance of the sol-gel coated ED MS panels were even better than the chrome plated panels. A pencil scratch hardness of 9H and adhesion rank of 5B (no peel off after adhesion test) was obtained for the sol-gel coated mild steel panels. The above results showed that the developed sol-gel nanocomposite coatings can be very promising for replacement of hard chrome plating on mild steel and the process is very much amenable for use by the industry.

Table 1 Results of the Taber abrasion testing using CS17 wheels for 1000 cycles with 2 x 500 g load

Sl. No.	Sample Nomenclature	Weight of the sample (in grams)		% of Metal Wear
		Before abrasion	After abrasion	
1.	Chrome plated MS panel	122.7276	122.7030	0.02000
2.	Electrodeposited MS panel	120.5296	120.4799	0.04123
3.	Solgel coated Electro deposited MS Panel	121.1619	121.1529	0.00743

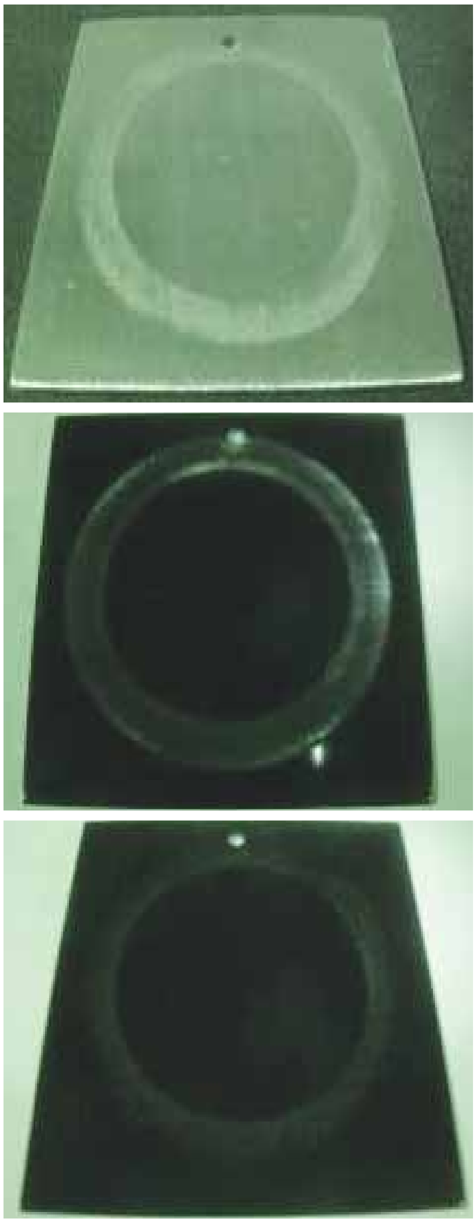

Fig 1. Photographs of MS panels after abrasion testing (a) chrome-plated ; (b) electrodeposited and (c) sol-gel coated ED

Contributors: D. Sreenivas Reddy and R. Subasri

Antibiofilm forming coatings on plastic contact eye lens cases

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Contact lens-related microbial keratitis (CL-MK) is the most devastating ocular infectious condition associated with the lens wear. With an estimated 140 million contact lens wearers globally, this complication is a cause of serious concern. The moist environment of the lens cases promotes bacterial colonization and biofilm formation, which in turn get transferred on contact lenses and become the source of infection. One of the possible methods for inhibition of biofilm formation on the lens cases is to create surfaces that are hydrophobic. Further, incorporation of biocidal material such as nanosilver to such surfaces will provide antibacterial properties and will have additive effect. Organic-inorganic hybrid nano-composite formulations derived by sol-gel technology with incorporation of nanosilver as bacteridical material, provides a promising solution by rendering both antibiofilm and antibacterial properties. The advantages of this technology are: a) sol-gel matrices are promising for immobilizing bactericidal nanomaterials that in turn prevent leaching of the material while providing bactericidal properties; b) the formulation is extremely adherent to any surface due to formation of covalent bonds; c) ease of application on a wide variety of surfaces; and d) multi-functionalities like hydrophobicity, antibacterial, scratch resistance can be achieved in a single layer of coating. Hence, the objective of this investigation was to evaluate the efficacy of a coating derived from nanosilver immobilized in a hybrid sol gel matrix in preventing biofilm formation on plastic (polymethyl methacrylate PMMA) eye lens cases. For this purpose, a hydrophobic sol was prepared by the hydrolysis and co-condensation of a radiation curable silane along with a metal alkoxide precursor to which, silver nitrate was added as the source of silver. Silver nanoparticles were generated in-situ by UV irradiation of the coating deposited on small circular coupons sliced from the contact lens cases by a dip coating method. Subsequent to UV curing, the coupons were then heat treated at 75±5˚C in air. The efficacy of coated surface in reducing biofilm formation was assessed by comparing biofilm parameters between coated and uncoated surfaces. Bacterial growth was monitored by log reduction method. The duration of efficacy of the coating was evaluated by exposing the coated surface to contact lens cleaning solution for various length of time up to 30 days and assessing biofilm characteristics between coated and uncoated coupons. The cytotoxicity of the coated surface was also assessed using cell culture studies. The coatings were seen to inhibit nearly 95% reductions in metabolic activity with both gram negative bacilli as well as gram positive cocci, as shown in Fig 1. Log reduction studies demonstrated that the coating results in 99.9% (or 3 log) reduction in the growth of clinical isolate of gram negative bacilli. SEM studies showed a significant drop in growth of bacteria on the coated coupons, as depicted in Fig 2. Cytotoxicity studies using cell culture and SEM revealed that the coating material is non-toxic to corneal epithelial cell lines. The coating remained stable and retained its ability to prevent biofilm formation for up to 30 days despite exposure to contact lens cleaning solution. The present studies showed the promise of the sol-gel coating technology for preventing contact lens related infections.

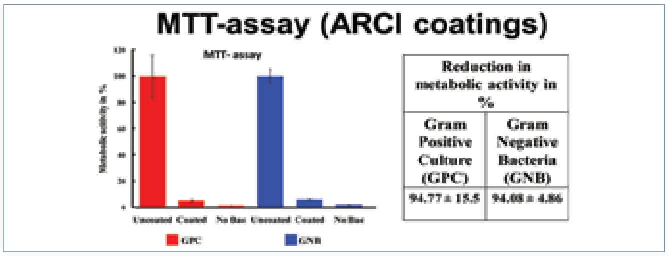


Fig. 1 Results showing reduction in metabolic activity of both gram positive and gram negative bacteria

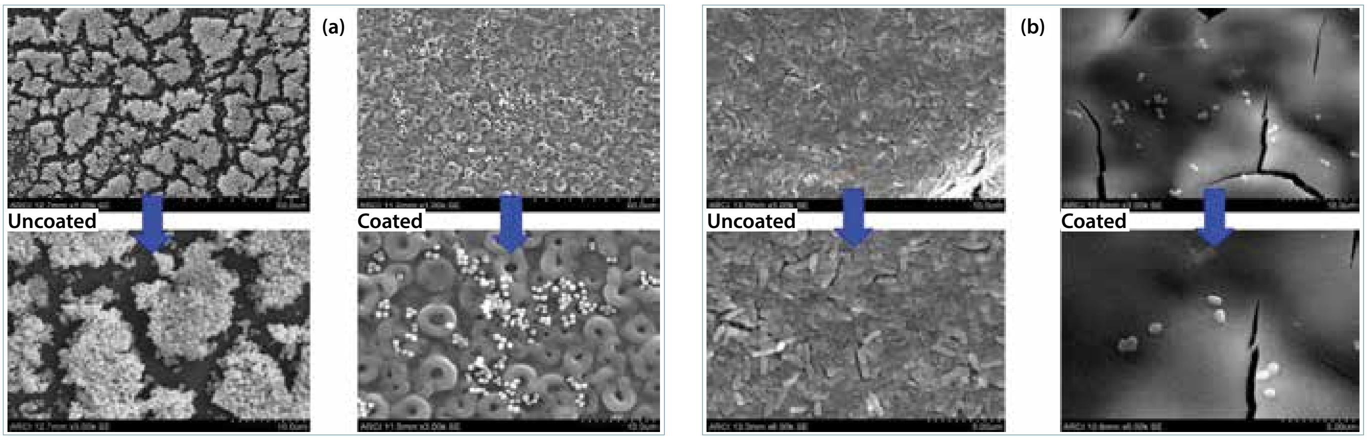


Fig. 2 (a) SEM analysis of plastic contact eye lens coupons after antibacterial testing with Gram positive bacteria showing drastic reduction in the counts of bacteria on coated coupon; (b) SEM analysis of plastic contact eye lens coupons after antibacterial testing with Gram negative bacteria showing drastic reduction in the counts of bacteria on coated coupon

Contributors: R. Subasri, Khatija Tabassum, Prashant Garg* (*LV Prasad Eye Institute, Hyderabad)*

Centre for Materials Characterization and Testing

The Centre for Materials Characterization and Testing continues to work to fulfil the following mandate:

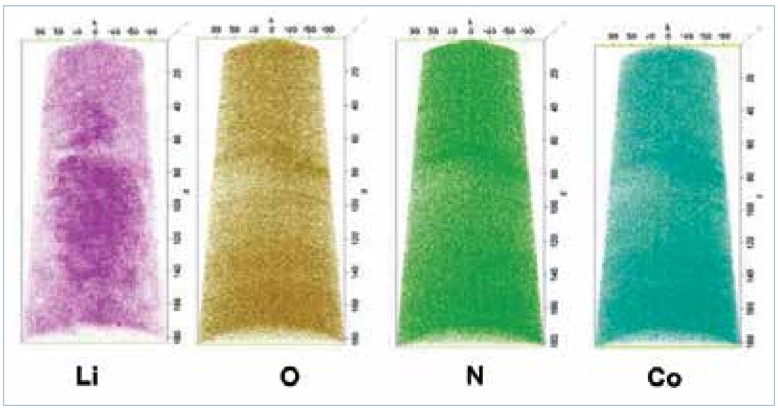
- *Provide state-of-the-art characterization facilities for materials characterization and testing to support ARCI's activities in technology development and transfer*
- *Extend support to industries and academic institutions in Hyderabad and beyond for the characterization of materials, and to help in data analysis when needed*
- *Carry out basic research in the line of ARCI's areas of interest*

The focus of the work at the Centre is on microstructure-structure-property correlations. Transmission electron microscopy (TEM), focused ion beam milling and field emission scanning electron microscopy, in conjunction with optical microscopy and non contact optical profiling are extensively used to study microstructure over a wide range of lengthscales. ARCI being a node for atom probe tomography (APT), studies are carried out in the National Facility at IIT Madras from the remote terminal located in the Centre. The X-ray diffraction unit with a 9 kW rotating anode generator, installed the previous year, is now the mainstay for structural work. Sample loading in this unit is automated, leading to higher productivity. Further, phases with low volume fractions in multiphasic materials can be detected with ease using this unit. Mechanical property studies are carried out using a universal tensile testing machine. Hardness measurements can be performed on bulk materials, while nanoindentation is used to probe mechanical properties of thin films and coatings. The Centre is thus well-equipped to carry out multiscale materials characterization.

The portal 'Facilities for Materials Characterization and Testing (FMCT)' is incorporated into the ARCI website and external users are able to access the facilities in the Centre regularly.

Team Members are also actively involved in research projects in diverse areas and are involved in independent research, and in collaborations with Scientists from other Centres. To complement ARCI's expanding interests in additive manufacturing, in-depth TEM studies are being carried out on Inconel 718. A new area of work is the synthesis and study of multicomponent alloys, and different characterization techniques are bring used to probe this interesting class of materials.

APT Results of Li-ion battery materials



3D-atom probe tomography (APT) reconstruction maps of Li-ion ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$) material showing the elemental distribution of Li, O, Ni and Co

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Influence of mechanical properties evaluated from nano-indentation testing on nanoimpact performance of PVD coatings

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TiN, TiAlN and TiAlCN coatings (H = 24-30 GPa) are widely used in the general machining industry to enhance performance of the bulk HSS and WC-Co tools. To further improve machining efficiency, a new superhard nanocomposite (NC) coating material based on Ti-Al-Si-N quaternary system (H = 40 GPa) has been developed in the recent past.

Mechanical properties such as H, E, H/E, E/H, H3/E2, Wp, Wt, hr/hmax etc. evaluated by nanoindentation are reported to influence the wear resistance of the PVD coatings including sliding, erosion and impact. Recently, a new laboratory technique, cyclic nanoimpact testing for deriving fracture probability of the tested materials, has been developed to simulate interrupted milling conditions. The aim of the present study is to correlate the fracture probability of TiN (a conventional hard coating), superhard NC and TiN/NC multilayered coatings with their mechanical properties.

Fig. 1 shows fracture probability vs impact time of the coatings obtained with 150 mN load for 600s using a Berkovich indenter. The figure shows the highest fracture probability of zero for TiN, 0.08 for TiN/NC and 0.56 for NC, concluding their performance order as TiN >TiN/NC > NC.

Table 1 shows the mechanical properties of the coatings evaluated by nanoindentation using Berkovich indenter with 250 mN load. The conflicting reports notwithstanding over attributes of H, E, H/E, E/H and H3/E2 that influence the wear resistance of the coatings, based on our earlier experience, E/H has a major effect on performance order of the coatings during the nanoimpact test. The order of the performance with respect to E/H, Wp, Wt, and hr/hmax, indicating plastic deformation, as TiN > TiN/NC > NC, is found to directly correlate with their nanoimpact performance. TiN, which is relatively more plastic (with hr/hmax = 0.77) has performed better than the less plastic NC (hr/hmax = 0.66) coatings. The intermediate performance of TiN/NC (with hr/hmax = 0.73) is expected because it has shared plastic and elastic behaviours of both TiN and NC coatings, respectively. However, the order in their elastic properties such as elastic work of indentation, We and elastic displacement, hmax-hr, have inverse relation with that of their fracture probability.

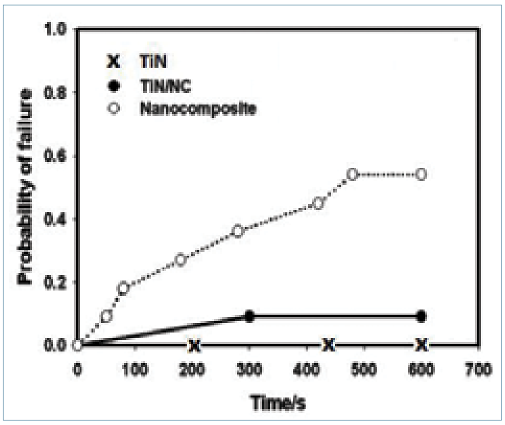

Fig. 1 Fracture probability of PVD coatings indicating the order of performance as TiN>TiAlN/NC>NC

Table 1 Mechanical properties evaluated from nanoindentation for all the PVD coatings, their definitions and order of values

Coating/ Property	TiN	TiN/NC	NC	Property, in the order of coatings	Property meaning
Fmax (mN)	250	250	250	TiN=TiN/NC=NC	Applied load
Hit (GPa)	28.2	35.7	43.4	TiN<TiN/NC<NC	Indent. hardness
HV (Vicker's)	2612	3312	4019	TiN<TiN/NC<NC	Equivalent Vicker's hardness
Eit (GPa)	608	599	504	TiN>TiN/NC>NC	Elastic modulus
E/H	21.6	16.8	11.6	TiN>TiN/NC>NC	Parameter used in fracture toughness
H/E	0.05	0.06	0.09	TiN<TiN/NC<NC	Elastic strain to failure
H^3/E^2 (GPa)	0.06	0.12	0.32	TiN<TiN/NC<NC	Resistance to plastic deformation
S (mN/nm)	1.47	1.29	1.05	TiN>TiN/NC>NC	Stiffness
Wp (pJ)	41290	32714	27954	TiN>TiN/NC>NC	Plastic work of indentation
We (pJ)	23589	30357	34241	TiN<TiN/NC<NC	Elastic work of indentation
Wt (pJ)	65150	63071	62195	TiN>TiN/NC>NC	Total work of indentation
hmax (nm)	750.4	706.8	701.7	TiN>TiN/NC>NC	Maximum depth of indentation
Ap ($x10^5 nm^2$)	88.5	69.8	57.6	TiN>TiN/NC>NC	Contact area
hr or hf (nm)	580	513	464	TiN>TiN/NC>NC	Residual/Final depth of indentation
hr/hmax	0.77	0.73	0.66	TiN>TiN/NC>NC	=1 for pure plastic materials =0 for pure elastic materials
hmax-hr (nm)	169.6	193.4	237.2	TiN<TiN/NC<NC	Elastic displacement while unloading

Contributor: P. Suresh Babu

Correlative microscopy of advanced materials

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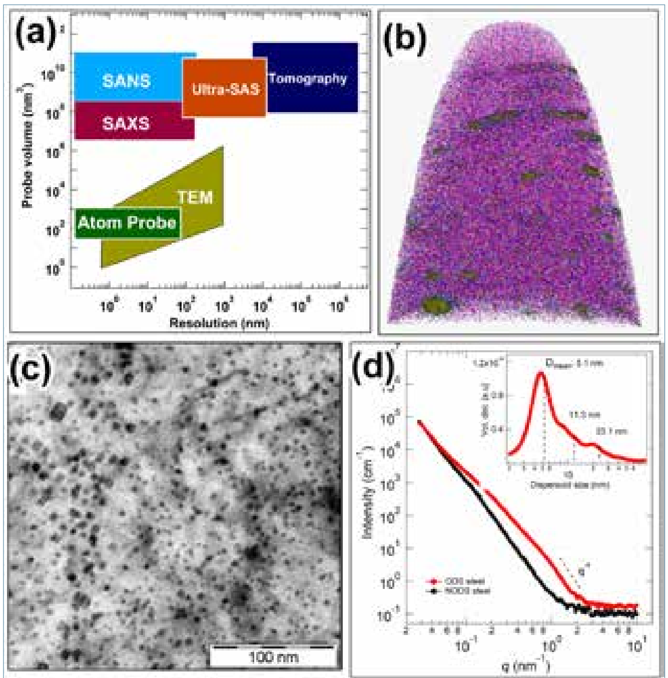
Dispersion of secondary phase particles (precipitates/ dispersoids) at the nanometer length scale is an effective way to develop ultra-high-strength alloys and is called dispersoid strengthening. The mean inter-precipitate distance of dispersoids ⟨d⟩ is important since the strength increases with the decrease of ⟨d⟩. Therefore smaller ⟨d⟩ is required, which is determined by the size of the precipitates: smaller the precipitate size, lower the ⟨d⟩. Ideally, the size and volume fraction of dispersoids should be a few nanometer (≤ 5-10 nm) and ≤ 2%, respectively.

Conventionally, transmission electron microscopy (TEM) has been the most common technique to study dispersoid microstructure. Recently, atom probe tomography (APT) is being regularly applied to study the precipitate features, and additionally, the chemistry of dispersoids is being obtained with ever-increasing precision. The other method, called small angle scattering using X-rays or neutrons, can also be used to study precipitate features. TEM, APT and SAS are complementary techniques to one another. TEM and APT are direct space measurement techniques with limited probing volume confined to a few hundred nm^3, while SAS is a non-destructive technique that probes an ensemble average of structural information over a macroscopic region (almost three to five orders of higher volume than that examined by the TEM and APT) (Fig. 1(a)). Therefore, information obtained from SAS is statistically significant and is representative of the microstructural features of the bulk volume of the specimen under investigation.

SAS is a diffraction (reciprocal space) based method that requires a model to extract the microstructural features, the inputs to which are the shape and chemistry of the precipitates. Since the scattering intensity is very sensitive to the local chemical fluctuations (average electron density variation/ scattering contrast) ($I(q) \propto |\rho_{pre.} - \rho_{matrix}|^2$), it requires a knowledge of the chemistry of the precipitates, which can be obtained from the APT studies. TEM, being a real space imaging technique, provides the shape of the precipitate. Considering the merits and limitations of each technique, correlative microscopy that is carried out by combining TEM, APT and SAS data would be the optimum method to obtain statistically average precipitate features; thus, it is representative of bulk microstructural features.

We have carried out correlative microscopy using the combination of TEM, APT, and SAXS techniques on oxide dispersion strengthened 18CrODS steel to characterize the dispersoids for their size, number density and volume fraction (images shown in Fig. 1(b-d)). Shape and crystal structure of the dispersoids have been obtained by imaging and diffraction from TEM, and chemistry was obtained from APT studies. Based on TEM and APT studies, scattering contrast length density was calculated and through a model fitting of the SAXS data, the size, number density, and volume fraction were obtained and are given in the table (part of Fig. 1). The table also summaries dispersoid parameters obtained from TEM and APT, which agree with each other. Therefore, correlative microscopy performed by combining local probing techniques (TEM and APT) with a global probing technique (SAS), provides accurate information regarding the features of precipitates/dispersoids, which is not possible from the individual methods.



(e)

Technique	Size ⟨D⟩ (nm)	Number den. (d_N) (m^{-3})	Volume frac. (f) (%)
TEM	5.4 ±2.4	1.12×10^{23}	0.96
APT	3.3 ±1.0	1.15×10^{23}	-
SAXS	5.1 ±0.7	1.03×10^{23}	1.07±0.1

Fig. 1 (a) Probe volume with resolution for different techniques, and (b) 3D-atomic distribution map (c) TEM-BF micrograph, (c) SAXS profile with (inset) size distribution of the complex oxide dispersoids in 18Cr-ODS steel. The table summarises parameters of the dispersoids by the TEM, APT and SAXS techniques

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3D atom probe tomography observations of additively manufactured IN718

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Metal additive manufacturing (AM) was adopted by the aerospace industry soon after the advent of the technique due to the freedom it offers in creating components with novel designs, which was hitherto not possible with conventional manufacturing routes. the powder bed fusion (PBF)-based additive manufacturing technique is the most widely used due to is superior control in creating intricate shapes with fine surface finish. IN718 is one of the prominent aerospace alloys, and due to its good weldability, it is the most studied alloy with respect to metal additive manufacturing. IN718 is a Ni-based alloy with Cr, Fe, Nb, Al ,Ti and C as prominent alloying elements. Fe, Cr and Mo dissolve in the matrix and thus provide solid solution strengthening. The maximum operating temperature of this alloy is around 650°C and thus it needs resistance to creep deformation and also to high temperature oxidation and corrosion. IN718 owes its superior high temperature mechanical behavior to γ" and γ' precipitates. γ" is Ni_3Nb with DO_{22} structure and γ' is $Ni_3(Al, Ti)$ with $L1_2$ structure. IN718 powder has been synthesized in ARCI using inert gas atomization, which is further classified to make it suitable for PBF-AM. IN718 coupons were built using the technique. During processing the powder gets melted and quickly gets solidified due to the rapid heat removal through the surroundings. Fig. 1A shows the SEM image of the as-built IN718. It can be observed that the solidification takes place by formation of dendrites. During such solidification of IN718 due to negligible solubility of Nb and Mo in Ni, these elements along with C segregate into interdendritic region and form the Laves phase and NbC. The former is primarily Fe_2Nb with hexagonal closed packed structure. Since the partition coefficient of Ni and Cr is close to unity, both the elements are also present in the Laves phase. It was thought that both the elements assume Fe site in the Laves phase. In order to understand the chemistry of the Laves phase, energy dispersive spectroscopy (EDS) was carried out in a transmission electron microscope (TEM). Fig1B shows the TEM bright field image, with the spectrum in the inset. For unambiguous elemental quantification of the Laves phase, 3D- atom probe tomography (3D-APT) has been carried out. Tips for atom probe study were prepared using FEI-Helios cross beam system with tip axis perpendicular to the dendrite axis. Atom probe tomography was carried out using the Cameca system at the National Facility for Atom Probe Tomography (NFAPT) at IIT Madras. Fig. 1C shows the Ni, Nb, Fe and Cr 3D elemental maps thus determined. An iso-concentration surface was developed using Nb in order to generate the Lave phase shape within the tip. A cylindrical ROI was created within the Laves phase and the composition was determined, which can be seen in Table 1. From the composition, it can be said that Cr shares Fe sites in the Laves phase and Ni gets partitioned between the Fe and Nb sites.

Table1 Composition of the Lave phase from 3D-APT

Ni	Fe	Cr	Nb	Mo	Al	Ti
39.08	16.78	16.81	20.17	3.19	0.79	1.75

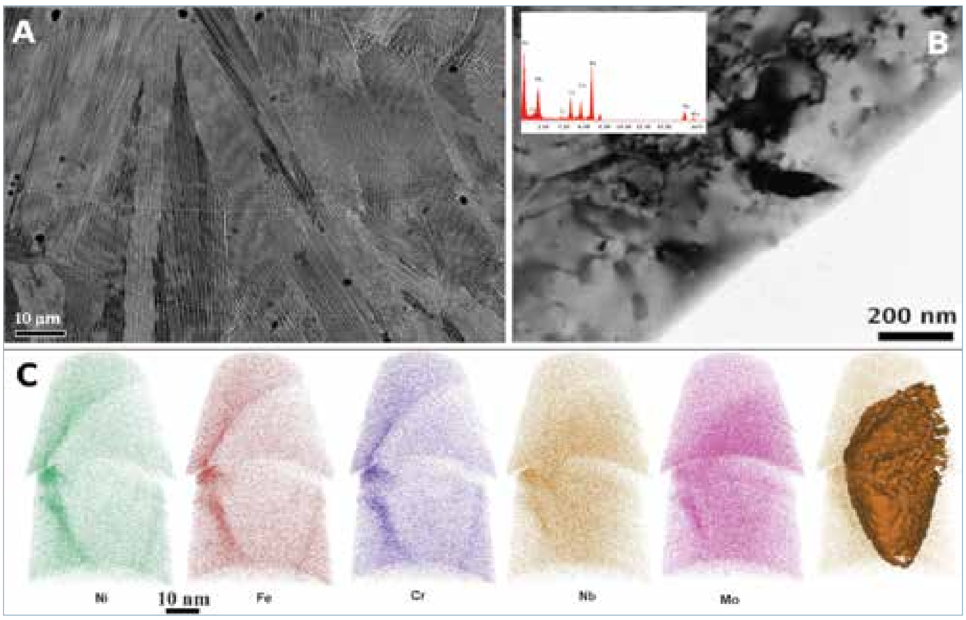

Fig. 1 A) SEM image depicting dendritic structure in As-built IN718. B)TEM BF image showing Laves phase particle (rounded) with the EDS spectrum from the particle as inset. C) Elemental map generated using 3D-APT along, the last image is Nb map along with iso-concentration surface

Contributor: G. Padmanabham

Microstructural evolution during high temperature exposure of cold sprayed composite coating

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Nickel chromium-chromium carbide (NiCr-Cr_3C_2) composite coatings exhibit superior oxidation resistance compared to the commonly used WC-Co composite coatings at temperatures above 500ºC. The usual methods of deposition of such coatings are thermal spraying and laser cladding. In this study, we have used an alternative method called cold spraying, a variant of the former, to coat composite materials. Further, improvement in bonding state was studied after heat treatment.

The bonding mechanism in cold spraying is by plastic deformation and hence ceramics cannot be coated by cold spraying due to lack of plasticity. To overcome this situation, ceramic Cr_3C_2 particles encapsulated by a metallic layer were blended with metallic NiCr to successfully deposit thick coatings.

From Fig. 1 (a), it is seen that although the coating is dense, the splat boundaries are distinct and the carbide particles are fractured. Fig. 1(b) shows the microstructure of the coating heat treated at 1000ºC for 2h, from which the following changes can be seen: (a) Fractured carbides in the as-coated structure appear to have got welded more or less completely; (b) There is depletion of carbon around the periphery of the carbide particles, and c) Small new carbides have precipitated in the matrix.

Phase identification was carried out by electron back scattered diffraction (EBSD) and the results are shown in Fig. 2. It can be seen clearly that there is a phase change due to the loss of carbon from the periphery of the carbide particles. The interior of the carbide grain is orthogonal single crystalline Cr_3C_2, whereas the grains at the periphery of the carbide particles are hexagonal polycrystalline Cr_7C_3. The newer finer carbides that precipitate are also hexagonal Cr_7C_3. The matrix has cubic Nickel structure with annealing twins.

On heating, there is diffusion of carbon from the carbide particles into the nickel-rich matrix, which continues with time, and the periphery of the carbides gets depleted of carbon. This results in the phase change of high carbon Cr_3C_2 to low carbon Cr_7C_3. The solubility of carbon in nickel at room temperature is negligible but with increasing temperature, increases to a maximum of 2.7 atomic % at 1326ºC. Therefore upon cooling, the Nickel-rich matrix would be supersaturated with carbon and these carbides would come out of the solution. The presence of 20 weight% chromium and its very high affinity to carbon results in the formation of Cr_7C_3 type chromium carbide, which is also thermo-dynamically the most stable form among chromium carbides.

In conclusion, metal matrix composite coating using chromium carbide ceramic was successfully deposited using cold spraying. Post heat treatment considerably improved the bonding state of the coating. The effect of phase changes on the functional properties observed after heat treatment is part of future research of this group.

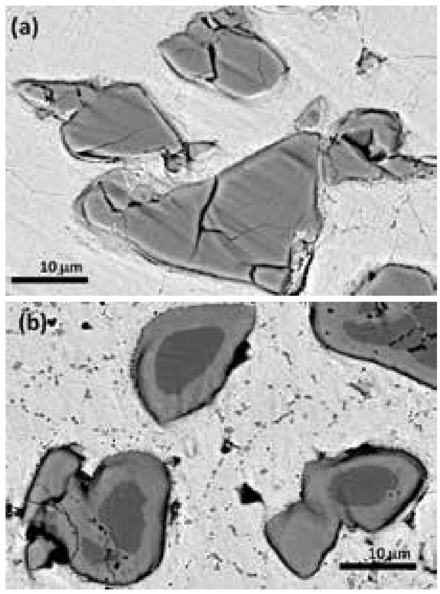

Fig. 1 Backscattered electron images showing (a) As-coated microstructure and (b) Microstructure after heat treatment at 1000ºC

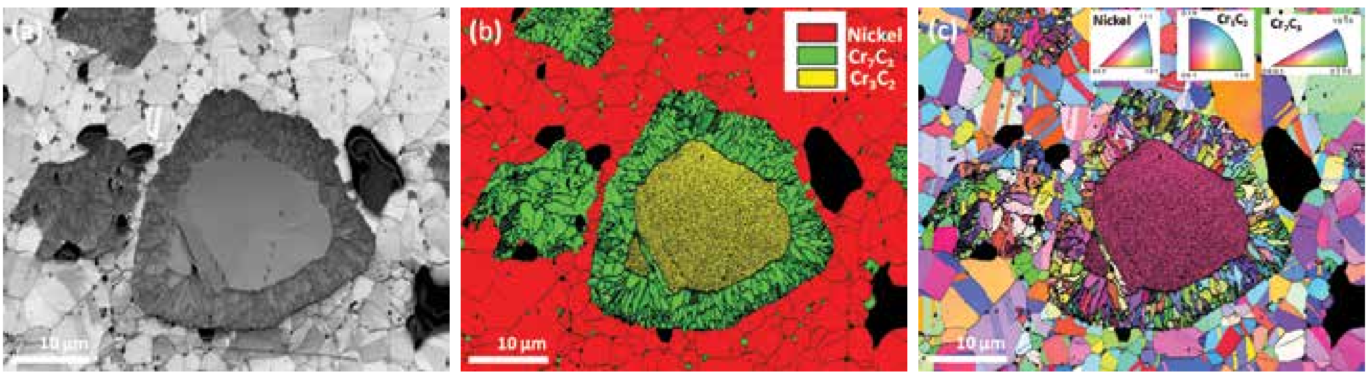

Fig. 2 EBSD images of coating after heat treatment at 1000ºC: (a) Image quality map (b) Colour coded phase map (c) Inverse pole figure map of all phases

Contributor: S. Kumar

Comparison of Electrochemical performance of Ni based coatings by Plasma and D-Gun techniques

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T91 steel is a typical material used in coal fired boiler applications. It is a low carbon ferritic-martensitic steel containing 9% Cr and 1% Mo used in critical boiler parts like super-heater and reheater tubes. This grade of steel is often affected by a type of high temperature alkali salt-induced corrosion called 'Hot corrosion' or 'Fireside corrosion'. Alkali chlorides/sulphates like Na_2SO_4, K_2SO_4, KCl and NaCl which are produced during the combustion of low quality coal aggravate the corrosion process by dissolution of any protective scale formed by the steel. Hence, protective coatings that are capable of forming chromia and/or alumina scales are mostly used on these boiler steel materials. Thermal spray techniques are widely adopted to provide the coatings. In this study, two thermal spray techniques, namely Atmospheric Plasma spray (APS) and Detonation spray (D-gun) were used to deposit four different coating compositions on T91 steel. The coatings were nickel and cobalt based ones with varying amounts of Cr:Al ratio. Room temperature DC electrochemical corrosion tests were conducted to study the performance of these coatings in a Na_2SO_4 salt solution. This enables us to compare the room temperature corrosion results with the corresponding results of traditional High temperature hot corrosion tests and look for possible correlations.

Potentiodynamic polarization tests were carried out using an electrochemical interface (Solartron SI 1287) after 1hr exposure to 3.5% Na_2SO_4 solution. A three-electrode cell with the sample as working electode, platinum as counter electode and standard calomel electrode as reference (SCE) were used. A potenial range from -1V to +2V was applied against SCE and the current obtained was recorded. The polarization plots recorded are shown in Fig. 1. The data is analysed by Rp fit method and the corrosion potentials (E_{corr}), current densities (I_{corr}), polarisation resistance (Rp) and corrosion rates obtained are shown in Table.1.

From the results, it is evident that all the coatings have performed well in resisting the corrosion process and hence have a lower corrosion rate than the corrosion rate of uncoated T91 steel. Kinetic energy is more in case of D-gun whereas thermal energy is more in case of APS, due to which defect density will be higher in D-Gun coatings (due to partial melting). Because of this effect, area of interaction with electrolyte will be more and the formation of a well-established passive layer by corrosion products is observed. As there js a higher number of defects in D-Gun coatings, the corrosion potentials are more negative compared to those of APS coatings. Due to high temperature oxidation, stoichiometry of the coating drastically varies, resulting in a higher corrosion rate in case of all the three coatings except NiCr of APS coatings. In the case of NiCr, APS coating has shown better corrosion resistance as compared to coatings deposited by than that of D-Gun.

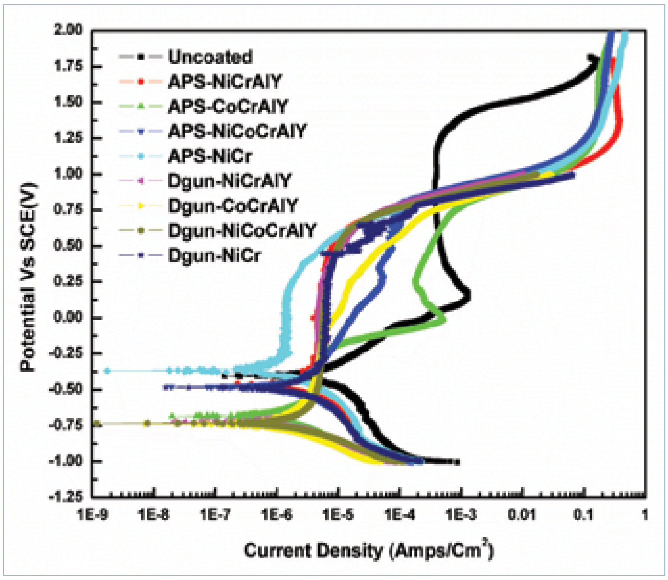

Fig.1 Potentiodynamic polarisation plots of APS and D-Gun coatings

Table.1 Results obtained form polarisation graphs

Coating Technique	Coating	E_{Corr} (V Vs SCE)	R_p (Ohms. cm^{-2})	I_{Corr} (Amp. cm^{-2})	Corrosion Rate (Mils/ year)
Uncoated T91		-0.402	7601	3.43×10^{-6}	1.5
APS	NiCrAlY	-0.469	16570	1.57×10^{-6}	0.593
D-Gun	NiCrAlY	-0.722	24872	1.05×10^{-6}	0.374
APS	CoCrAlY	-0.681	30262	8.62×10^{-7}	0.329
D-Gun	CoCrAlY	-0.739	34249	7.62×10^{-7}	0.275
APS	NiCoCrAlY	-0.477	21985	1.19×10^{-6}	0.459
D-Gun	NiCoCrAlY	-0.732	20237	1.29×10^{-6}	0.472
APS	NiCr	-0.360	35215	7.41×10^{-7}	0.320
D-Gun	NiCr	-0.485	17205	1.52×10^{-6}	0.620

Contributors: G. SivaKumar and C. Sundaresan

Microstructural study of Medium Entropy MoNbTaW Refractory Multi-Component Alloy

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In the past two decades or so, a new class alloys has emerged where the constituent metals are in equiatomic or nearly equiatomic ratios. These multicomponent alloys (MCAs) are also termed as high entropy alloys when the number of elements is five or more. Basic laws governing the properties of MCAs are as follows: (1) High entropy effect, where the maximum entropy decreases the Gibbs free energy to form a solid solution and suppresses the formation of intermetallics (2) Solid solution strengthening induced by lattice distortion, (3) Sluggish diffusion explaining the high-temperature structural stability of the alloy and (4) Cocktail effect which enhances the properties of the alloy in comparison to the individual metallic constituents. Based on entropy, alloys are classified as low ($\Delta Sconf < 0.69R$), medium ($0.69R \leq \Delta Sconf \leq 1.61R$), and high entropy ($\Delta Sconf > 1.61R$) where $\Delta Sconf$ is the configurational entropy and R is the Universal Gas Constant.

MCAs are expected to possess enhanced properties compared to conventional alloys. If we consider entropic materials like a multi-fruit tree as shown in Fig. 1(a), each fruit pertains to the specific property of the material. Researchers can select elements from the periodic table according to property requirements. One of the subgroups is a set of refractory multicomponent alloys comprising of high-temperature materials having melting point greater than 2000°C, with the potential for use in the aerospace industry where high temperatures and stresses are present. These high-density refractory alloys can also be used in ballistic applications.

We have synthesized the MoNbTaW refractory MCA by vacuum arc melting. The calculated entropy of this alloy is 1.386R, which falls under medium entropy alloys. Rapid solidification concomitant with the technique leads to the formation of dendritic structure. To reduce the dendritic microstructure, thermo-mechanical processing (TMP) was performed at 1000°C and the samples were homogenized at 1400°C for 20hrs. Fig. 1(b) shows the X-ray diffraction patterns, from which it can be seen that the alloy forms as a single phase solid solution with the body centred cubic crystal structure. A small fraction of niobium oxide that may have formed due to the adsorbed oxygen in the starting powders can also beobserved from the patterns. Field Emission Scanning Electron Microscope images were used to quantify the volume fraction of dendritic region and niobium oxide using Image j analysis software. Energy Dispersive Spectroscopy (line analysis and elemental mapping) was used to detect the presence of niobium oxide in the matrix. TMP of as-melted sample eradicated the dendritic microstructure and induced strain by the pile-up of dislocations. The volume fraction of niobium oxide also increased from 1.6% to 2.8% after this step. During homogenization, the highly strained regions relieved the strain by recovery and formed strain-free new recrystallized grains near to niobium oxide particles and grain boundaries, which can be seen in the crystal orientation map (COM) in Fig. 2(a). The criteria chosen for recrystallization studies are that the grain size should be greater than 3µm and the orientation spread within the grain be ≤ 0.75°. The colored grains shown in Fig. 2(b) are the recrystallized grains generated by following the above criteria and colors of grains indicate grain orientation spread not the crystallographic orientation. The fraction of recrystallized grains is determined to be 10%. The hardness of the TMP sample increased due to strains inside the material compared to as-melted and homogenized condition.

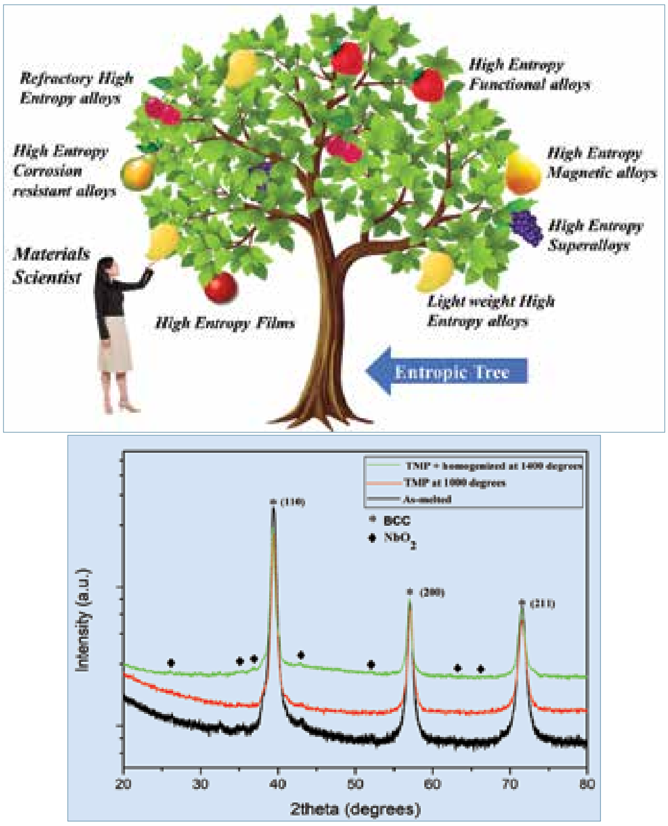


Fig. 1(a) Entropic tree showing the development of advanced materials (b) X-ray diffractograms of MoNbTaW alloy

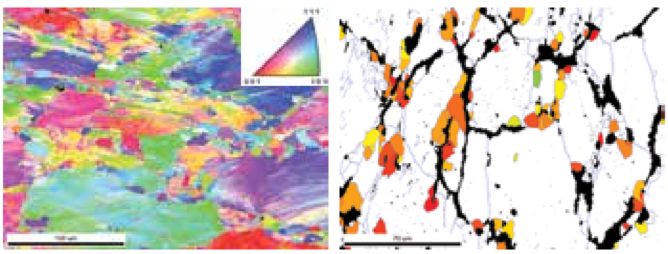
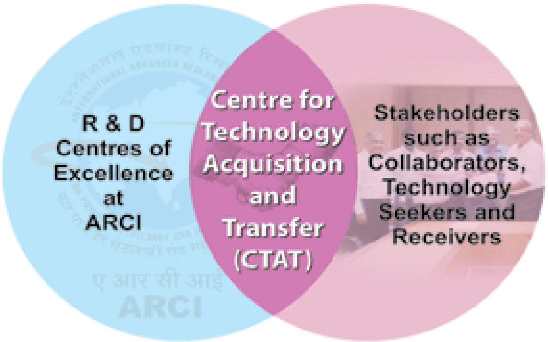


Fig. 2(a) Crystal orientation map of the sample that was thermomechanically processed followed by homogenization (b) Recrystallized grains after homogenization

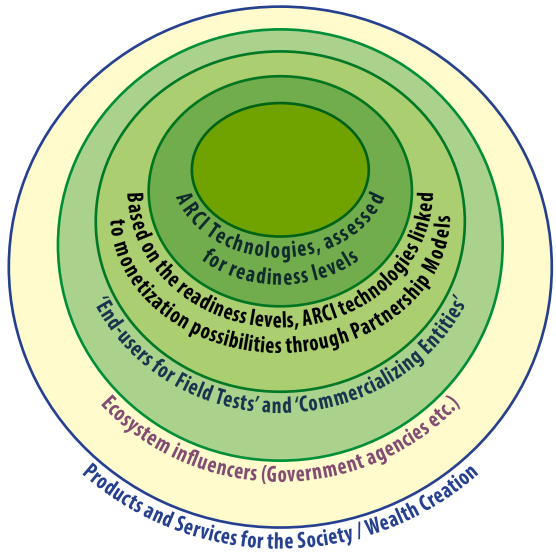
Contributor: Anjali Kanchi

Centre for Technology Acquisition and Transfer



CTAT: Interfacing between R&D and external stakeholders

Centre for Technology Acquisition and Transfer (CTAT) acts as a bridge between the technology groups of ARCI and the external entities for the purpose of technology development as well as transfer to enable successful translation of research in to technology. The centre has been adding value in the Research to Technology Chain (RTC) for progression of R & D projects from IPDI 1 to IPDI 10, as mentioned in the write-up titled "Intellectual Property Development Indices (IPDI)-based Collaborative and Technology Transfer Models" of this Report.



Conceptual Representation: Approach adopted to translate ARCI IP into useful products/services

Accomplishments:

* *Structured, negotiated and/or finalized Agreements: 18 (including aspects such as responsibility matrix/milestones linking to financials/ know-fee and royalty/exclusivity-nonexclusivity and variants/IP rights creation, ownership and grant conditions depending upon the partnership situations etc.)*
* *Leads generated for collaborations/technology transfer: 71 (through various outreach and marketing efforts such as participation in 13 exhibitions/seminars/workshops, delivering invited lectures, making presentations, panel discussions) leading to signing of 53 NDAs*
* *Costing for projects/technologies: 53*
* *Reports generated for market evaluation, R&D planning and patenting: 39 (using patents/literature/business information)*
* *Indian patents granted/filed: 16*
* *Database of prospective industrial partners created: 700+ Companies*

Some of the important engagements realized are:

Collaborative Research and Technology Development Agreements/ MoUs Topics:

- *Materials synthesis and processing technologies*
- *Mn-Zn-Ferrite core shell based soft magnetic composites using Fe customer supplied powders for futuristic magnetic applications*
- *Delivering work packages under the Thirty Meter Telescope Project*
- *Setting up of demonstration Lithium-ion battery (LIB) production facility*
- *Novel Eco-friendly nano-composite coatings for prevention of surgical site infections*
- *New Aluminum Alloy development for Additive Manufacturing for Industrial Application in the Italian and Indian Markets*
- *Zn/Zn-Ni/Zn-Fe reinforced nanocomposite coatings using pulsed electro deposition*
- *PV system integrated PEM based hydrogen generator for energy storage applications*
- *Facility establishment and realization of low expansion glass-ceramic (LEGC)*
- *Pilot scale facility for the scale up and production of 1 kW * 10 capacity building solid oxide fuel cell stack facility*

Technical Services:

- *Conference on 'Application of Lasers in manufacturing concurrent to Laser World of Photonics India 2019'*
- *Industrial Design for ARCI's Fuel Cell System*
- *Procuring Electron Beam Melting (EBM) and its associated items, Product support (equipment-hardware & Software) and professional services relating to additive manufacturing, Master Consultancy Services to provide additional training on using EBM for advanced materials through EBM Materials Development Workshop*

MoU with DST including Performance Indicators:

- *Performance on key selected parameters against the targets*

Other Enabling Activities:

- *Provided inputs to R & D groups for possible steps in bringing down the cost of technology-derived products/services.*
- *Project Management System developed to capture the technical and financial information of Sponsored projects*

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Intellectual Property Development Indices (IPDI) - based Collaborative and Technology Transfer Models for an R & D Organization

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R & D organizations, mandated to transfer their results, need to find ways to experiment not only with the products and processes but also with the innovative partnership models to effectively and efficiently leverage the research results. Partnership models are necessary to access the complementary resources and capabilities available beyond the conventional boundaries of a lab. New technologies should be developed and judiciously field tested to buy options for the future for eventual commercialization/ monetization. Business models used to develop, demonstrate and commercialize technologies greatly influence the extent to which these technologies can be utilized/exploited/put to use. Therefore, prototyping and experimentation with novel partnership models, including refinements from experience derived by usage of such models, have to be continuously attempted to strengthen the Research to Technology Chain (RTC) of technology development, demonstration, transfer and commercialization.

For well-considered decision making towards appropriate R & D collaborations and technology transfers/business model suited to an ongoing technology programme, the process from conceptualizing an R & D project to technology transfer is captured through Intellectual Property Development Indices (IPDIs) from level 1 to 10. Detailed chart is shown in the next page. ARCI has been assessing its R & D programmes at periodic intervals. Value addition needs, including external partnerships to leverage synergistic capabilities of diverse organizations, are identified for each R & D project based on its IPDI level. Simultaneously, efforts are made to identify the organizations which can potentially benefit from ARCI's knowledge-base. In some cases, IPs not otherwise used are coupled with the ongoing research work in other academic institutions/R & D organizations, and in other cases, IPs may increase their chances of commercialization if they find industrial organization(s) which can envisage their commercial potential. Several alternatives are being continuously conceptualized so that R & D at different IPDI levels can find utility in potentially high-growth markets/social use/national priority areas. Accordingly, patent portfolio strategy associated with a technology, for target application(s)/markets, is also pursued. Envisaging the possible newer applications/ markets for a technology and optimization to realize the targeted applications become a key towards enhancing the value of a technology. And this dictates the focus of technology development efforts. Envisaged technology–application connections also require different roadmaps, inter-relatedness with other parts of a system and disparate collaborative models. While progressing from IPDI 6 to 8, aim is to tap the perspectives of users'/external organizations for debugging the prototypes before technology transfer followed by the launch of technology-based products by the technology recipient company. After IPDI 8, efforts are directed to accelerate the technology transfer by associating with a commercializing entity.

To facilitate the above requirements, ARCI has created flexible engagement models envisaging multiple partnership situations including field tests in diverse user domains like aerospace, power, alternative energy, automotive, manufacturing, oil & gas, healthcare, electronics, textiles, architectural, water and several others etc. as well as technology transfer to commercializing entities (start-ups/established companies etc.). And these formats are continuously being evolved to gainfully engage with relevant stakeholders. A Collaborative/Technology Transfer model is chosen based on identified needs, decided as per the IPDI assessment of an R & D project.

Salient features of the IPDI-based Collaborative and Technology Transfer (CTT) Models are as follows:

- Consideration of the sector specific characteristics addressing the nuances of innovations in materials science / applied research and development.
- Assist an R & D lab in what and why aspects of crucial decision points during the process of technology development, demonstration and transfer, thereby providing systematic approach to partnering in the RTC
- Help in optimum utilization of available intellectual capital by enhancing its impact.
- Identification of the value addition requirements/support systems/complementary capabilities for progression of an R & D project from one level to the next.
- Imparting flexibility to engage industry collaborators / potential technology receivers / academic / R & D organizations at any stage from ideation to the time, when technology is ready for commercialization.
- Help to devise a clear roadmap with milestones, understandable by ARCI and the partner organization(s), from `the point of initiating partnership' to `the point of envisaged objective', logical estimation of financial aspects based on the milestone-linked-deliverables as well as IP sharing and utilization strategy.

In summary, IPDI approach immensely helped in articulating a Technology Development Roadmap including possible challenges, formulate strategies to address such bottlenecks and also chose appropriate engagement models with industrial or R & D partners. For example, while progressing from IPDI 6 to 7, the aspects to be covered included: application development plan, competition assessment, collaborators' identification, cost competitiveness efforts, supply chain assessment, patent portfolio strategy, required validations, safety, health and environmental (SHE) issues associated with the future commercialization, and outreach/ technology transfer efforts.

Contributor: G. Padmanabham

Fig. 1 Schematic showing IP Development Indices (IPDI), milestones, engagement models and role of CTAT

IPDI →	1	2	3	4	5	6	7	8	9	10
Activities →	Basic concepts and understanding of underlying scientific principles	Shortlist possible applications	Research to prove technical feasibility for targeted application	Coupon level testing in simulated conditions	Check repeatability/ consistency in lab at coupon level (miniaturized version of actual component)	Prototype testing in real-life conditions	Check repeatability/ consistency in field/real-life conditions	Reassessing feasibility (IP competition technology, commercial)	Initiate technology transfer	Support in stabilizing production
IP Chain Milestone(s) →	Exploratory studies		Laboratory testing			Field demonstration			Technology transfer	
Engagement models (collaborative and /or technology transfer) to address different partnership situations →	• **Cooperative R&D:** ARCI associates with an industrial organization for the scientific and technical conduct of a project • **R&D Consortium:** ARCI collaborates with academic institutions, other R & D organizations and industrial organization(s) to find innovative solution(s) that can potentially benefit an industry sector • **Inter- Institutional:** ARCI collaborates with academic or R&D institute to take the exploratory research forward • **Sponsored R&D:** ARCI undertakes sponsored projects funded by government agencies • **Contract R&D:** ARCI undertakes contract R&D projects from private agencies • **Technical Service:** For a transaction to access/ provide available capability					• **Joint Demonstration:** ARCI and partner organization work towards field trials/ demonstration followed by joint efforts towards technology transfer to third parties • **Technology Demonstration and Transfer:** ARCI demonstrates a technology for the applications of interest to a potential technology seeker and subsequently transfers the technology • **Knowledge Transfer:** Knowledge gathered about a process / product is transferred to interested seekers • **Option:** An industrial organization can decide about possible licensing after conducting field tests • **Product Supply for Niche Uses:** Limited supply of products from a technology is undertaken for niche applications • **Technical Service:** For a transaction to access/provide available capability			• **Option:** Though technology has reached upto IPDI 8, potential commercializing entity can engage to conduct field tests for identified applications • **Technology Transfer:** This engagement model is appropriate for technologies which have reached the IPDI 8	
Role of CTAT →	• Competitive intelligence • Identification of possible collaborators • Selecting appropriate engagement model (decision variables, IPDIs, collaborators, IP ownership & licensing methodology, deliverables, milestones, financial etc.) • Negotiating and finalizing Collaborative and / or Technology Transfer Agreements					• Activities mentioned from IPDI 1 to 5 • Preparing status reports on ongoing R&D projects and using them for IP/technology marketing efforts • Feasibility assessment • Costing of technologies and projects			• Activities mentioned from IPDI 1 to 8 • Receivable management (collection of technology transfer fees/royalties) even beyond IPDI 10	

Securing Patent Protection in Foreign Territories

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Intellectual property is a form of property created by the human mind. This creativity could be in the form of a work of art (paintings, musical notes), literature, designs or scientific inventions. Intellectual property can be protected as copyrights, trademarks, patents, industrial designs, geographical indications etc. Among all forms of intellectual property rights, patent right is very significant for the scientific community.

Patent is an exclusive right granted to an inventor for excluding others from practicing his/her invention without consent. Generally, the life of a patent is 20 years from the date of filing (priority), provided maintenance/ renewal fees are paid to the patent office as prescribed. Patent right is territorial in nature, i.e, if a patent is granted in India; the inventor can exclude others from exploiting his/her invention only in India. In the Indian context, for an invention to qualify as a patent, it should be novel, have an inventive step and must have industrial utility.

A worldwide valid patent does not exist, in other words there is no single application through which patent protection is granted in all countries of the world. An application should be filed only in those countries where patent protection is required. The reasons for filing of foreign patent application could be many and varies from person to person and entity to entity. For example, a newly developed process or product for which patent application has been recently filed in India, it would be beneficial to seek protection in those countries where it is likely to be exported, marketed, manufacturing plants are going to be set-up, collaboration prospects are promising or it could be to eliminate competition.

The two most common modes of patent filing abroad by claiming priority of the Indian patent application are 1) Conventional Route and 2) Patent Cooperation Treaty (PCT) Route. Conventional Route: India being a member of the Paris convention, can file patent applications in the member countries (within 12 months of priority). PCT Route: As on April 01, 2020, there are 153 countries including India that are party to the PCT treaty administered by World Intellectual Property Organization (WIPO) having its headquarters in Geneva, Switzerland. Indian patent office is now designated as one of the Receiving Offices (RO) for a PCT application. That means, if an applicant desires to file a PCT application, it could be done at the Indian patent office. PCT application should be filed within 12 months of filing the Indian patent application. The main advantage through PCT route is that this process usually gives the applicant a time of 30 months from the priority date to choose the countries to pursue the patent application. However, it is advisable that the applicant makes the choice of countries well in advance i.e., before the dead line of 30 months. Generally, for most countries the deadline for entering national phase is 30 months with a few exceptions.

An applicant who plans to seek patent protection in multiple countries, but has not yet decided in which countries to file due to various reasons, choosing the PCT route may be beneficial as it a) facilitates processing in multiple countries with a single (PCT) patent application and b) it also gives the additional time to choose the countries. An appropriate mode of filing is adopted at ARCI. However, granting a patent is completely up to the national patent offices of the respective countries.

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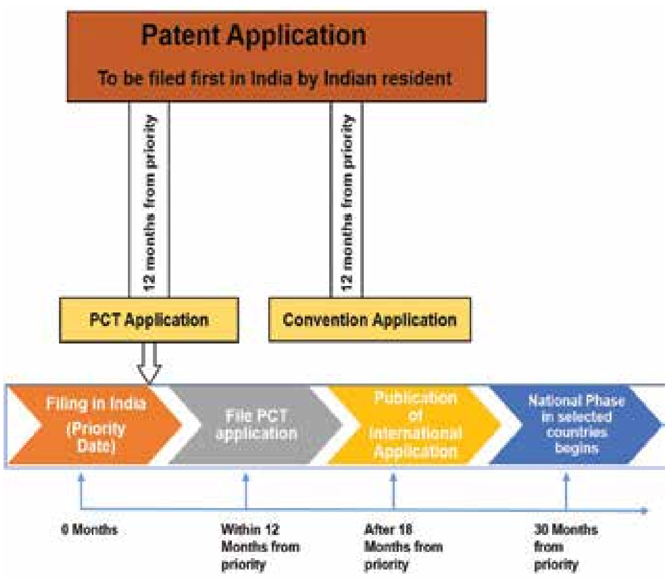

General Timeline Flowchart to file abroad

Contributor: K. Swati (Associate)

Strategy for Linking Solar Energy Based Technologies with Potential Commercialization Opportunities

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The emergence of new solar energy technologies has been a potential game changer in the modern era of power generation. ARCI has developed materials-based technologies for solar photovoltaic (PV) and solar thermal domains. Centre for Technology Acquisition and Transfer at ARCI is implementing a well-considered strategy to promote solar energy based technologies. Few technologies, which were successfully promoted in different industrial sectors, are as follows:

Easy-to-clean (Self-cleaning), Super-hydrophobic Coating for PV Panels and other Applications

Key features are Low cost production, highly transparent coating, Super hydrophobic property (> 1100 water contact angle), High weather and mechanical stability and Low dust deposition compared to bare and other commercial coated sample.

<u>Strategy Used to Field test and Transfer the Technology</u>

Initially the technology's features and applications were studied to identify the potential users and commercializing entities from the following related patents:

1. A Super Hydrophobic Coating with High Optical Properties having Easy to Clean Property, UV and Corrosion Resistance Properties, a Process of Preparation and Application of the Same. Patent application no. 402/DEL/2014. Application Date: 12/02/2014 (Awaiting grant)
2. Ambient Condition Curable Transparent Super Hydrophobic Coating For Easy To Clean Applications and Method of Producing the Same. Patent application no. 201911009429. Application Date: 11/03/2019 (Awaiting grant)

Once the target audience was established, an exhaustive company database consisting of solar PV panel, glass (automotive and architectural) manufacturers was prepared. Companies in industry sectors such as solar panels, architectural and automotive glass, etc. were contacted. Overall, 18 companies showed interest and visited ARCI. The technology's features and application were then demonstrated in-house to these entrepreneurs.

The technology was demonstrated and transferred to a leading thermal power generation organization, who tested the PV panels at their site for more than a year without cleaning and observed 7.5% more power was generated for coated string of panels compared to that of uncoated string. In order to generate better validation test results under different conditions, ARCI demonstrated the robustness and capability of the technology to various companies and has obtained good results on PV panels on rooftops as well as ground level. ARCI also visited a leading glass manufacturer to understand their production activities and demonstrated ARCI's technology on their products.

Cost-efficient Solar Receiver Tube for Low and Medium Temperature Solar Thermal Applications

Some key features are: High selective properties (solar absorptance ~95%; spectral emittance ~0.12), Low heat loss property: ~0.14 at 250°C, Temperature stability: < 250°C, High corrosion resistance > 200 hrs withstands in salt spray test (ASTM B117), and High mechanical stability

<u>Strategy Used to Field Test and Transfer the Technology</u>

Initially the technology's features and applications were studied from the following patent portfolio so that organizations, for possible field trials and technology transfer, can be identified.

1. A High Thermal Stable Selective Solar Absorber layer with Low Emissive Barrier Coating over a Substrate and a Process of Producing the Same. Patent no. 323497. Date of Grant: 23/10/2019
2. An Improved Performance of Nanocomposite Oxide Selective Absorber Coating with Excellent Optical and Thermal Resistant Properties and Method of Manufacturing the Same. Patent no. 345443. Date of Grant: 28/08/2020
3. An Improved Solar Selective Absorber Coating with Excellent Optical Absorptance, Low Thermal Emissivity and Excellent Corrosion Resistance Property and a Process of Producing the Same. Patent application no. 1129/DEL/2013. Application date: 16/04/2013
4. Solar Selective Coating for Solar Energy Collector / Absorber Tubes with Improved Performance and a Method of Producing the Same. Patent application no. 2142/DEL/2015. Application date: 15/07/2015
5. Transition metal-based solar selective absorber coated substrate and method of manufacturing the same. Patent application no. 201911019139. Application date: 14/05/2019

Companies in industry sectors such as solar water heaters, solar drying and cooking equipment, industrial process heat application, power generation etc. were targeted to identify potential technology receivers. Once the target audience was established, an exhaustive company database was prepared. Overall 10 companies showed interest and visited ARCI. The technology's features and application was then demonstrated in-house to these entrepreneurs. The technology was demonstrated in-house and transferred to a startup company in the area of solar thermal application on non-exclusive basis. Recently, the technology which was field tested by another start up found the encouraging results and has shown interest to initiate technology transfer.

Contributors: Sanjay Bhardwaj and Abhishek Bethi (Associate)

Portfolio of ARCI Technologies

Technology Transfers Undertaken

Based on the perceived market size of products/ services based on ARCI technologies, ARCI has adopted exclusive and non-exclusive modes of technology transfer to facilitate healthy competition in the market. So far, ARCI has successfully transferred 20 technologies to 32 receivers and few technologies are under transfer. The following table depicts the technologies transferred:

S.No	Technology	Industry Targeted	Status
1-8	Electro Spark Coating (ESC) Equipment	Hard, wear resistant coatings	Transferred to 8 companies on non-exclusive basis
9	Magnesia Aluminate Spinel (MAS)	Steel, cement and power plants	Transferred on exclusive basis
10	Ceramic Crucibles	Carbon and Sulphur analysis	Transferred on exclusive basis
11	Energy Efficient Air Heaters from Ceramic Honeycombs	Industrial heating	Transferred on exclusive basis
12-15	Detonation Spray Coating (DSC)	Wear and corrosion resistant coatings on various components	Transferred to 4 companies on region exclusive basis
16	Reinforced Graphite Sheets and Seals	Automotive sector	Transferred on exclusive basis
17	Heat Pipes Heat Sinks	Waste heat recovery systems, solar energy applications, power electronics	Transferred on exclusive basis
18	Evaporation Boats	Metallization	Transferred on exclusive basis
19	Ceramic Honeycomb Molten Metal Filters	Molten metal filtration	Transferred on exclusive basis
20	Calcium Aluminate Cements and Furnace Sealants	Refractory castables	Transferred on exclusive basis
21-23	Micro Arc Oxidation (MAO)	Hard (1800 VHN) wear resistant coatings on Aluminum and Titanium alloys	Transferred to 3 companies on region exclusive basis
24	ESC Equipment Manufacturing	Diverse segments	Transferred on non-exclusive basis
25	Nanosilver Impregnated Ceramic Water Filter Candles to Impart Antibacterial Function	Water purification	Transferred on non-exclusive basis
26	Nanosilver based Textile Finishes for Antibacterial Applications	Anti-bacterial applications	Transferred on exclusive basis
27	Nanotitaniumdioxide based Textile Finishes for Self Cleaning Applications	Self-cleaning applications	Transferred on exclusive basis
28	Decorative Coatings on Glass	Aesthetic applications	Transferred on non-exclusive basis
29	Aerogel Flexible Sheet Technology	Thermal Insulation applications	Transferred on exclusive basis
30	Ceramic Honeycomb Based Energy Efficient Air Heaters and Eco-friendly Sanitary Napkin Incinerators	Incinerator Applications	Transferred on exclusive basis
31	Laser Cladding Technology for burner tip nozzles	Thermal Power Plants Applications	Transfer Complete
32	Development of super hydrophobic easy to clean coatings	Solar PV Panels	Transfer Complete
33	Low and medium temperature solar selective absorber coatings on SS 304 substrate	Solar Thermal Application	Ongoing
34	Pulsed Electrodeposition of Nickel Tungsten Alloy Coatings	Wear and Corrosion resistance applications	Ongoing

Technologies Available for Adaptation / Transfer

S. No	Technology and Related Issues	Key Features and Applications	
1.	**Ceramic Honeycomb Based Energy Efficient Air Heaters and Eco-friendly Sanitary Napkin Incinerators** IPDI: Technology Readily Available	**Key Features:** • Eco-friendly incinerator • Specially designed, honeycomb based, energy efficient air heaters • Generates > 850°C, which is mandatory to minimize production of dioxins and toxins while burning • Available with power rating 2kW and 4kW • Incineration can be done in batches • Compact in structure • One-to-one replacement of conventional heaters and retrofitting can be done • Energy savings up to 40% • Prolonged life by eliminating hotspots • Low thermal inertia and high coefficient of heat transfer offers higher efficiency	**Possible Applications:** • Industrial Heating such as confectionery industry, welding rod warmers, and large volume air heating, hot air ovens etc. • Sanitary napkin incinerator
2.	**Super Hydrophobic (Easy to Clean) Coating for Self-cleaning of PV Panels and Other Applications** IPDI: Initiate Technology Transfer	**Key Features:** • Low cost production (simple coating technique / easy scalable / curable by ambient temp.) • Highly transparent coating (no loss in transmittance / power conversion efficiency after deposition) • Super hydrophobic property: > 1100 water contact angle • High weather stability (withstand long duration accelerated test - IEC 61646 • High mechanical stability • Low dust deposition compared to bare and other commercial coated samples	**Possible Applications:** • Solar PV & CSP cover glass • Optical lenses • Video display panels • Architectural glasses
3.	**Cost-efficient Solar Receiver Tube Technology for Low & Medium Temperature Solar Thermal Applications** IPDI: Initiate Technology Transfer	**Key Features:** • High selective properties (Solar Abs ~95%; Spectral emittance ~0.12) • Low heat loss property: ~0.14 at 3000C • Temperature stability: < 3000C • Corrosion stability: > 200 hrs withstand in salt spray test • High mechanical stability, Long durability and highly enhanced weather protection	**Possible Applications:** • Solar water heater /Solar dryer • Solar desalination • Stream generation for various industrial applications • ORC solar collector based power generation
4.	**Advanced Detonation Spray Coating Technology** IPDI Level: Reassessing feasibility (IP, Competition, Technology, Commercial)	**Key Features:** • High productivity due to high pulse frequency • Less maintenance: absence of mechanically moving parts • Good adhesion strength (>10000 psi) • Dense microstructure (< 1%) • Negligible thermal degradation and excellent tribological properties • Ability to coat wide range of powders, carbide, oxide, metal powders • Lower substrate temperature & low oxide content • Coatings with 50-2000 microns thickness can be produced	**Possible Applications:** • Steel industry application such as Bridle rolls • Textile & Paper industry applications such as wire passing pulleys, plungers, steeped cone pulleys, bearing stopper plates, guide rolls • Gas compressor applications such as spindle valve, compressor disc, compressor shaft • HP & LP turbine blades, compressor discs, LCA nozzles, thrust beating sleeves, propeller shaft seals. • Power and Energy applications such as guide vanes, spindle valves, hydro turbine blades.
5.	**Micro Arc Oxidation Coating Technology (Academic Version)** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Ability to coat Al, Ti, Mg and Zr metals and their alloys • Ease to coat complex shapes and also regions difficult to access • Uniform, dense, hard and thick coatings • Superior coating properties and performance compared to other conventional acid based processes like anodizing and hard anodizing • Excellent tribological properties and corrosion resistance • Eco-friendly • 5-40 times service life improvement	**Possible Applications:** • For a wide array of applications in industry sectors such as textile, automobile etc.

S. No	Technology and Related Issues	Key Features and Applications	
6.	**PEM Fuel Cell Based Power Supply Systems** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Developed Grid Independent fuel cell systems in the range of 1-20kW power • PEM Fuel cells developed have been continuously operated for 500 hrs and intermittently for several thousand hours with stable performance • Suitable control systems for load following cycle, cell monitoring characteristics, power conditioners and thermal management have been developed	**Possible Applications:** • Power generation, EV applications • As decentralized power pack for homes, industries etc. • As combined heat and power units for homes • As uninterrupted power source even when the power outage is for long duration (>8hrs) • As backup power for telecom industries.
7.	**Lead Free Copper Alloys for Bimetallic Bearings** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Elimination of lead as per B-4 emission norms • Yield Strength: 450 MPa (BMC840), 470 MPa (BMC841) • Hardness: 119 HVN (BMC840), 127 HVN (BMC841) • Wear Resistance: 18 mm/h • Fatigue Strength: 110 MPa	**Possible Applications:** • Main bearings and connecting rod bearings for heavy duty vehicles • Cars and motor cycle bearings • Transmission and hydraulic pump bushings • Wear plates • Camshaft bushings for medium size vehicles
8.	**Cold Gas Dynamic Spray Coating Technology** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Indigenously developed state of the art PLC based automated Portable control panel (Max Pressure -20 bar) • Different set of nozzles • For Low melting materials (polymer based) o High deposition rate or coverage area o Low deposition rate or coverage area o For Ni based materials, Steels (Optional) • Compressed AIR as process and carrier gas • Maximum Pressure - 20 bar; Maximum Temperature: 600°C • Cu, Al, Ag, Zn, Sn,Ni, SS, Ta, Nb, Ti and alloys and composites	**Possible Applications:** • Repair and Refurbishment Applications • Coatings for electrical contacts, lugs, EMI shielding, heat sinks • Coatings for high temp. corrosion resistance, bio-medical, sputter target • Cathodic protection coatings • Anodic protection coatings • Wear resistant coatings • Nanostructured / amorphous coatings • High entropy alloy coatings for high temperature applications
9.	**Ceramic Inserts for Anti-Mine Boots** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Ceramic honeycomb inserts: A new concept • Sacrificial inserts and no splinters • Flexible in design and light weight • Reflection of shock waves by air in channels • Higher energy absorption by the ceramic honeycomb configuration • GSQR 1095 – Qualified	**Possible Applications** • Anti-mine boots used in military and mining applications
10.	**Pulse Electro Deposition** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Non line of site process, economical and ecofriendly • Porosity free finished product, higher production rates • Control over microstructure, mechanical properties, particle content in composite coating • Higher current efficiency and deposition rates compared to traditional hard chrome process • Easy technology transfer from research lab to existing infrastructure	**Possible Applications:** • Corrosion resistance and decorative coatings: automobiles include car, truck trim, motorcycle, kitchen and bathroom appliances • Wear resistance: hydraulic actuators, railway engine shafts, aircraft landing gears, shaft journals, farm machinery, earth movers, snow plows, road repair equipment, mining equipment, automobile engine valves • Industrial tools such as rolls for Al and steel manufacturing, stamping tools and dies, molds for plastic manufacturing utilized chrome plating for increasing its (tool) life

<table>
<tr><th>S. No</th><th>Technology and Related Issues</th><th colspan="2">Key Features and Applications</th></tr>
<tr><td>11.</td><td>Sintered Silicon Carbide (SiC) Components

IPDI Level: Check Repeatability/ Consistency at Prototype Level</td><td>Key Features:
• Tunable density and other thermo-mechanical properties.
• Flexibility in producing SiC parts incorporating solid-state or liquid phase sintering additives.
• Capable to produce SiC components up to 750 mm ϕ.
• Critical SiC parts can be manufactured.</td><td>Possible Applications:
• Mechanical seals particularly for corrosive environment.
• Impact & abrasion resistance parts.
• Light-weight structural parts for aerospace applications.
• Impact and wear resistant parts.</td></tr>
<tr><td>12.</td><td>2D-Nanolayered Transition Metal Sulfides (2D-NTMS)

IPDI Level: Check Repeatability/ Consistency at Prototype Level</td><td>Key Features:
• Synthesis of pure as well as mixed WS2/MoS_2 nanosheet powders
• Synthesis of doped-WS_2/MoS_2 nanosheet powders
• Reasonably good oxidation resistance
• Feasibility to synthesize 2D-nanostructures of other transition metal sulphides
• Scalable process for bulk production</td><td>Possible Applications:
• Solid lubricant for aerospace and automotive sector
• Solid lubricant for forging and other manufacturing processes
• Additive to automobile Lub-oil
• Additive to grease for improved performance under high shear stress
• Petrochem catalyst
• Electrocatalysts for HER
• Li-ion battery electrode
• Self-lubricating composites and coatings (metallic/ceramics/ polymer)
• Sensors and actuators</td></tr>
<tr><td>13.</td><td>Repair and Refurbishment of Pressure Die Casting Components Using Laser Cladding

IPDI Level: Check Repeatability/ Consistency at Prototype Level</td><td>Key Features:
• Repair is possible without preheating of the components/tools
• Low heat input to the component, so less damage
• Narrow soft zone created with relatively high hardness
• Fully automated and repeatable
• Precise deposition and less post processing</td><td>Possible Applications:
• Wear plates for different applications
• Component repair and refurbishment</td></tr>
<tr><td>14.</td><td>Development of Indigenous Electrode Material, Lithium Iron Phosphate (LFP) for EV Applications

IPDI Level: Prototype testing in real-time conditions</td><td>Key Features:
• Identified sources of cost-effective lithium and iron precursors
• The processing cost of 1 Kg of LFP is Rs. 3,144/- developed at ARCI.
• Cost can be reduced by 20% by designing suitable cost-effective large capacity furnace and optimum heating cycles with less time
• ARCI developed LFP's electrochemical performance in terms of specific capacity; cyclic stability and rate capability is at par with the performance of the commercially available LFP
• Considering the existing facilities for LFP the batch size is 29 kgs per day is being produced.</td><td>Possible Applications:
• LiB batteries used in electric vehicle applications</td></tr>
<tr><td>15.</td><td>Development of Indigenous Electrode Material, Lithium Titanate (LTO) for EV Applications

IPDI Level: Prototype testing in real-time conditions</td><td>Key Features:
• Identified sources of cost-effective lithium and Ti precursors
• The processing Cost of 1 Kg of LTO is Rs.1700 developed at ARCI. Cost can be reduced by 20% by designing suitable cost-effective large capacity furnace and optimum heating cycles with less time
• ARCI developed LTO's electrochemical performance in terms of specific capacity; cyclic stability and rate capability is at par with the performance of the commercially available LTO
• Considering the existing facilities for LTO, the batch size of 72 kgs per day is being produced</td><td>Possible Applications:
• LiB batteries used in electric vehicle applications</td></tr>
</table>

S. No	Technology and Related Issues	Key Features and Applications	
16.	**Scratch resistant coatings on retro reflective lenses of road markers** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • High scratch hardness and abrasion resistance • Long life and good adhesion • Colored coatings possible • Can be coated on Polycarbonate, PMMA etc	**Possible Applications:** • Road markers • Helmet visors
17.	**Smart carbon based C-TiO_2 for heat transfer, lubrication and self-cleaning applications** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Good visible light photocatalytic activity for indoor/ outdoor self cleaning applications • Prototype fabric has been developed and validated • High heat capacity and thermal conductivity for heat transfer application • Low coefficient of friction compared to base lubricant oil • Good visible light photocatalytic activity for indoor/ outdoor self-cleaning application • Cost effective and easy to scale up	**Possible Applications:** • Industrial heat transportation • Solar thermal power generation • Cooling of microchips • Lubricants in machinery • Self-cleaning activity on incorporation with TiO_2 • Self cleaning textiles
18.	**Cathodic Arc Physical Vapor Deposition Facility (CAPVD)** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Films/coatings of different structures with good control over chemistry and thickness can be developed: (i). Mono-layer, (ii) Multi-layer, (iii) Gradient and (iv) Functionally multi-layered/graded • Films/coatings containing Ti, Cr, AlSi & AlTi can be coated in pure metallic or nitride or carbide form. i.e. TiN, CrN, TiAlN, TiAlSiN, CrAlSiN, TiCrAlSiN, TiC, TiCN, TiAlCN, etc. • Physical and mechanical properties can be tuned by varying deposition conditions • Environmentally green and easily up scalable process with high production rates	**Possible Applications:** • Hard and wear resistant coatings for cutting tools – up to hardness of 45 GPa • Wear resistant coatings for dies, bearings, etc. – Low friction coefficient of < 0.2 • Erosion resistant coatings for compressor blades – A thickness of 20 µm is achieved • Solar selective coatings for solar thermal applications – ~ α: 0.96 & ε: 0.09 at 400°C • Diffusion barrier coatings for electronic components • Decorative coatings for aesthetic applications, etc.
19.	**Dual functional anti-fogging and antireflective coatings for optical, solar and display applications** IPDI Level: Check repeatability/ consistency at coupon level	**Key Features:** • High transmittances in visible and solar regions: >98% (in visible) >96% (in solar) • Low temperature curable (80-100°C) • High temperature stability: Max up to 1000°C • Weather stability: > 200 hrs withstand in high humidity (>90%) at 50°C • High mechanical stability and Long durability • Coat effective coating technique	**Possible Applications:** • Solar PV & CSP cover glass • Optical lenses • Video display panels • Architectural glasses • High power lasers
20.	**Anti-bacterial coatings on scrub pads** IPDI Level: Check repeatability/ consistency at coupon level	**Key Features:** • Prevents and controls the formation of new and growth of existing bacteria • Transparent, imperceptible by touch, feel and look remains unchanged • Chemical resistant and non-toxic • Minimization of the infection risk • Can be coated on any surface. • Forms a strong bond with its substrate • Helps prevent discoloration and degradation	**Possible Applications:** • Glass(borosilicate glass, soda-lime glass, quartz glass etc.) • Ceramics (tiles etc.) • Metal(SS, chrome, aluminum etc.) • Plastics (polycarbonate, PMMA, etc.) • Wooden structures • Contact eye lenses case • Non woven fabrics

Support Groups

Automation of DSC process with added features to meet the Modern Industry Prerequisites

S. Nirmala, Electronics and Instrumentation Group **nirmala@arci.res.in**

The AWAAZ Detonation Spray Coating system completed its successful journey in the Indian industry for more than a decade with promising results. To keep in pace with the global scenario, the control system and the Gun assembly is redesigned to make it Advanced with a PLC-HMI to simplify the operation of the coating process and to generate coatings by the DSC technique. The entire control cabinet (RITTAL make) is ergonomically designed to suit operator convenience. All the operations are literally at the fingertips by touch buttons on the front panel. Care has been taken to ensure safety by building checks and setting alarms.

Fuel and purge gasses enter into a detonation chamber in a cyclic preset sequence, where they are ignited to generate a detonation. This releases a series of shock waves through a long barrel where powder particles are introduced synchronously in their path. These powder particles attain a high temperature and high velocity as they travel down the gun barrel and bombard on to the target surface to be coated, placed at the exit at a short distance.

Various control components like Electromagnetic Solenoid Valves, Mass Flow Controllers, PLC with Analog and Digital IO modules, Multichannel relay module and HMI with mimic (Fig. 1) are assembled and wired in the control cabinet of the DSC system. The control system is integrated with the mechanical assembly of the D Gun as well as the Ignition control module. Several protection devices like Flash Back Arresters [FBAs] Pressure Switches, Temperature and water flow sensors etc. have been incorporated in the system to prevent accidents and ensure safety.

The entire electronic controls are programmed using a Siemen's make PLC. The HMI displays various screens such as Set Parameter Screen for setting the process parameters, IO Status Screen for checking the status of Inputs and Outputs, Analog Settings Screen for setting the ranges of Flow, Pressure and Temperature and a Totalizer screen to display the consumption of process gases and a couple of other screens. Some standard recipes are pre-loaded into the system, based on the in-house R&D experiments, which were carried out to optimize the process parameters. Additionally, there is a provision to change any or all of these parameters so that the process can be tailored to the customer's requirements. It is also possible to load and store any set of process parameters in an editable file in a USB compatible device so that the files can be recalled for later use.

The status of different Input and Output signals is available to simplify error diagnostics and to override them, if needed. User Administration permits restriction of screen displays to authorized competent personnel only. This way, some screen displays can be viewed only by entering a password.

The process begins by pressing the Start Push Button on the Control Panel and the PLC executes the sequence as per stored program and stops automatically once the set number of shots are fired. Process can also be stopped in between either by pressing the Stop Push Button or Emergency Push Button (Fig. 2).

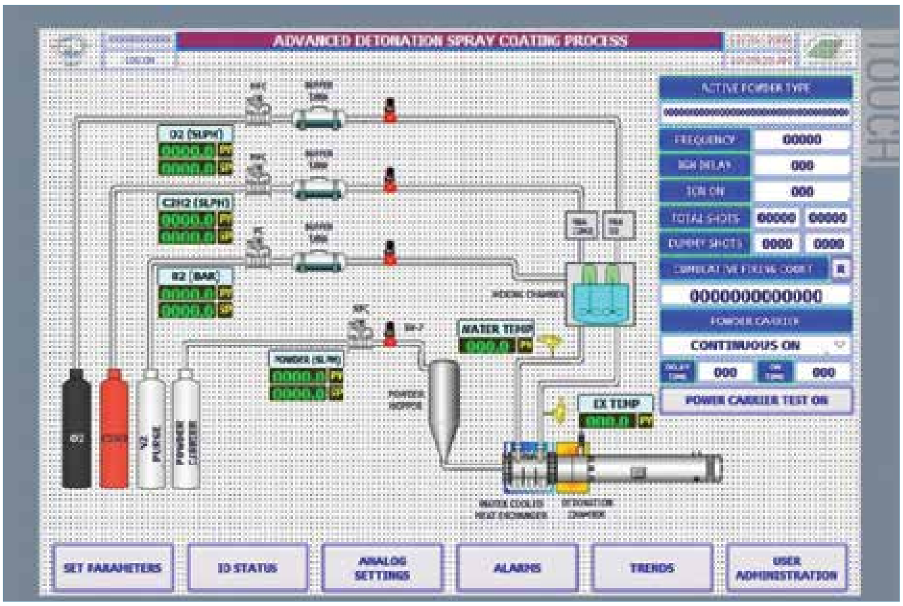

Fig.1 Main/Mimic Screen of ADSC Process

Fig. 2 Control Panel

Contributor: N. Aruna

VI Plotter-An application of Programmable Instrument for Industrial R&D

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Most instrument manufacturers started catering to the increasing need of users to develop units in such a way that they can be integrated with other instruments under the common command of a central computer so that users can develop and make any desired set up to suit their application.

In order to do this, there was a need to arrive at a common protocol that clearly defined the input commands and output digital signals that all instruments understood in an unambiguous manner.

Hewlett Packard was one of the pioneers in this development and specified a specification called HP-IB interface. This was widely accepted by the industry and is called as GPIB or IEEE-488.Apart from this, other standards also became popular like Ethernet, USB, Serial, PCI and PXI.

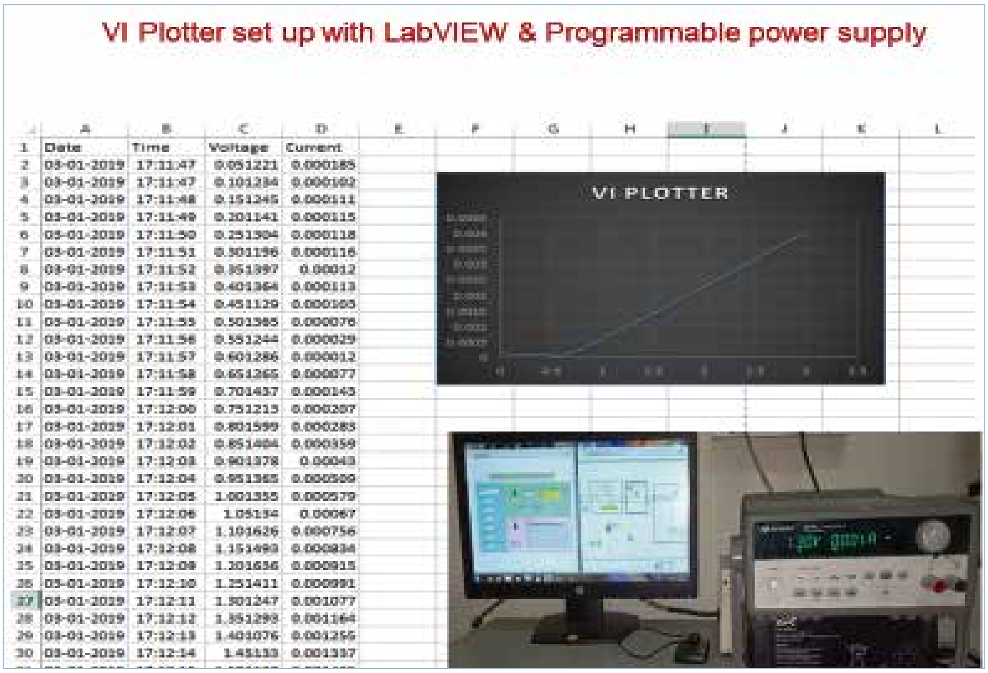
In parallel with the introduction of the above standards, programmers also started developing application packages on their own. Thus, there was a concurrent need to have a standard for such software that could be easily adapted for Plug and Play type of instruments. Virtual Instrument Software Architecture, or VISA, was developed by VME eXtensions to fulfil this need. LabVIEW is one such application package that uses VISA to communicate with Instruments and control.

Electronics and Instrumentation Group at ARCI deals with different test and measuring equipment to support various centres in terms of maintenance and troubleshooting. Apart from this, the group has also been involved in in-house development of prototype test setups that helps the Research and Development being carried out by fellow scientists. One such activity is described below.

Using the available bench top instrument (Agilent Programmable Power supply) and the Graphical User Interface based VISA software (National Instruments LabVIEW), a programmable instrument setup was developed that can be utilised to plot the voltage-current characteristics of diodes, LDRs, PV cells etc.

The instrument can be programmed in such a way that the user can define the manner in which the voltage is applied to the Device Under Test (DUT). For example, the voltage can be applied in discrete steps in which case the max voltage, the size of each step and the number of steps to be applied is selectable by the operator. The front panel as shown in Fig.1. permits these values to be entered, The block diagram, which runs in the background, uses these values to perform the necessary calculations and apply the calculated voltages to the DUT sequentially. At each value, the resulting current is measured by the program and logged in a file at the specified sampling rate so that it is available for post analysis.

The figure also shows the data processed for a diode 1N4007 connected in series with a 500 ohms resistor. The knee voltage recorded was around 0.7V, which represents the diode characteristic. The setups can be altered or customised to suit the user requirements at any point of time.



Contributor: S. Nirmala

Electrical and Civil Infrastructure

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Electrical and civil infrastructure group has deep rooted tentacles in carrying out exemplary work in construction, electrical maintenance, paving road for new ideas in the related field works. Major works taken up by the group are Electrical, Civil-infra, Water works & Air-Conditioning. All facilities under one-group gives secure and comfort to respective centre/centre of excellence.

Regular and preventive maintenance of HT 33/11KV and 11/0.415KVsystems, 2.5MV DG and respective building PDB are up-kept in routine scheduled regular intervals. Logistics w.r.t power requirements are dealt for commissioning of new equipment's. Conservation of energy applicable ideas are implemented at site, to name a few: installing sensor based light fittings which auto switches, BLDC ceiling fans which are energy efficient as compared to AC fans are installed.

New construction and building expansion with aesthetic enhancement are the core crust works of this team. Civil and electrical go hand in glove co-ordination to bring wholeness in construction to achieve completion objective. Estimation, tendering procedure, implementing etc., works are taken as one capsule of work. Recent work which have taken shape this year -The new canteen facility as shown in fig. restructured internal area, providing larger space to the student and staff to accommodate higher strength of canteen users. The kitchen facility upgraded to suit the users to accommodate the modern kitchen gadgets.

Drinking water facility and hygiene to all the buildings, up keep of 36 nos., of water dispensers/coolers connected with the Aqua-guard water purifiers and filter are monitored, industrial water facility to ensure water to all the furnaces and equipment's during operation are maintained. Supply and maintenance of water to greenery in the campus spread around 30 acers.

Under air-conditioning system maintenance, the group carried out maintenance and repair work of air conditioners at different COEs and administrative block, for a total of 330 units. About 30 tons of new AC units installed this year across the campus.

ARCI joined the National Solar Mission under National Action Plan on Climate Change (NAPCC). Under this mission, the ECI group has taken up a project to set up 518 KWp grid connected Roof Top Solar (RTS) plant. This plant is spread over three selected rooftops; care has been taken so that, no effect of shadowing covers the solar panels, to reap maximum power generation and strength of the building structurally evaluated for withstanding the load of solar panel installation. Installed a 518 KWp power plant with two types, Mono/Poly crystalline type and also all solar panels are tested for Electro Luminescence (EL) test, developed by the group, as part of quality assurance plan of the ongoing RTS plant installation work. EL test eliminates installation of damaged panels as shown in fig, which may have cropped up during transport and in-proper handling by non-professionals

Ongoing works presently being executed in electrical system renovation project, for upgrading/renovating the control & protection systems of Electric substations (33/11 KV& 11/0.415 KV). This project is taken up under the able guidance of reputed consultancy firm.

Proposal are put forth to DST to take up assignments for up gradation of Infrastructure works such as water pipe lines which include drinking and industrial pipe lines, Fire hydrants and pipe line, BMS- Building Management System. Detailed works involved at site for upgradation and cost estimation are been prepared by the team with help of competent external agency. The above works are taken up for the first time after 25 years of ARCI inception. Apart from this a project for improving life of Lead-Acid battery of electric vehicles, employing super capacitors are some of the other major works taken by the department.

Solar roof top power plant

Refurbished canteen building

Contributors: V. Uma, V. C. Sajeev, P. Ramakrishna Reddy and A. R. Srinivas

Implementation of in-house live streaming facility

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Live streaming has emerged as a new form to connect and interact with audiences in real-time using multiple media forms. The event is simultaneously recorded and broadcast for viewing both during the event and after for later viewing. ARCI organizes various conferences, workshops, seminars, and events in its thrust areas, which attracts more audiences. However, it is challenging to accommodate more number of audiences at existing Seminar Hall due to limited capacity and also audiences from ARCI, Chennai. Live streaming is the best solution to view the event from remote locations using the available standard setup. There is diverse live streaming platforms available free and open environment such as Facebook, YouTube, Twitter, etc. However, these live streaming platforms are not suitable for ARCI's events, need a more secure and targeted audience.

We have developed in-house live streaming facility using the optimum resources such as a camcorder, laptop, and open-source tools. Black Magic Design Intensity Shuttle is used to capture the video directly from the camcorder to a computer or laptop using USB 3.0. Open Broadcaster Software (OBS) Studio, free and open-source software used for video recording and live streaming. Nginx web server is used as a streaming server for broadcasting the output of OBS Studio and VLC media player used to view live streaming.

The live actions captured in the camcorder are transferred to the video capturing device using HDMI cable. The audio output from the audio mixer & video output from the video capturing device is connected to the laptop. The OBS studio mixes all the received inputs, presentation material, and other contents and converts all together into a 'scene.' These created scenes are streamed into the Nginx web server using the 'rtmp' protocol. It also records the 'scene' created by the software into the local storage. The live streaming content is accessible through the URL of the webserver within the ARCI network using VLC Media Player.

ARCI started this live streaming session during National Science Day 2019 to telecast the lectures at ARCI, Hyderabad to ARCI, Chennai. It was used during the ARCI Outreach Program 2019 for broadcasting the entire event to the invited students and visitors. Also used for many other events and training such as one day workshop on "Advanced Sensor Materials and Devices" ASMD-2019, Students Flash Talk during National Science Day - 2020, Government e-Marketplace Training program, etc. Highlights of the same are presented in the following figures.

Contributors: K. Naresh Kumar and M. Renju

Events, Data and Statistics

Major Events

Jayanthi Celebrations

Dr. B. R. Ambedkar, Dr. Babu Jagjivan Ram and Mahatma Jyothirao Phule Jayanthi celebrations were held at ARCI on April 14, 2019. Dr. K. Murugan, President ARCI SC/ST Employees Welfare Association welcomed the gathering. Dr. T. Narasinga Rao, Associate Director, Dr. P. K. Jain, Chairman, ARCI Welfare Committee and ARCI SC/ST Employees Welfare Association members paid rich floral tributes and spoke about their contributions towards society.

Floral tributes to Dr. BR Ambedkar and Dr. Babu Jagjivan Ram

Technology Day Celebrations

Technology Day was celebrated at ARCI on May 9, 2019. Dr. Sanjay Bhardwaj, Scientist "F" & Team Leader, Centre for Technology Acquisition and Transfer welcomed the gathering and Dr. G. Padmanabham, Director briefed about the importance of Technology Day Celebrations in the Country. Technology day lecture was delivered by Prof. B. Ravi, Institute Chair Professor, Mechanical Engineering Department, Indian Institute of Technology (Bombay), Mumbai. on "Innovation Eco-System: From Idea to Impact". Staff members and research students participated in technology day celebrations.

Prof. B. Ravi, IIT-B, delivering a talk at ARCI

International Yoga Day

"International Yoga Day (IYD)" was celebrated with great enthusiasm at ARCI on June 21, 2019. Dr. P.K. Jain, Chairman, Welfare Committee welcomed the gathering Dr. G. Padmanabham, Director ARCI, briefed about the science behind the rich ancient traditions of India, for example Yoga, Rangoli etc., and how these practices are now gaining prominence due to their vast health benefits and finding their way into mainstream. Ms. P. Prameela, Founder Prameela Yoga Studio delivered a talk on 'Yoga for Healthy Life' and demonstrated yogic postures that are beneficial for stress relief, curing diabetes, back aches etc. Mr. G. Anil, Director- Brahmanada Enlightenment Trust, Hyderabad made a presentation on benefits of practicing Transcendental Meditation for stress relief.

Ms. P. Prameela demonstrating the Yoga postures

Mr. G. Anil presenting the benefits of Transcendental Meditation

Mass Tree Plantation

Under Government of Telangana's Haritha Haram programme, ARCI has taken up mass tree plantation on July 30, 2019. Dr. T. Narasinga Rao, Associate Director and Dr. Roy Johnson, Associate Director and Chairman-Greenery Committee inaugurated the programme by planting saplings. Employees and students actively planted saplings on the occasion.

Independence Day

ARCI celebrated Independence Day on August 15, 2019. Mr. D. Ramesh, Security, Fire & Safety Officer welcomed the gathering. Dr. G. Padmanabham, Director ARCI hoisted the National Flag and addressed the gathering. Dr. T. Narasinga Rao and Dr. Roy Johnson, Associate Directors also spoke on the occasion.

Dr. G. Padmanabham, Director, ARCI hoisting the National Flag

Official Language (Hindi) Implementation at ARCI

The Official Language Implementation Committee (OLIC) under the Chairmanship of Dr. G. Padmanabham, Director, ARCI has been successful in the implementation and progressive use of Hindi at ARCI. Quarterly OLIC meetings were conducted to review the progressive use of Hindi at ARCI. During the year, ARCI issued more than 3000 letters in bilingual form and surpassed the target set by the D.O.L, Ministry of Home Affairs, Govt. of India. To propagate, the use of Hindi in a better way, ARCI conducted Hindi workshops on a quarterly basis for its employees as well as for the nominated research students. ARCI has also been imparting regular training in Hindi to its employees under the Hindi Teaching Scheme.

To encourage the employees to carry out their day-to-day official works in Hindi, a cash incentive scheme is in place. So as to encourage more number of employees to carry out their official works in Hindi, the awards are categorized into technical and non-technical categories. Accordingly, Shri K. Ramesh Reddy, Technical Officer "B" and Shri Mothe Lingaiah, Technician "B" received cash prizes of Rs. 5000/- and Rs. 3000/- respectively in technical category. In non-technical category, Shri J. Bansilal, Jr. Assistant (MACP), Shri Narendra Kumar Bhakta, Assistant "B" and Kum. K. Madhura Vani, Assistant "B" received cash prizes of Rs. 5000/-, Rs. 3000/- and Rs. 2000/- respectively.

TOLIC-Hyderabad (3) Half-yearly meeting: On June 26, 2019, ARCI has organized "Town Official Language Implementation Committee, TOLIC-Hyderabad (3)" half-yearly meeting.

Inspection by DST, Ministry of S&T: During August 27-28, 2019 Rajbasha Vibhag officials of Department of Science & Technology, Ministry of Science & Technology, Government of India, New Delhi have carried out thorough inspection of the

Dr. Roy Johnson, Associate Director addressing the gathering on the occasion of Hindi Week Celebrations

Dr. Rajnarayan Awasthi, ECIL, Hyderabad and Shri Kamakhya Narayan Singh, Assistant Director (O.L.), DST, delivering talks during Hindi Workshops

Rajbhasha Vibhag Officials of DST carrying out Inspection

Participants in competition during Hindi Week Celebrations

works being carried out in Hindi and proper implementation of Official Language at ARCI.

Hindi Saptah Celebrations: ARCI celebrated "Hindi Saptah" during September 4-17, 2019. As part of Hindi Saptah celebrations, employees and students participated in various Hindi competitions like quiz, elocution, noting & drafting, essay writing, hand writing, translation, typing, scrabble, Just-A- Minute, debate and poem.

Release of 2nd Issue of Annual Hindi Magazine: In continuation to ARCI's activities in the successful promotion of Implementation of Official Language, an effort was made to publish an Annual Hindi in-house magazine "SRUJAN". The magazine contains scientific and technical research articles, achievements of ARCI and general articles received from staff and research students. Accordingly, the 2nd edition was released on January 26, 2020 during Republic Day Celebration’s by Dr. G Padmanabham, Director, ARCI.

Swatch Bharat Abhiyan

As part of 'Swatch Bharat Mission’, ARCI regularly observes cleanliness. All the staff members of ARCI-Hyderabad, Chennai and Gurugram Offices actively participated in the “Swatchhta Hi Seva” campaign held during September 11 to October 02, 2019. Mass cleaning of the ARCI premises at Hyderabad, Chennai and Gurugram Offices were organized. An Awareness Program in ARCI was conducted in which Mass pledge was administered on elimination of single use plastic from our daily lives. ARCI premises was designated as “Plastic Free Zone” and Jute bags were distributed to all the employees, research students and others.

An Awareness Program was conducted at Zilla Parishad Government High School in Balapur village and few employees delivered talks on Plastic Waste Management and Effective Disposal of Single Use Plastic.

Dr. P. K. Jain, Scientist 'G' and Dr. M Buchi Suresh along with other Members of the Committee at the awareness program conducted at Zilla Parishad Government High School, Balapur

Annual Medical Check-up

Annual Medical Check-up (AMC) programme for ARCI employees for the year 2019 was carried out during October 22-23, 2019. Medical tests were carried-out for the employees categorized into two age groups i.e. below 45 years and 45 years & above. Apart from prescribed medical tests under AMC, special tests such as TMT, Liver function, Vitamin D tests etc., were carried out for the employees who were 45 years and above. Additional tests like Vitamin B12 and Ultrasound scanning were carried out for the women employees who were 45 years and above.

Outreach Programme

As part of Scientific Social Responsibility, for the first time an "Outreach Programme" was held at ARCI, Hyderabad on October 24, 2019 under the auspices of the Ministry of Science and Technology and Vijnana Bharati (VIBHA). The following events were conducted:

- Open Day for the general public as well as students and staff of Schools and Colleges.
- Quiz competition for 8-10 class students and Elocution competition for students of B.E/B.Tech, B. Sc. and M. Sc.
- An activity for assembly of dye-sensitized solar cells.
- Interaction session with Scientists.

Dr. G. Padmanabham, Director, ARCI, welcomed the participants in the Inaugural Session, and also delivered a public lecture. Chief Guest Dr. G. Madhusudhan Reddy, Director, DMRL, and Guest of Honour Dr. K. Ratna, Secretary, KV Rao Scientific Society, Hyderabad, addressed

Students and Staff touring the Campus

Quiz competition in progress

the gathering. This was followed by a brief report on the Outreach Programme by Dr. G. Ravi Chandra, Nodal Officer for the event. A film on Vijnana Bharati was screened for all the participants.

A total of 1550 visitors participated in the Open Day which included students from schools and colleges as well as general public. All the participants visited ARCI's Centres of Excellence. Live demonstration of some of the equipment were shown, products were displayed and they had a chance to look at objects magnified through optical and scanning electron microscopes. Visitors had a chance to view various processing and characterization facilities at various Centers of Excellence 16 schools and 35 colleges/ Universities students participated in the quiz and elocution programmes respectively.

A student trying out the battery-operated bicycle and interacting with Scientist

Vigilance Awareness Week

Vigilance Awareness Week was observed at ARCI from October 28 to November 02, 2019. The theme of Vigilance Awareness Week was “Integrity – A Way of Life”. The messages from the honourable President and CVC were read by Dr. Roy Johnson, Associate Director and Dr. L. Ramakrishna, Scientist “F” & Vigilance Officer, ARCI. Director, ARCI administered "Integrity Pledge" to all the employees, project staff and students and they were also encouraged to take the e-pledge. ARCI Chennai and Gurugram Office staff members were also administered the pledge. As part of the

Dr. L. Ramakrishna reading the message from CVC

Shri K. V. Chowdary, IRS delivering a lecture

Vigilance Awareness Week, Shri K.V. Chowdary, IRS, Former Central Vigilance Commissioner, Govt. of India delivered a lecture on October 29, 2019 which was attended by all the employees and students. On this occasion, posters on vigilance awareness were displayed in the Administrative Building and slogans were also displayed on all the digital boards.

Rashtriya Ekta Diwas/National Unity Day

To commemorate the Birth Anniversary of Shri Sardar Vallabhbhai Patel, who unified the Country, ARCI observed "Rashtriya Ekta Diwas"/"National Unity Day" on October 31, 2019. Director, ARCI administered "Rashtriya Ekta Diwas" pledge to all the employees, project staff and students. Pledge was also administered to the staff at ARCI, Chennai Centres and Gurugram Office.

Employees administering the pledge at ARCI, Hyderabad, Chennai and Gurugram Offices

Constitution Day

As a part of 70th Anniversary of the Indian Constitution, "Constitution Day" was celebrated on November 26, 2019 at ARCI. The Preamable of the Indian Constitution was read out by the Team Leaders/Section Heads along with staff and research students at their respective Centres of Excellence and Centres/Sections.

Annual Day

The 23rd Annual Day was celebrated at ARCI, Hyderabad on December 27, 2019. This year, the Welfare Committee was given the responsibility of organizing Annual Day Celebrations. Every effort was made to bring-in at one place, a variety of entertainment and amusement activities, so that all employees, their families of all age groups, and research students take part in the events wholeheartedly. The celebration was inaugurated with Lightning of Lamp by Dr G. Padmanabham, Director and Associate Directors. Dr. P. K. Jain, Scientist "G", Chairman, Welfare Committee, welcomed the august gathering. Director, ARCI briefed about the major achievements of ARCI during the year and initiatives to be taken up in the coming years. Dr. Tata Narasinga Rao and Dr. Roy Johnson, Associate Directors also addressed the gathering and encouraged employees to get involved and be part of the successful journey of ARCI. Various cultural and entertainment events like, orchestra and fun activities were arranged.

Dr. G. Padmanabham, Director, ARCI along with Dr. TN Rao & Dr. Roy Johnson, Associate Directors and Dr. P. K. Jain, Chairman, Annual Day Organizing Committee on the dias

Republic Day

ARCI celebrated Republic Day on January 26, 2020. Mr. D. Ramesh, Security, Fire & Safety Officer welcomed the gathering, Dr. G. Padmanabham, Director ARCI hoisted the National Flag and addressed the gathering. Dr. T. Narasinga Rao and Dr. Roy Johnson, Associate Directors also addressed the gathering.

Dr. G. Padmanabham, Director, ARCI hoisting the National Flag

Sports & Games

Sports and games was inaugurated on January 27, 2020 by Director, Dr. G. Padmanabham along with Associate

Chairman and Members of the Annual Day Organizing Committee with Dr. G. Padmanabham, Director, ARCI

Employees and Students with families on the occasion of Annual Day Celebrations at ARCI

Directors, Dr. T. Narasinga Rao and Dr. Roy Johnson. Director emphasized on the necessity of regular physical activity for employees and staff at ARCI for their physical and mental fitness. The events started with inauguration of renovated recreation room followed by 2k walk in the ARCI premises. Overall 170 participants including employees, project staff, research fellows and students have recorded for 13 different games and sports events. Furthermore, excellent response was received for events like fitness challenge activity and women's cricket, which were introduced for the first time.

Director, Associate Directors and other employees at the 2k walk at ARCI

Winners of Women's Cricket organized for the first time at ARCI

Inauguration of Phytorid-SWAB an Eco-friendly Sewage Treatment Plant

The first Phytorid - Scientific Wetland with Active Biodegradation (SWAB) based sewage treatment plant in state of Telangana is formally inaugurated by Dr. G. Padmanabham, Director, ARCI and Dr. Rakesh Kumar, Director CSIR-NEERI on February 11, 2020. The sewage contains organic wastes, suspended solids and pathogenic micro-organisms as the primary source of water pollution. In order to treat the sewage before it is discharged to the environment and to use the water efficiently CSIR-NEERI (National Environmental Engineering Research Institute) developed a patented Phytorid technology based on the concept of engineered constructed wetland. Speaking on the occasion, Dr. Padmanabham Director, ARCI emphasized the importance of scientific communities to evolve strategies that utilizes their scientific skills to develop environment friendly technologies as well as to develop innovative systems for more sustainability. He also expressed keen

Inauguration of Phytorid by Dr. G. Padmanabham, Director, ARCI and Dr. Rakesh Kumar, Director CSIR-NEERI

interest in collaborating with CSIR-NEERI in areas of development of materials for environmental technologies.

National Science Day

National Science Day (NSD) was celebrated at ARCI during February 27-28, 2020. This year's theme for NSD was "Women in Science". A slide show on Dr. CV Raman's life and the achievements made by Indian women were displayed in all the digital boards.

On February 27, 2020 a 'Special Lecture' was delivered by renowned Metallurgist Prof. Indranil Manna, Indian Institute of Technology-Kharagpur (former Director, IIT-Kanpur) on 'Advanced Materials for High Temperature and High Specific Strength Structural Applications'.

Prof. Indranil Manna being presented with a Memento by Dr. G. Padmanabham, Director, ARCI

On February 28, 2020 'Science Flash Talk – Creativity Unleashed', was organized to intensify the scientific thinking in young minds. All the project students, trainees, project associates and research fellows of ARCI were given an opportunity to express their novel concepts/ideas on science and technology in 2 minutes with a single slide. Fifty-eight students participated in the 'Science Flash Talk' and presented ideas ranging from addressing issues related

Employees, Research Fellows and Students with Director, ARCI on the occasion of National Science Day Celebrations

to pollution, affordable drinking water, renewable energy to smart materials. Dr. G. Padmanabham, Director, Dr. Tata Narasinga Rao and Dr. Roy Johnson, Associate Directors addressed the staff and students on the occasion.

Dr. P. K. Jain, Scientist "G" and Chairman of NSD Celebrations Committee, gave a talk on 'Science behind Ancient Indian Traditions' and importance of scientific developments for societal use.

Winners Imran Karajagi, V. Sri Harsha Swarna Kumar, D. Nazeer Basha, Kigozi Moses, Jaijeet Singh Rathore, G. Nivetha, Nirogi Aamani, V. P. Madhurima, Allen John and S. Manasa were given awards by Dr. G. Padmanabham, Director-ARCI for their good concepts and out-of-the-box ideas.

Dr. P. K. Jain, Scientist 'G', delivering a talk on the occasion of National Science Day

Safety

ARCI observed National Safety Week during March 4-10, 2020. As part of 49th National Safety Day celebrations which was held on March 5, 2020, Dr. Roy Johnson, Associate Director and Chairman, Safety Committee welcomed the gathering and in his address highlighted that ARCI, as an organization has the policy which gives utmost priority for the Safety, Health and Environment Safety lecture was delivered by Mr. G. Jeevan Raghavendra, Manager, Health, Safety & Environment, from M/s. Sai Life Science Ltd., Hyderabad. Prizes and appreciation certificates were presented to the winners of slogan competitions and those who observed strict safety norms at their work place and in ARCI campus.

Fire-fighting demo being conducted by Shri D. Ramesh, Security, Fire and Safety Officer

Dr. G. Padmanabham congratulating all participants and presenting awards to winners of 'Science Flash Talk'

Participants at the National Safety Day Celebrations with Dr. Roy Johnson and Shri G. Jeevan Raghavendra

During the year, as part of safety awareness programme at ARCI, a Safety Induction training programme and fire-fighting demo was conducted by Shri D. Ramesh, Security, Fire and Safety Officer on November 22, 2019. All the project staff and research students have actively attended the programme.

ARCI Internal Complaints Committee

ARCI Internal Complaints Committees (AICCs) are functioning both at ARCI, Hyderabad and Chennai, Centres. Bilingual awareness posters were displayed at prominent locations both the places. An awareness program by Telangana State Police SHE Teams on "Women Safety" was organized on February 6, 2020 at ARCI, Hyderabad. The program was conducted by Smt. Saleema Shaik, Additional Deputy Commissioner of Police, SHE Teams, Rachakonda Commissionerate.

At ARCI Chennai Centre, the ICC arranged a talk on "General Awareness on Internal Compliance Committee (ICC)" delivered by Ms. Sumitha Vibhu and Ms. Kavitha Ananth, Advocates on February 19, 2020. They have briefed about the role of ICC and work place harassment and the steps that are necessary to taken by the organization and institute to prevent harassment of women at work place.

ICC at ARCI, Hyderabad and Chennai Centres did not receive any complaints during the year of the report.

International Women's Day Celebrations

International Women's Day (IWD) was celebrated on March 9, 2020 at ARCI, Hyderabad. Prof. Gita Sharma, Director-R&D at Tapadia Diagonstics, Hyderabad graced the occasion as Chief Guest. Dr. G. Padmanabham, Director, ARCI addressed the gathering and focussed on the word 'equality', in line with the theme of International Women's Day 2020 of the United Nations, "I am Generation Equality: Realising Women's Right". He stressed that the real growth of women lies in providing equal opportunities and right environment for the growth of the women. Prof. Gita delivered a motivational talk titled "Women Technoprenuership: Enabling Policies".

Participants at International Women's Day celebrations with Dr. G. Padmanabham, Director, ARCI and Prof. Gita Sharma at ARCI, Hyderabad & Dr. R. Gopalan, Regional Director, ARCI and Dr. Pinky Jowel at Chennai

ARCI Chennai Centres celebrated International Women's Day (IWD) on March 9, 2020. Dr. K. Ramya, Senior Scientist and Chairperson, AICC welcomed the gathering. Dr. R. Gopalan, Regional Director addressed the gathering and shared his views about the importance and contributions of women in today's world. Dr. S. Kavita, Project Scientist and Convener, AICC gave a general keynote address and introduced the speaker Dr. Pinky Jowel, IAS, Special Secretary, Rural Development and Panchayat Raj, Government of Tamil Nadu.

Conference/Workshops/Symposia Organized by ARCI

1. One-day training programme on 'Powder Bed Metal Additive Manufacturing' was conducted in two batches at ARCI on April 26, 2019 and April 29, 2019. Three days basic training programme on 'SLM Additive Manufacturing System Operation and Maintenance' was organized at ARCI for the clients of SLM Solution GmbH, Germany during January 21-23, 2020.

   ARCI has proven the AM technology in tooling, aerospace, and defense application and has experienced post-processing of various complicated real-time components. Additive Manufacturing (AM) training session at ARCI included courses covering a variety of topics from design (design for additive manufacturing, DFAM) possibilities, additive manufacturing process, software tools, operation principles, and post processes like heat treatment and surface finishing. The training course has been customized to professionals' needs, including lectures, detailed technical discussions, real-time examples, and hands-on demonstrations led by professionals. The mission of ARCI is to educate and share knowledge with aspiring professionals from different organizations on additive manufacturing technology and its benefits.

2. ARCI along with Sensor Research Society, Hyderabad and Indian Ceramic Society (ICS, Hyderabad Chapter) organized a one-day workshop on Advanced Sensor Materials and Devices (ASMD-2019) on August 23, 2019 at ARCI. Dr. G. Padmanabham inaugurated the event and emphasized on the importance of sensors for manufacturing technologies in national context especially for applications in cyber physical systems. In his address, Dr. Jagannath Nayak, Director, CHESS and Vice President Sensor Research Society discussed on the challenges in carrying out basic research in the area of sensors and seamlessly upscaling them from lab scale to industrial scale. Eminent scientists and students witnessed the technical presentations and demonstrations of devices, including one indigenously developed by sensor group at ARCI.

3. A 'Workshop on Emotional Well-being at Work Place, Including Aspects of Emotional Intelligence, Interpersonal Skills' was conducted at ARCI, Hyderabad during September 26-27, 2019. 25 ARCI personnel participated in the programme.

4. Messe Muenchen India (MM India) and ARCI hosted the 'International Conference on Applications of Lasers in Manufacturing (CALM 2019)' concurrently organized with the 'Laser World of Photonics India Exhibition'atthe Bombay Exhibition Centre, Mumbai during October 17-18, 2020. CALM 2019 witnessed internationally renowned experts from R&D/Academia/Industry of peerless speakers who have given outstanding, quality research works presentations and panel discussions which allowed to triggered lively discussions on various laser-based manufacturing processes such as hardening, cladding, texturing, alloying, welding/brazing, micro-nano fabrication, and additive manufacturing. CALM 2019 provided an attractive platform for all delegates to meet and discuss various aspects of laser-based manufacturing.

5. Hydrogen based clean energy systems are revolutionizing the energy scenario and touted as the energy for sustainable future. Capitalizing the enormous potential of hydrogen energy, Centre for Fuel Cell Technology (CFCT), International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) conducted "2nd One Day Workshop on Hydrogen and Fuel Cell for Sustainable Future" consecutively the second year to mark the occasion of "National Hydrogen and Fuel Cell Day". The workshop was conducted to create awareness on clean technologies based on hydrogen and fuel cells for sustainable future. It also offered a common platform for the academics and industries to interact and bridge the gaps involved in the transition of the hydrogen based clean technologies from lab to practical utility.

   The workshop commenced with welcome address by Dr. G. Padmanabham, Director, ARCI and inaugurated by the chief guest, Prof. Bhaskar Ramamurthi, Director, IIT Madras. The workshop also aimed at the popularization of the clean technologies along with the understanding of its current status among the developers, suppliers and users in India. An interactive panel discussion was also conducted as the part of the workshop to understand intricacies involved in hydrogen and fuel cell based clean technologies. The panel was chaired by Dr. G. Padmanabham, Director, ARCI and the panellist comprised of notable experts of the field from Indian Government funding agencies, industries and academics like DST, MNRE, GAIL, ARAI, TERI, CSIR-CGCRI, BHEL, Chiyoda Corporations, Siemens, and CFCT. The workshop witnessed immense participation around 150, which is increasing from last year, from various institutions across the country . A poster presentation competition pertaining to the theme of the workshop was conducted and the awards were sponsored by Deakin University, Australia and M/s. Coatema, Germany.

6. Two-day training programme on 'Procurement through Government e-Marketing Place (GeM)' was organized at ARCI, Hyderabad during March 10-11, 2020. GeM Telangana Officials conducted the programme and about 100 ARCI personnel attended the training programme.

Human Resource Development

Recognition of ARCI as an External Centre for Carrying Out Ph.D. Research

A. **Foreign University** - Deakin University, Australia

B. **Indian Academic Institutions/Universities -** Apart from the above, the following Indian academic institutes recognized ARCI as an External Centre for carrying out Ph.D. Research. Accordingly, interested ARCI employees, Project Scientists and Research Fellows are encouraged to register for Ph.D. (as per university norms) at the Institute/University.

1.	Indian Institute of Technology – Bombay
2.	Indian Institute of Technology – Kharagpur
3.	Indian Institute of Technology – Kanpur
4.	Indian Institute of Technology – Hyderabad
5.	Indian Institute of Technology – Madras

6.	National Institute of Technology – Warangal
7.	National Institute of Technology – Tiruchirappalli
8.	University of Hyderabad (Central University) – Hyderabad
9.	Andhra University – Visakhapatnam

List of Project Scientits/Research Fellows who Completed Ph.D. during the year 2019-20

Name of the Project Scientist/Fellow	Topic	Ph.D. Registered at	Degree Awarded on
Dr. N. Manjula	Development of Advanced Electrochemical Methanol Reformation for Hydrogen Production in Proton Exchange Membrane Electrolysis Cell	National Institute of Technology, Warangal	08.01.2020
Dr. K. Hari Gopi	Studies of New Anion Exchange Membranes for Alkaline Polymer Electrolyte Fuel Cells	University of Madras, Chennai	19.11.2019
Dr. Hari Mohan	Synthesis and Characterization of Nano Structured Electrodes for Li-s Batteries	National Institute of Technology, Warangal	04.10.2019
Dr. NS Anas	Microstructure, Mechanical and Tribological Properties of Al Alloy-CNT Composites	University of Hyderabad (HCU)	27.08.2019
Dr. Puneet Chandran	Design and Development of Hard Protective Coatings on Cutting Tools for Dry Machining Applications	National Institute of Technology, Warangal	26.08.2019
Dr. Anusree Unnikrishnan	Experimental and Modeling Studies of High Temperature Polymer Electrolyte Membrane Fuel Cell Performance Under Poisoning Conditions	Indian Institute of Technology, Hyderabad	10.08.2019
Dr. Bolla Reddy Bodapati	Uniaxial Compression and Spherical Indentation Behaviour of Porous Cu	Indian Institute of Technology, Hyderabad	10.08.2019

Post Doctoral Fellows, Research Scholars, Senior /Junior Research Fellows, Post Graduate/ Graduate Trainees and M.Tech. /B.Tech. /M.Sc. Project Students joined during the Year at ARCI

DST - Inspire Faculty	01
SERB – Research Scientist	-
SERB – National Post Doctoral Fellowship	-
INSA Visiting Scientist Fellowship	-
Post Doctoral Fellows/Research Scholars	10
DST Women Scientist – A (WOS – A)	-
Visiting Scholars under Bilateral agreements	02

Senior Research Fellow	07
Junior Research Fellow	18
Post Graduate Trainees	16
Graduate and Diploma Trainees	13
M. Tech. Project Students	31
Diploma/B. Tech. / M.Sc. Projects Students	20
Summer Research Interns	57

Project Scientist/ Research Fellows whose Ph.D. is Ongoing

List of Project Scientists (as per date of Ph.D. registration)

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
1.	VVN Phani Kumar	Investigation on Natural and Synthetic Polymer as on Aqueous Binder for Anode of Li-Ion Battery (Li-Bs)	National Institute of Technology, Warangal

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
2.	JA Prithi	Corrosion and Impurity Tolerance Study of Platinum Electrocatalysts for Proton Exchange Membrane Fuel Cells	Indian Institute of Technology, Madras
3.	K. Nanaji	Development of Porous Carbon Electrode Materials for Super Capacitors	Indian Institute of Technology, Madras
4.	Sumit Ranjan Sahu	Carbon Nano Horns based Anode Material for Lithium-Ion Battery	Indian Institute of Technology, Madras
5.	Ravi Gautam	Microstructure- Magnetic Properties Correlation of Fe-P based Soft Magnetic Alloy	Indian Institute of Technology, Madras
6.	Amol C. Badgujar	Development of Copper Indium Gallium Diselenide CIGS Solar Cells by Non-Vacuum Techniques	Indian Institute of Technology, Bombay
7.	Vallabharao Rikka	Study on Ageing Mechanism of Lithium Ion Battery	Indian Institute of Technology, Bombay
8.	Kumari Konda	Electrochemical Performance of various Cathode Materials using Half and Full Cell	Indian Institute of Technology, Bombay
9.	S. Vasu	Enhancement of Cycle Life Lithium Ion Battery by In-situ Carbon Encapsulation on Layered Oxide based Cathode Materials	Indian Institute of Technology, Madras
10.	Srinivasa Rao Atchuta	Development of Stable Selective Solar Absorber Coating for Concentrated Solar Thermal Application	AcSIR – National Aerospace Laboratories, Bangalore
11.	P. Mahender	Development of Composite Cathode Materials for High Energy Density Li-ion Battery	Indian Institute of Technology, Madras
12.	Muni Bhaskar Siva Kumar	Microstructure – Magnetic Properties Correction in Grain Boundary Diffused NdFeB Magnetic Material	Indian Institute of Technology, Madras
13.	Pothula Vijaya Durga	Processing and Evaluation of Micro Structural and Mechanical Properties of Oxide Dispersion Strengthened Iron Aluminides for High Temperature Applications	Indian Institute of Technology, Madras
14.	Puppala Laxman Mani Kanta	Development of High Energy Density Electrode Materials for Sodium Ion Battery	Indian Institute of Technology, Madras
15.	G. Vijayaraghavan	Microstructure-Property Correlation of High Performance Sm-Fe-N Permanent Magnetic Materials	Indian Institute of Technology, Madras
16.	S. Ramakrishnan	Corrosion protection Coatings on Metallic Flow Field Plates for PEM Fuel Cell (Lt-PEM)	Indian Institute of Technology, Kanpur
17.	Md. Ayub Shareef	Alternate Energy Devices Development and Testing like Batteries and Fuel cell for Niche Market	Indian Institute of Technology, Madras
18.	Minati Tiadi	Nanoscale Thermoelectric Materials and Devices for Sustainable Applications	Indian Institute of Technology, Madras

Research Fellows whose Ph.D. is Ongoing (as per date of Ph.D. registration)

Sl. No	Name of the Student Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
1.	L. Subhashini	Laser- MIG Hybrid Welding of Thick Sections of High Alloy Steels in a Single Pass	University of Hyderabad, Hyderabad
2.	P. Tejassvi	Electro Spun Nano Fibrous Materials Li-ion and Li-s Batteries	National Institute of Technology, Warangal
3.	S. Bhuvaneshwari	Synthesis, Structure, Morphology and Electrochemical performance of Scandium Doped Li Magnate Spinel Phases as Lithium Ion Battery Cathode Materials	Indian Institute of Technology, Madras
4.	T. Ramesh	Development of Novel Porous Carbons using Agricultural Biomass for High Performance and Cost Effective Electrodes for Supercapacitor Application	National Institute of Technology, Warangal
5.	PM Pratheeksha	Development of Nano Structured Electrodes for High Energy Density Lithium Ion Battery Applications	National Institute of Technology, Warangal

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
6.	VV Ramakrishna	Micro Structure and Magnetic Property Correlation in Permanent Magnets	National Institute of Technology, Tiruchirappalli
7.	S. Sasikala	Aluminium Distribution Induced H2⇔H3 Phase Reversibility Resulting in Improved rate Capability of Lini1-x-yCoxAiyO2 with increased Voltage and Temperature Window	Indian Institute of Technology, Madras
8.	S. Harish	Design, Development, Performance evaluation of Optimization of Engineering Parameters of Thermoelectric Generator System for Automotive Exhaust Waste Heat Recovery	Indian Institute of Technology, Madras
9.	Imran Karajagi	Studies and Development of Metal-Air Batteries	Indian Institute of Technology, Bombay
10.	S. Manasa	Nano Clay-based Self-Healing, Corrosion Protection Coatings on Aluminium Alloys AA2024-T4 and A356.0	National Institute of Technology, Warangal
11.	B. Divya	Fabrication of Solar Cell Photovoltaic Energy System using Pulsed-Electrodeposited CIGS Absorber layer under n-type CdS Semiconductor Film Window	National Institute of Technology, Warangal
12.	T. Mitravinda	Design and Development of Electrode Active Materials for Supercapacitor Application	Indian Institute of Technology, Hyderabad
13.	Brijesh Singh Yadav	Development and detailed Investigation of Chalcopyrite CIGS Absorber layer	Indian Institute of Technology, Hyderabad
14.	B. Jayachandran	Interface Engineering of High Temperature Thermoelectric Materials and its effect on the Thermoelectric Device Performance	Indian Institute of Technology, Bombay
15.	M. Shiva Prasad	Development of Solar Selective Absorber Coatings for Concentrating Solar Power Applications	National Institute of Technology, Warangal
16.	B. Priyadarshini	Synthesis and Investigation of Nanostructured Thermoelectric Materials for Waste Heat recovery Applications	National Institute of Technology, Tiruchirappalli
17.	Keerthi Sangamitra Kollipara	Study of Thermo-physical Properties of Aerogel Products for Thermal Insulation Application	National Institute of Technology, Warangal
18.	Shaik Mubina	Processing and Properties Evaluation of Carbon nanofibers Dispersed SiC based Composites	National Institute of Technology, Warangal
19.	Y. Madhavi	Plain High Cycle Fatigue and Corrosion-Fatigue Behavior of Micro Arc Oxidation Coated 6061-T6Al Alloy	National Institute of Technology, Warangal
20.	Swapnil Hanmant Adsul	Nano Clay- based Self – Healing Corrosion Protection Coatings on Magnesium Alloys	National Institute of Technology, Warangal
21.	Adigilli Harish Kumar	2D-Nanolayered WS2 based Self Lubricating Composites	National Institute of Technology, Warangal
22.	Mohd. Aqeel	Suitability of Laser Hybrid Welding of Inconel 617 Alloy for Steam Boilers	University of Hyderabad, Hyderabad
23.	E. Anusha	Optimization and Control of Heat Input in Laser Based Manufacturing Processes	National Institute of Technology, Warangal
24.	V.P. Madhurima	Synthesis of Carbon Nano Materials and their Composites	National Institute of Technology, Warangal
25.	P. Samhita	Development of Nano structure Metal Oxide based Electrode Material for Super Capacitor	Indian Institute of Technology, Hyderabad
26.	KK Phani Kumar	Development of Nano Composite Based Solar Selective Absorber Coatings	Indian Institute of Technology, Bombay
27.	P. Sreeraj	Studies on Precious Component recovery form PEM Fuel Cell	Indian Institute of Technology, Bombay
28.	Narendra Chundi	Development of Anti Soiling Coatings and their Evaluation for Applications in Photovoltaic Modulus	Indian Institute of Technology, Bombay
29.	Battula Ramya Krishna	Detailed Investigation on the Degradation of Organo Metal Halide Perovskite Solar Cells	Indian Institute of Technology, Madras

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
30.	Surabattula Yasodhar	Multiphase Flow Analysis and Performance of Aqueous Methanol Electrolyser	Indian Institute of Technology, Madras
31.	V. Sai Harsha Swarna Kumar	Development of Metallic Bipolar Plates of PEM Electrolyser for Hydrogen Production	Indian Institute of Technology, Madras
32.	Gudimella Tirumala Harini	Synthesis of Titanium Foams for PEMFC as Gas Diffusion Layer cum Flow Field Plates	Indian Institute of Technology, Madras
33.	A.B. Aravind	Development of Secondary Aluminium based Batteries.	National Institute of Technology, Tiruchirappalli
34.	M. Tarun Babu	Structure Property Correlation of Cold Sprayed Aluminium Alloys	Indian Institute of Technology, Madras
35.	D. Chandrakala	Studies on the Effect of Processing Parameters and Evaluation of Properties for the Development of Low Dielectric Materials	National Institute of Technology, Tiruchirappalli
36.	D. Nazeer Basha	Laser Surface Texturing of Automotive Engine Components using Ultrafast Laser	Indian Institute of Technology, Madras
37.	Bathini Lava Kumar	Fatigue and Corrosion Fatigue of PED Coated Monolayer and Multilayer Ni-W Coatings	Indian Institute of Technology, Bombay
38.	K. Sriram	Development of Conductive and Corrosion Resistant Coatings over Metallic Bipolar Plates for PEM Fuel Cells Applications	Indian Institute of Technology, Madras
39.	M. Venkatesh	Development of Low Cost and High Specific Energy Electrode Materials for Sodium-Ion Battery	Indian Institute of Technology, Madras
40.	Vikrant Trivedi	Nanostructured Cosb3 Type Skutterudite Thermoelectro Materials for waste Heat Energy recovery Application	Indian Institute of Technology, Madras
41.	P. Raju	Investigations on the Applicability of Pressure Slip Casting for Al2O3 and Al2O3-TiO2 & Al2O3-ZrO2 Systems.	National Institute of Technology, Warangal
42.	D. M. Santoshsarang	Design and Modelling of Residual Stresses of additive Manufacturing	Indian Institute of Technology, Madras
43.	S. Mamatha	Nearnet shaping of Simple and Complex Ceramic Parts by 3D Printing and Investigations of the Thermo-Mechanical and Microstructural Properties	University of Hyderabad, Hyderabad
44.	Jyothi Gupta	Investigation of Efficient and Stable Nanostructured Mo based Chalcogenides Electrocatalyst for Hydrogen Evolution Reaction	University of Hyderabad, Hyderabad
45.	B. Amarendhar Rao	Laser Assisted Machining of Nickel based Super Alloys IN617, IN625 with Surface Textured Carbide Cutting Tools	National Institute of Technology, Warangal
46.	K. S. Srin	Laser Assisted Micromachining for Self Cleaning Application	Indian Institute of Technology, Kanpur
47.	Kanchi Anjali	Microstructural studies on refractory multi component alloys	University of Hyderabad, Hyderabad
48.	Rahul Jude Alroy	Process - Structure - Property correlation of HVAF sprayed Cr3C2 - NiCr Coatings for enhanced erosion resistance	Indian Institute of Technology, Madras
49.	Aarti Gautam	Self Healing Corrosion Protection Coatings on Mild Steel	National Institute of Technology, Warangal
50.	A. R. Dilipan	High Entropy Alloy based Permanent Magnetic Materials	Indian Institute of Technology, Madras
51.	K. Reshma Dileep	Carbon based Perovskite Solar Cell	Indian Institute of Technology, Bombay
52.	Guduru Neelima Devi	Ongoing Course work	National Institute of Technology, Warangal
53.	Harita Seekala	Ongoing Course work	Indian Institute of Technology, Madras

Visits by Students and Faculty to ARCI

1. 45 M.Sc. & B.Sc. (Physics) students & faculty from Sarojini Naidu Vanita Maha Vidyalaya, Hyderabad visited ARCI on April 18, 2019.
2. 24 Ph.D. & M.Sc. (Nanotechnology) students & faculty from University of Agricultural Sciences, Raichur, Karnataka visited ARCI on October 17, 2019.
3. 50 M.Tech. (Nano Science & Technology) students & faculty from JNTU-Hyderabad visited ARCI on November 8, 2019.
4. 32 B.E. (Nano Technology) students & faculty from Srinivas Institute of Technology Mangaluru, Karnataka visited ARCI on November 13, 2019.
5. 25 Scientists from various Govt. Departments who participated in ASCI's program on "Science Administration and Research Management" visited ARCI on November 13, 2019.
6. 32 M.Sc. (Chemistry) students & faculty from Central University of Kerala, Kasaragod visited ARCI on November 26, 2019.
7. 17 participants from various Govt. Departments who participated in DST programme on "Enhancing Accountability & Responsiveness in Scientific Organizations" being held at the Institute of Public Enterprise, Osmania University, Hyderabad visited ARCI on December 5, 2019.
8. 8 delegates from Indian Chamber of Commerce (ICC), Hyderabad visited ARCI on December 13, 2019.
9. 40 BSc. (Physics) students & faculty from Bhavans Vivekananda College, Sainikpuri visited ARCI on December 20, 2019.
10. 17 faculty from various colleges & universities who participated in DST sponsored FDP Entrepreneurship Development Programme at MSME, Hyderabad visited ARCI on January 1, 2020.
11. 39 B.Tech. (Metallurgical & Materials Engineering) students from National Institute of Technology (NIT), Warangal visited ARCI by January 31, 2020.
12. 35 B. Tech. (Mechanical Engineering) students from Vivekananda Institute of Technology & Science (VITS), Karimnagar visited ARCI on February 18, 2020.
13. 17 Scientists from various Govt. Departments who participated DST sponsored programme at ASCI, Hyderabad visited ARCI on March 4, 2020.
14. 14 M.Tech (Mechanical Engineering) students & faculty from National Institute of Technology (NIT), Warangal visited ARCI on March 5, 2020.

Summer Research Internship Programme

Students from IIT's, NIT's, IIIT's, Central Universities and various other state and private universities from all over the country were short-listed for availing Summer Research Internship Programme (SRIP) at ARCI, Hyderabad and Chennai Centres for the year 2019. 57 students, who were selected, have attended the programme from 17th May, 2019 for a minimum period of 45 days to a maximum period of 60 days. The selected students initially underwent a week long orientation course at various Centres of Excellence so as to get familiar with the activities being carried out at ARCI. Each student was guided by a scientist to carry out a mini project. The students were issued certificates on successful completion of the programme.

Regular/Contract Appointments

ARCI has added the following employees to its fold to take up varied responsibilities:

Employee Name	Designation	Date of Joining
Dr. Shiv Prakash Singh	Scientist (Contract)	01.11.2019
Amit Das	Scientist "B"	28.02.2020

Promotions

ARCI has been following its existing assessment and promotion policy since the year 2000-01. As per the policy, assessments were carried out for all eligible employees and the following were promoted during the year 2019-20:

Name of the Promotees	Effective Date	Promotion for the post	
		From	To
P. Venkata Ramana	July 1, 2019	Officer "A"	Officer "B"
Ravi Singh	July 1, 2019	Assistant "B"	Officer "A"
Gaje Singh	July 1, 2019	Lab. Assistant "D"	Technician "A"
Hussain Ali Khan	July 1, 2019	Lab. Assistant "C"	Lab. Assistant "D"
Dr. R. Vijay	October 1, 2019	Scientist "F"	Scientist "G"
Dr. R. Prakash	October 1, 2019	Scientist "E"	Scientist "F"

Name of the Promotees	Effective Date	Promotion for the post	
		From	To
Dr. S.M. Shariff	October 1, 2019	Scientist "E"	Scientist "F"
Dr. D. Siva Prahasam	October 1, 2019	Scientist "E"	Scientist "F"
Dr. B.V. Sarada	October 1, 2019	Scientist "E"	Scientist "F"
K.V. Phani Prabhakar	October 1, 2019	Scientist "E"	Scientist "F"
Manish Tak	October 1, 2019	Scientist "D"	Scientist "E"
Dr. Papiya Biswas	October 1, 2019	Scientist "D"	Scientist "E"
Dr. Gururaj Telasang	October 1, 2019	Scientist "D"	Scientist "E"
Dr. R. Easwaramoorthi	October 1, 2019	Scientist "D"	Scientist "E"
R. Senthil Kumar	October 1, 2019	Scientist "D"	Scientist "E"
K. Divya	October 1, 2019	Scientist "B"	Scientist "C"
P. Rama Krishna Reddy	October 1, 2019	Technical Officer "C"	Technical Officer "D"
B.V. Shalini	October 1, 2019	Technical Officer "B"	Technical Officer "C"
N. Venkata Rao	October 1, 2019	Technical Officer "B"	Technical Officer "C"
M. Srihari	October 1, 2019	Technical Officer "B"	Technical Officer "C"
K. Ramesh Reddy	October 1, 2019	Technical Officer "A"	Technical Officer "B"
N. Aruna	October 1, 2019	Technical Officer "A"	Technical Officer "B"
R. Anbarasu	October 1, 2019	Technical Officer "A"	Technical Officer "B"
D. Krishna Sagar	October 1, 2019	Technician "D"	Technician "E"
K.V.B. Vasantha Rayudu	October 1, 2019	Technician "D"	Technician "E"
G. Venkata Rao	October 1, 2019	Technician "D"	Technician "E"
A. Janga Reddy	October 1, 2019	Technician "C"	Technician "D"
Kurra Venkata Ramana	October 1, 2019	Technician "C"	Technician "D"
Govinda Kumar	October 1, 2019	Technician "C"	Technician "D"
I. Prabhu	October 1, 2019	Technician "B"	Technician "C"
Ch. Jangaiah	October 1, 2019	Technician "B"	Technician "C"

Superannuation

Employee Name	Designation Held	Date of Superannuation
B. Uday Kumar	Officer "B"	30.06.2019

Resignations

Employee Name	Designation Held	Date of Relieving
Dr. Supriya Chakrabarti	Scientist (contract)	31.07.2019
Paila Santosh Kumar	Technical Assistant "A"	25.10.2019
Achinta Mondal	Assistant "A"	24.02.2020

Reservations and Concessions

The Reservations and Concessions for SCs/STs/OBCs and persons with disabilities are followed as per Government of India orders from time to time. At ARCI, the overall representation of employees under SC is 18.51%, S.T is 4.32%, OBC is 26.54% and that of persons with disabilities is 1.85% as on March 31, 2020.

Faculty Internship Programme

Under Faculty Internship Programme, teaching faculty from Engineering colleges who are interested to be associated with research work, to carry out part of their research work or wanted to become familiar with latest R&D activities and facilities are permitted to work for a period of 2 to 8 weeks during their vacation.

Outreach Programme under Scientific Social Responsibility

Some of the Scientists on voluntary basis have visited nearby government schools and delivered motivational talks / science talks for the benefit of the school students. On invitation by reputed government/private engineering colleges, scientist delivered lectures in the area of their specializations and shared their research experiences with the faculty and students.

A. Lectures by Indian and Foreign Visitors

S.N	Name of the Visitor	Designation	Affiliation	Lecture Title	Date
1.	Dr. B. Ravi	Institute Chair Professor- Mechanical Engineering	Indian Institute of Technology (IIT) Bombay, Mumbai	Innovation Eco-System: from Idea to Impact	May 09, 2019
2.	Dr. Aravind Chinchure	Founder & CEO Chair Professor of Innovation and Entrepreneurship	QLeap Academy Symbiosis International University, Pune	Achieving Leadership in Scientific Research for Academic, Industrial and Societal Impact	June 12, 2019
3.	Dr. Raju Ramanujan	Professor	Nanyang Technological University (NTU), Singapore	Accelerated Development of Magnetic Materials	July 11, 2019
4.	Dr. A. Subrahmanyam	Professor	IIT Madras, Chennai	Kelvin Probe Technique for Surface Work Function Measurements	July 15, 2019
5.	Dr. J. Wayne Jones	Arthur F. Thurnau Professor Emeritus Materials and Metallurgical Engineering	University of Michigan, USA	From Defects to Microstructure Neighborhoods: A Review of Ultrasonic Fatigue Techniques in Assessing Very High Cycle Fatigue in Structural Alloys	Sept. 26, 2019
6.	Dr.Ghanshyam Acharya	Associate Professor	Baylor College of Medicine, USA	Nanofabricated Drug Delivery Systems- Design and Clinical Translation	Oct. 16, 2019
7.	Dr. Swaminathan Sivaram	Honorary Professor and INSA Senior Scientist	Indian Institute of Science Education and Research, Pune	Lithium Ion Battery Technology and Business Challenges	Dec. 04, 2019
8.	Dr. Warren C. Oliver	Adjunct Professor Senior Scientist	University of Tennessee KLA Corporation, USA	Recent Advances in Materials Characterization using Instrumented Indentation Tests	Dec. 12, 2019
9.	Mr. Thibault Azam	Sales Director	Tekna India, Chennai	Advanced Material Manufacturing by TEKNA Induction Coupled Plasma	Dec. 16, 2019
10.	Dr. K.V. Gobi	Professor	National Institute of Technology (NIT), Warangal	Electrochemical Science and Technology for Portable On-site Sensor Systems	Jan. 13, 2020
11.	Dr. Mukundan Thelakkat	Professor	University of Bayreuth, Germany	Polymer-based Batteries- all Solid-State Electrical Energy Storage	Feb. 03, 2020
12.	Dr. Simon P. Ringer	Professor	The University of Sydney, Australia	Atomic-Scale Materials Design and the Enabling Role of Advanced Microscopy and Computational Simulation	Feb. 07, 2020
13.	Dr. Sai Rama Krishna Malladi	Assistant Professor	IIT Hyderabad	Challenges with In-Situ Electron Microscopy: Heating, Environmental and Liquid Cells	Feb. 19, 2020

B. Indian and Foreign Visitors for Technical Discussion

1. Mr. Jens Dreshsel, Managing Director, Crea Phys, Germany and Mr. Paul Bane, Managing Director, MBraun, U.K. visited on April 04, 2019.
2. Dr. Stephen P. Gaydos and Mr. William W. Cottle, The Boeing Company, USA visitedon May 06, 2019.
3. Dr. Oksana Golovynia, Senior Researcher, M.N Mikheev Institue of Metal Physics, Russia visited ARCI- Chennai on July 15, 2019.
4. Dr.Thomas Kolbusch, Vice President, Coatema, Germany visited ARCI-Chennai on September 03, 2019.
5. Mr. Moses Kigozi, Ph.D Scholar, African University of Science andTechnology, Nigeria carried out R&D work at ARCI as a visiting scholar during September 11, 2019 - March 10, 2020.
6. Two students from Japan Advanced Institute of Science and Technology (JAIST), Japan visited ARCI-Chennai and worked on 'Evaluation of Pt-based Electrocatalysts' during September 15-30, 2019.
7. Dr. Abdulahakeem Bello, Faculty- Materials Department, African University of Science and Technology, Nigeria carried out R&D work at ARCI as a visiting faculty during September 16-October 15, 2019.
8. Mr. Wolfgang Betz, Director-Sales, Physical Electronics visited on October 16, 2019.
9. Dr. Masuda, Nobuhisa, Chief of Operations, Chiyoda Corporation, Japan visited ARCI-Chennai on October 18, 2019.
10. Dr. Sunder V. Atre, Endowed Chair of Manufacturing and Materials, Director of AMIST, University of Louisville, USA visited on October 23, 2019.
11. Dr. Manikandan Ramani, Director, Plug Power, USA visited ARCI-Chennai on December 17, 2019.
12. An Engineeering team from JSR Micro, Japan visited ARCI- Chennai on January 06, 2020.
13. Mr. Andeks Thelander, Official , GE Additive, Sweden visited on January 07, 2020.
14. Mr. Ralf Edinger, Official, Canmora Tech Inc., Canada visited on January 10, 2020.
15. Mr. Jacobi Nardi, Official, Rina Consulting Centro Sviluppo Materiali SpA, Italy visited on January 23, 2020.
16. Mr. Louis Mussa, Director of Business Development, LK Metrology, UK visited on January 24, 2020.
17. Mr. Amanda J. Saville, Mr. Paramel P. Rajeev Mr. Stephen P. Blake, Mr. Charlotte E. Sanders, Mr. Martin K. Tolley, Mr. Daniel R. Symes, Mr. Tinesimba M. Zata and Mr. Sam H. Astbury, Officials from U.K Science and Technology Facilities Council (STFC), U.K and STC Rutherford Appleton Lab, U.K. visited on January 29, 2020.
18. Dr. V. K. Saraswat, Honourable Member, NITI AYOG, New Delhi visited ARCI on February 03, 2020.
19. Mr. Rajiv Bhatia, Director, Ind Aust Maritime Pvt. Ltd, Mumbai visited ARCI-Chennai on February 20, 2020.

C. Visits Abroad

1. Dr. Easwaramoorthi Ramaswamy visited Stanford University, California, USA during April 01, 2019 - September 30, 2019 under the 'Bhaskara Advanced Solar Energy (BASE) Fellowship' to study the stability of perovskite solar cell at Stanford Synchrotron Radiation Lightsource (SSRL).
2. Ms. E. Anusha (Dr. S.M. Shariff) visited Miami, Florida, USA during April 14-18, 2019 to participate in the '22nd International Conference on Wear of Materials' and made a poster presentation on "Diode Laser Surface Treatment of Bearing Steel for Improved Sliding Wear Performance".
3. Dr. R. Balaji visited Vancouver, Canada during May 21-24, 2019 to participate in the 'F-Cell+HFC Conference and Expo' and presented a paper on "PEM fuel cell Activities at Advanced Research Centre International (ARCI)".
4. Mr. K. Nanaji visited Dallas, USA during May 26-31, 2019 to participate in the '235th Electro Chemical Society (ECS) Meeting' and presented a paper on "Graphene like Porous Carbon Sheets derived from Hibiscus Cannabinus as a Versatile Electrochemical Energy Storage Material".
5. Mr. Sumit Ranjan Sahu visited Dallas, USA during May 26-31, 2019 to participate in the '235th ECS Meeting' and presented a paper on "Effect of Carbon Nanohorns on the Electrochemical Performance of Orthorhombhic, Hexagonal and Monoclinic Tungsten Trixode Nanoplatelets as High Energy Anode Material for Lithium-Ion Batteries".
6. Ms. J.A.Prithi visited Dallas, USA during May 26-31, 2019 to participate in the '235thECS Meeting' and presented a paper on "Evaluation of Carbon Support Corrosion using Accelerated Stress Protocol and Impedance Spectroscopy".
7. Dr. G. Padmanabham visited France during June 04-07, 2019 to attend, as a Member, the Industrial Research Committee (IRC) meeting of the Indo-French Centre for the Promotion of Advanced Research (IFCPAR/CEFIPRA).
8. Dr. N. Rajalakshmi visited Boston, U.S.A during June 17-19, 2019 to participate in the 'Tech Connect – World Innovation Conference and Expo' and deliver an invited talk on "PEMFC Technology at ARCI-CFCT: Challenges and Perspective".
9. Dr. Bijoy Kumar Das visited Singapore during June 23-28, 2019 to participate in the '10th International Conference on Materials for Advanced Technologies (ICMAT)' and presented a paper on "Improved Electrochemical Performance of Iron and Cobalt Co-Substituted Layered P2-Na0.67MnO2Cathode Material for Sodium-Ion Battery Application".
10. Mr. Amol C. Badgujar visited Singapore during June 23-28, 2019 to participate in the 'ICMAT' and presented a paper on "Pulsed Nanosecond Laser Sintering of CIGS Nanocrystal Thin Film for Solar Cell Application".
11. Ms. S. Bhuvaneswari (Dr. Raju Prakash)visited Singapore, during June 23-28, 2019 to participate in the 'ICMAT' and made a poster presentation on "LiSc0.06Mn1.94O4 as Prospective Cathode for Lithium Ion Batteries for Mobility Application".

12. Mr. S. Harish (Dr. D. Sivaprahasam) visited South Koreaduring June 30-July 04, 2019 to participate in the '38th International Conference on Thermoelectrics (ICT 2019)' and presented a paper on "Assessing the Degradation Behavior of Thermoelectric Module in an Automotive Exhaust Thermoelectric Generator".
13. Ms. B. Priyadarshini(Dr. Manjusha Battabyal)visited South Koreaduring June 30-July 04, 2019 to participate in the 'ICT 2019' and presented a paper on "Effect of carbon nanotube dispersion on the thermoelectric properties in Zinc Antimonide".
14. Dr. S. Sakthivel visited Berlin, Germany during July 24-26, 2019 to participate in the 'International Conference on Concentrated Solar Power and Technology (ICECTSP-2019)' and presented a paper on "Cost efficient receiver tube technology for eco-friendly concentrated solar thermal (CST) applications". He also visited Institute for Technical Chemistry of the Leibniz Universität Hannover, Institute for Solar Energy Research, Hammeln, and Leibniz Institute for New Materials, Saarbrucken and delivered lectures on "Cost efficient Absorber and Easy to Clean Coating Technology for Eco-friendly CST and Photovoltaic (PV) Applications" and "Cost Efficient Functional Materials and Coatings Developments for Eco-friendly Solar Thermal and PV Applications" respectively.
15. Dr. Srinivasan Anandan, Dr. V. Pavan Srinivas and Mr. L. Babu visited Xiamen, China during August 17-23, 2019 for pre-dispatch inspection of equipment for the fabrication of cylindrical type supercapacitors cells.
16. Dr. Easwaramoorthi Ramaswamy, who was pursuing his BASE Fellowship at USA during 2019 participated in the 'ACS National Meeting' held at San Diego during August 25-29, 2019.
17. Mr. Ravi Gautam visited Poznan, Poland during September 03-09, 2019 to participate in the '24th Soft Magnetic Materials Conference' and made a poster presentation on "Influence of Microstructure on the Magnetic Properties of Fe-P based Soft Magnetic Alloy".
18. Dr.R. Gopalan visited Russia during September 08-13, 2019 to a) participate in the 'VII Euro-Asian Symposium-Trends in MAGnetism (EASTMAG-2019)' and delivered a talk on "Microstructure-Microchemistry-Magnetic properties in Derivative Sm-Co Magnets" and b) for technical discussion on the BRICS project-'Nanocrystaline Hard Magnetic Sm-Co-Fe-T alloys (T=Cu, Ti, Zn and Zr)' at the M.N. Mikheev Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences.
19. Dr. Srikanti Kavita visited Ekaterinburg, Russia during September 08-13, 2019 to participate in the 'EASTMAG-2019' and presented a paper on "Magnetocaloric Effect and Huge AdiabaticTemperature Change in Mn1.15Fe0.85P0.65Si0.13Ge0.2B0.02 alloy prepared by Spark Plasma Sintering" and made a poster presentation on "Magnetic Properties of Liquid Phase Sintering Sm-Fe-N Powder with Low Melting Eutectics".
20. Ms. N. Sasikala (Dr. M. B. Sahana) visited Guildford, England during September 11-13, 2019 to participate in the 'International Conference on Advanced Energy Materials (AEM-2019)' and presented a paper on "Radial Ni/Co/Al Composition Engineering of Nano/Micro-Hierarchical Structured LiNi1-x-yCoxAlyO2: Improved Specific Energy and Stability".
21. Dr. G. Padmanabham visited Minsk, Belarus during September 25-27, 2019 to attend the 'India-Belarus Seminar on Nanomaterials and Advanced Materials' under India Belarus Science and Technology Cooperationand delivered a lecture on 'Additive Manufacturing and Challenges'; Dr. Padmanabham also visited OV Roman Powder Metallurgy Institute, Minsk for technical discussions.
22. Dr. R.Vijay visited Minsk, Belarus during September 25-27, 2019 to attend 'India-Belarus Seminar on Nanomaterials and Advanced Materials'under the India Belarus Science andTechnology Cooperationand delivered a lecture on "Development of Powders for Additive Manufacturing and Nano Powders for Various Applications"; Dr. R. Vijay also visited OV Roman Powder Metallurgy Institute, Minsk for technical discussions.
23. Mr. D. Srinivasa Rao and Dr. G. Sivakumar visited Canada during September 28-October 08, 2019 for the pre-dispatch inspection of Axial Feed High Energy Plasma Spray System at Northwest Mettech Corporation.
24. Dr. P. Sudharshan Phani visited Spain during September 28-October 09, 2019 to a) participate in the 'ECI Conference on Nanomechanical testing in Materials Research and Development VII' and delivered a talk on "Measurement of Hardness and Elastic Modules by Depth Sensing Indentation: Further Advances in Understanding and Refinements in Methodoogy". He also delivered an invited talk on 'Advances in Nanomechanical Characterization' at the University of Rome.
25. Dr. Dibyendu Chakravarty visited Portland, U.S.A during September 28-October 13, 2019toparticipate in the 'International Conference onMaterials Science and Technology (MS&T19)' and presented a paper on "Development of Tungsten based Plates by Spark Plasma Sintering". He also visited University of Colorodo and Boulderand Thermal Technology LLC, California for technical discussions.
26. Dr. G. Padmanabham visited Ankara, Turkey during October 03-04, 2019 for inspection of 10kW Laser Arc Hybrid Welding System at M/s. Intecro Robotic A.S.
27. Dr. S. Sakthivel visited Cologne, Germany during October 17-18, 2019 to participate in the 'Bilateral Workshop on Solar Thermal Chemical Technologies for Green and Sustainable Development' and deliverd an invited lecture on "Cost Efficient Receiver Tube Technology for Medium and High Temperature Concentrated Solar Thermal Applications".
28. Shri D. Srinivasa Rao and Dr. G. Sivakumar visited Kermetico Inc., USA during October 26-November 04, 2019 for the pre-dispatch inspection of equipment - Activated Combustion-High Velocity Air-Fuel Spray System.
29. Mr. Srinivasa Rao Atchuta visited Santiago, Chile during November 04-09, 2019to participate in

the 'International Solar World Congress-2019' and presented a paper on "High Temperature Stable Spinel Nanocomposite Solar Selective Absorber Coating for Concentrated Solar Thermal Applications".

30. Dr. D. Prabhu and Dr. V. Chandrasekaran visited Kyoto, Japan during November 03-09, 2019 to procure the New Pressless Processing of Rare Earth Magnets (NPLP) equipment from NDFEB Corporation.
31. Dr. R. Gopalan, visited Las Vegas, U.S.A. during November 04-08 to participate in the 'Magnetism and Magnetic Materials Conference 2019' as a programme sub committee member and presented a paper on "Effect of Martensite Modulation on Magnetocaloric Properties of Ni-Mn-In". Dr. Gopalan also vsisted the University of Florida for technical discussion.
32. Dr. Bijoy Kumar Das visited Germany during November 16-22, 2019 for training and pre-shipment inspection of Raman Spectrometerat WiTec GmbH.
33. Dr. N. Rajalakshmi visited Jakarta, Indonesia during December 14-21, 2019 to participate in the '1st Working Group Meeting for Demand and Supply Potential of Hydrogen Energy in EAS Region' and delivered a lecture on "ARCI's Initiatives towards Hydrogen Technology".

D. Lectures by ARCI Personnel in India

S.N	Name	Title	Event	Organization, Place	Date
1.	Mr. K. V. Phani Prabhakar	Laser and Laser Hybrid Welding of Various Materials used in Strategic Sector	Metalfairs 2019 Exhibition	Hyderabad	Apr. 03, 2019
2.	Dr. R. Balaji	An Alternative Fuel for Cleaner Environment	National Conference on Clean Energy	Sathyabama University, Chennai	Apr. 11, 2019.
3.	Dr. G. Padmanabham	Metal Additive Manufacturing	56th Foundation Day of CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT)	CSIR-IMMT, Bhubaneswar	Apr. 13, 2019
4.	Dr. G. Ravi Chandra	Introduction to Scanning Electron Microscopy and Energy Dispersive Spectroscopy	Materials Characterization – Hands-on Workshop (MCHW)	Osmania University (OU), Hyderabad	Apr. 15-19, 2019
5.	Dr. K. Suresh	Probing the nanostructures by X-ray Diffraction			
6.	Dr. Gururaj Telasang	Metal Additive Manufacturing (3D Printing)	Recent Advances in Manufacturing Processes (RAMP-2019)	K.G. Reddy College of Engineering and Technology, Hyderabad	Apr. 17, 2019
7.		Laser Metal Additive Manufacturing - Selective Laser Melting	One-week Short Term Training Program (STTP) on 3D Printing in Modern Engineering	ICFAI Foundation for Higher Education (IFHE) University, Hyderabad.	Apr. 22- 26, 2019
8.	Dr. R. Prakash	Lithium-Ion Battery Program at ARCI for Electric Mobility Application	Meeting on Establishment of Center of Excellence in Energy Storage Technologies for EV and Portable Mobile Device Applications	IIT, Bhilai	Apr. 30, 2019
9.	Dr. Roy Johnson	Advanced Materials Processing	1st International Conference on Applied Mechanical Engineering Research (ICAME)	NIT, Warangal	May 02 - 04, 2019
10.	Dr. G. Ravi Chandra	Characterization of Nanocomposite Materials by Microscopy and Scattering Techniques	Workshop on Fabrication of Nanocomposite Materials for Engineering Applications (FNMEA-2019)	NIT, Warangal	May 07 2019
11.	Dr. Sanjay Bhardwaj	Technology Commercialization	Seminar on Innovations in Chemical Sector	Nuclear Fuel Complex (NFC), Hyderabad	May 10, 2019
12.	Dr. G. Padmanabham	Additive Manufacturing: Prospects and Challenges	National Technology Day Lecture	DRDL, Hyderabad	May 20, 2019

S.N	Name	Title	Event	Organization, Place	Date
13.	Dr. Ravi Bathe	Role of Lasers in Additive Manufacturing	Workshop on 3D Printing	Defence Institute, Bengaluru	May 23-24, 2019
14.	Dr. Gururaj Telasang	Additive Manufacturing	Annual General Meeting of Indian Institute of Welding (IIW)	Hyderabad	May 28, 2019
15.	Dr.L. Rama Krishna	Out of Box Thinking to Realize Innovative Surface Engineering Technologies: A Journey from Mind to Market	National Frontiers of Engineering	IIT, Bhubaneswar	May 31- June 01, 2019
16.	Dr. Gururaj Telasang	Additive Manufacturing Facility at ARCI and Applications	Industrial Visit -CASTALL Technologies Ltd.	Hyderabad	June 14, 2019
17.	Dr. Joydip Joardar	Rietveld Refinement Techniques	Workshop on X-ray Applications in Industry	IIT Madras, Chennai	June 14-15, 2019
18.	Dr.V. Ganapathy	Advancements in Dye and Perovskite Solar Cells	Continuing Education Programme on Fabrication of Optoelectronic Devices and Sensors-Hands-on Experience (FODS 2019)	NIT, Warangal	June 17-21, 2019
19.	Dr. Dibyendu Chakravarty	Spark Plasma Sintering: A Novel Ultrafine Versatile Consolidation Tool for Emerging and Niche Applications	Workshop on Tribology for Sustainability	NIT, Srinagar	June 19-23, 2019
20.	Dr. Sanjay Bhardwaj	Technology Transfer in the Indian Ecosystem	Technology Commercialization Session	Gujarat Technological University (GTU), Ahmedabad	June 22, 2019
21.		Partnership Strategy for Science and Technology Value Chain			
22.		Engagement Models in Science and Technology Chain			
23.	Dr. G. Sivakumar	Advanced Materials Processing Technologies for Surface Engineering andRefurbishment of Gas Turbine Components	Advancements in GT Health Monitoring and Maintenance Technologies	INS EXSILA, Vishakhapatnam	June 27, 2019
24.	Dr. R. Subasri	Sol-Gel Derived Nano-Composite Coatings for Diverse Applications	26th International Symposium on Metastable, Amorphous and Nanostructured Materials (ISMANAM 2019)	Chennai	July 08-12, 2019
25.	Dr. Manjusha Battabyal	Enhancing the Thermoelectric Properties in Filled CoSb3Skutterudites by Doping and Nanostructuring			
26.	Dr. P. Sudharshan Phani	Novel High Resolution, High Speed Indentation Mapping			
27.	Dr. Joydip Joardar	2D-WO_3 and WS_2/WO_3 Heterostrucrure Formation by Oxidation of 2D-Nanolayered WS_2			
28.	Dr. Gururaj Telasang	Powder Bed Metal Additive Manufacturing	Faculty Development Program (FDP) on Advancement in Additive Manufacturing	CMR Institute of Technology, Bengaluru	July 10, 2019
29.	Dr. G. Padmanabham	Additive Manufacturing	Short Course on Metallurgy for Non-Metallurgists	IIM-Hyderabad Chapter, Hyderabad	July 12, 2019
30.		Advanced Materials and Manufacturing Process for High Temperature Applications	Indo-Korean Workshop (INAE-NAEK)	Hyderabad	July 15, 2019
31.	Dr. R. Balaji	Hydrogen – An Alternative Fuel for Clean Environment	Dr.MGR Educational and Research Institute	Chennai	July 17,2019

S.N	Name	Title	Event	Organization, Place	Date
32.	Dr. Y. Srinivasa Rao	Advanced Ceramics: Processing and Applications	Refresher Course on Advances in Material Science and Applications	UGC-Human Resource Development Centre, JNTUH	July 26, 2019
33.		Issues involved in Advanced Ceramic Technology Development			
34.	Dr. G. Ravi Chandra	Introduction to Materials Characterization	Faculty Development Programme	NFC, Hyderabad	July 30 2019
35.	Dr. Ravi Bathe	Laser based Metal Additive Manufacturing	India-Fraunhofer Additive Manufacturing Workshop 2019	National Chemical Laboratory (NCL), Pune	July 30, 2019
36.	Dr. Bijoy Kumar Das	Towards Rechargeable Sodium-Ion Battery- Materials Challenges and Developments	3rd International Conference on Advanced Materials (ICAM)	Kottayam	Aug. 09-11, 2019
37.	Dr. G. Padmanabham	Surface Engineering and Additive Manufacturing of Aerospace Components	Seminar on Modernisation and Sustenance Plans of the Indian Air Force	Indian Air Force, Delhi	Aug.22, 2019
38.	Dr. T.N. Rao	Translational Nanomaterials Research from Lab to Market	National Seminar on Nanotechnology – the Fascinating World of Science	Anna Adarsh College for Women, Chennai	Aug.22, 2019
39.	Dr. Pramod H. Borse	Sensor Technology Development- ARCI Perspective	Workshop on Advanced Sensor Material Development ASMD-19	ARCI, Hyderabad	Aug.23, 2019
40.	Dr. Dibyendu Chakravarty	Spark Plasma Sintering: A Versatile Technique for Developing High Performance Components for Niche Applications	Continuing Education Programme (CEP) on Processing of Advanced Powder Metallurgy Alloys	DMRL, Hyderabad	Aug. 26-28, 2019
41.	Dr Joydip Joardar	X-ray Diffraction: Basics and Advances	Workshop on Advanced Materials Characterization	Hyderabad	Aug.27-Sept.01, 2019
42.	Mr. K. V. Phani Prabhakar	Insight into Latest Developments in Laser based Welding Processes	Workshop on Emerging Trends in Welding and Non-Destructive Evaluation (WNDE-19)	NFC, Hyderabad	Aug.30, 2019
43.	Dr. N. Rajalakshmi	Fuel Cell Technology Development - Laboratory to Market	Indo-US Joint Workshop - Recent Advances in Advanced Biofuel Technologies; 'Biohydrogen, Fuel Cell and Biobutanol': Understanding the Challenges for Moving towards Commercialization	TERI Retreat, Gurgaon	Sept. 05-06, 2019
44.	Dr. G. Padmanabham	Some Recent Trends in Additive Manufacturing Technology, Materials and Applications	9th International Conference on 3D Printing and Additive Manufacturing Technologies (AM 2019)	Bengaluru	Sept.06, 2019
45.	Dr. V.Raman	Eco-friendly Synthetic Methods for Fuel Cell Electrocatalysts	14th International Conference on Ecomaterials (ICEM-14)	CSIR-National Institute of Inter-disciplinary Science and Technology (NIIST), Trivandrum	Sept. 15-30, 2019.
46.	Dr. N.Rajalakshmi	Nanomaterials for Energy Sector	State Level Seminar on Nanomaterials for Energy Applications	Justice Basheer Ahmed Sayeed College for Women, Chennai	Sept.16, 2019

S.N	Name	Title	Event	Organization, Place	Date
47.	Dr. V.Ganapathy	Third Generation Photovoltaics	India-UK Joint Hands on Training Program for Nanomaterials Characterization and Device Fabrication	KSR Educational Institution, Tiruchengode	Sept. 19-21, 2019
48.	Dr. M. B. Sahana	Multi-Analytical Techniques in Lithium Ion Battery Technology	Indian Analytical Science Congress 2019 (IASC-2019)	Thiruvananthapuram	Sept. 19-21, 2019
49.	Dr. T. N. Rao	Indigenous Nanomaterials-based Technologies-A Make in India Initiative	International Conference on Multifunctional Materials (ICMM-2019)	Geethanjali College of Engineering and Technology, Hyderabad	Sept.20, 2019
50.	Dr. R. Balaji	PEM based Water Electrolysis for Hydrogen Production – Present Status of R&D	National Workshop on Hydrogen Energy Technologies	Indian Institute of Science (IISc), Bengaluru	Sept.20, 2019.
51.		Hydrogen- Fuel for Sustainable Future	Department of Physics and Electronics Christ University, Bengaluru		Sept.21, 2019.
52.	Dr.L. Rama Krishna	Materials and Technologies for Defence and Aerospace Applications	Seminar on Vendor Development and Procurement Procedures with Defence and Public Sector Units	Confederation of Indian Industry (CII), Hyderabad	Sept.21, 2019
53.	Dr. T.N. Rao	Batteries: Li Ion Batteries and Beyond	India Storage – EV Technology and R&D Forum	Department of Sceience and Technology (DST), Delhi	Sept.23, 2019
54.	Dr. N.Rajalakshmi	Fuelcell Technology Development – Marketing Challenges	Manufacturing Trends in Electrochemical Energy Systems (MEES 2019)	Indian Institute of Chemical Engineers (IICE), Thiruvananthapuram	Sept.23, 2019
55.	Dr. Gururaj Telasang	Additive Manufacturing: Recent Trends	Recent Trends in Automation and Digital Manufacturing	The Institution of Engineers (IEI) India, Hyderabad	Sept.23, 2019
56.	Dr. G. Padmanabham	Additive Manufacturing for Aerospace Applications	International Conference on Advanced Materials and Processes for Defence Applications (ADMAT-2019)	Hyderabad	Sept. 23-25, 2019
57.	Dr. Gururaj Telasang	Metal Additive Manufacturing: PBAM	Workshop on Latest Technologies and Inauguration of SAEINDIA Collegiate Club	Gudlavalleru Engineering College, A.P.	Sept.25, 2019
58.	Dr.L. Rama Krishna	Emerging Technologies for Repair and Refurbishment of Aerospace Components (keynote)	International Conference on Advances in Minerals, Metals, Materials, Manufacturing and Modelling (ICAM5-2019)	NIT, Warangal	Sept. 25-27, 2019
59.	Dr. R. Balaji	Hydrogen Energy Technology –An Overview	Rural Energy Centre, Gandhigram Rural Institute, Gandhigram		Sept.30, 2019.
60.	Dr. Ravi Bathe	Laser Processing of Materials for Industrial Applications	Industrial Lecture Series for 4th year ME Students	IIT, Tirupati	Oct. 11, 2019
61.	Dr. Sanjay Bhardwaj	Commercializing ARCI Technologies and Knowledge-base	Lecture to MBA (Innovation and Entrepreneurship) Students of Symbiosis Institute of Business Management (SIBM), Pune	ARCI, Hyderabad	Oct. 16, 2019
62.		Technology Value Chains and Valorization	Programme on Managing Technology Value Chains for Government Sector Directors and Division Heads	Administrative Staff College of India(ASCI)	Oct. 17, 2019

S.N	Name	Title	Event	Organization, Place	Date
63.	Dr. Ravi Bathe	Multifunctional Surfaces by Ultrafast Laser Processing	International Conference on Application of Laser in Manufacturing (CALM -2019)	Bombay Exhibition Center, Mumbai	Oct. 17-18, 2019
64.	Dr. G. Padmanabham	Application of Laser Material Processing (Keynote)			
65.	Mr. K.V.P. Phani Prabhakar	Laser Hybrid Welding for Power Plant Application			
66.	Dr. S.M. Shariff	Laser Hardening Applications in Automotive Industry			
67.	Dr. Gururaj Telasang	Selective Laser Melting at ARCI: Design for Additive Manufacturing			
68.	Mr. Manish Tak	Additive Manufacturing for Repair and Refurbishment			
69.	Dr. P. Sudharshan Phani	Novel High Speed Nanomechanical Testing Techniques (Keynote)	International Conference on Advances in Mechanical Processing and Design (ICAMPD19)	Kalinga Institute of Industrial Technology (KIIT), Bhubaneshwar	Oct.18, 2019
70.	Dr. R. Vijay	Nano and Advanced Materials for Engineering Applications	Industrial Lecture Series	IIT, Tirupati	Oct. 18, 2019
71.	Dr. N.Rajalakshmi	PEMFC-Recent Development and Challenges	International Conference on Advances in Renowned Renewable Energy Technologies (ICARRET)	Siddhartha Engineering College, Vijayawada	Oct. 23 2019
72.	Dr. G. Ravi Chandra	Study of Mechanical Properties at the Micron Lengthscale	Faculty Development Programme on Emerging Technologies and Challenges in Mechanical Engineering (ETCME)	RVR and JC College, Guntur	Oct. 26, 2019
73.	Dr. B.P. Saha	Design Criticality and Processing Aspects of High Precision Silicon Carbide Space Mirror Substrate	Industrial Lecture	IIT, Tirupathi	Oct. 31, 2019
74.	Dr. G. Ravi Chandra	The Importance of Accurate and Precise Measurements	Refresher Course in Experimental Physics	University of Hyderabad, Hyderabad	Nov. 06, 2019
75.	Dr. Sanjay Bhardwaj	Research Collaborations and Technology Transfer	Programme on Science Administration and Research Management	ASCI, Hyderabad	Nov. 13, 2019
76.	Dr. L. Rama Krishna	Surface Engineering Technologies for Life Extension of Aerospace Applications (keynote)	57th National Metallurgists Day and 73rd Annual Technical Meeting (NMD-ATM 19)	Indian Institute of Metals (IIM), Thiruvananthapuram	Nov. 13-16, 2019
77.	Dr. Sanjay Dhage	Solar Energy Materials and Solar Cells	Refresher Course in Material Sciences	OU, Hyderabad	Nov. 21, 2019
78.	Dr. T. N. Rao	Translational Nanomaterials Research	Science Session	Jain University, Bengaluru	Nov. 24, 2019
79.	Dr. R. Balaji	ARCI's Initiative towards e-Mobility Programme	NuGEN-2019 Mobility Summit	Delhi	Nov. 27-29, 2019
80.	Dr. V. Raman	One Pot Synthesis of Electrocatalysts for Fuel Cell Application	International Conference on Nanoscience and Nanotechnology (ICNAN'19)	Vellore Institute of Technology (VIT), Vellore	Nov. 29- Dec 01, 2019
81.	Dr. S. Sakthivel	Cost Efficient Functional Coating Technologies for Eco-Friendly Concentrated Solar Thermal and PV Application			
82.	Dr. Mani Karthik	Design and Fabrication of Supercapacitor as Next Generation Energy Storage and Conversion Device			

S.N	Name	Title	Event	Organization, Place	Date
83.	Dr. T. N. Rao	Translational Materials Research at ARCI	Quality Month Celebrations of NFC	NFC, Hyderabad	Nov. 30, 2019
84.	Dr. R. Balaji	Thrust Areas for Research/Funding	Faculty Development Programme on Research Methodology and IPR	Rajalakshmi Engineering College, Chennai	Nov. 30, 2019
85.	Dr. S. Sakthivel	Cost Efficient Easy to Clean Coating Technology for Eco-Friendly PV Power Generation	Surface Engineering, Paint and Coating Forum-South 2019	Hitex Exhibition, Hyderabad	Dec. 04 2019
86.	Dr. G. Sivakumar	Thermal Spray Coatings	CEP on Low Friction Coatings	DMRL, Hyderabad	Dec. 04, 2019
87.	Dr. S. Kavita	Magnetocaloric Effect in La-Fe-Si Alloys	National Conference on Science, Technology and Applications of Rare Earths (STAR 2019)	Bhabha Atomic Research Centre (BARC), Mumbai	Dec. 05-07, 2019
88.	P. Sudharshan Phani	Latest Advances in Dynamic Nanoindentation Testing and High-Speed Mapping	Workshop on Latest Advances in Nanomechanical Testing	IIT Bombay, Mumbai	Dec. 09, 2019
89.				Jamia Millia Islamia University, New Delhi	Dec.11, 2019
90.	Dr. Roy Johnson	Transparent Polycrystalline Ceramics : Emerging Class of Optical Materials (keynote)	83rd Annual Session and National Conference on Innovation and Technologies for Ceramics	NIIST, Trivandrum	Dec. 11-12, 2019
91.	Dr. R. Subasri	Environment Friendly Organic-Inorganic Hybrid Nano-Composite Coatings for Industrial Applications	XIV Triennial National Conference of Indian Women Scientists' Association (IWSA) on Women Led Science, Technology and Innovation	Hyderabad	Dec. 11-13, 2019
92.	Dr. R. Prakash	Development of Lithium-Ion Battery for the Integration of e-Mobility and Renewable Energy	Industry-Academia Conclave for the Integration of e-Mobility and Renewable Energy	VIT, Vellore	Dec.13, 2019
93.	Dr. R. Balaji	The Role of Functional Materials in Hydrogen Economy	Second International Workshop on Functional Materials and Devices	SRM Institute of Science and Technology, Chennai	Dec.13, 2019
94.	Dr. G. Padmanabham	Metal AM Application Development by Powder Bed Fusion Method : Experiences and Challenges	Indo-US Workshop on Metal Additive Manufacturing	Coimbatore	Dec.16-17, 2019
95.	Dr. Nitin Wasekar	Mechanism of Metal Matrix Composite Electrodeposition	Electrodeposition of Composite Coatings Workshop	Tata Steel Ltd. (TSL), Jamshedpur	Dec. 16-17, 2019
96.	Dr. Malobila Karanjai	Beneficiation of Iron Ore Dust : Mines to Application	XVIII Conference on Mineral Processing Technology (MPT-2019)	Hyderabad	Dec. 16-18, 2019
97.	Dr. Neha Hebalkar	Development of Indegenous Technologies based on Nanomaterials: Journey from Lab to Market	Industry Institute Interaction	Siddhartha Engineering Colledge, Vijayawada	Dec.18, 2019
98.	Dr. V.Raman	Polymer Electrolyte Fuel Cells: the Science and Engineering Behind Realizing the Technology	VIT, Vellore		Dec.19, 2019
99.	Dr. B. V. Sarada	CIGS Based Flexible Thin-Film Solar Cells by Non-Vacuum Routes	3rdInternational Conference on Solar Energy Photovoltaics (ICSEP)	Bhubaneswar	Dec.19-21, 2019

S.N	Name	Title	Event	Organization, Place	Date
100.	Dr. Dibyendu Chakravarty	Spark Plasma Sintering: A Novel Powder Metallurgical Processing Tool for Niche Applications	NIT, Surathkal		Dec. 24, 2019
101.	Dr. R. Prakash	Tailoring the Structure of Materials and Electrode Fabrication Process for High Power Lithium Ion Batteries	International Workshop on Materials for Energy Conversion and Storage	IIT, Tirupati	Dec. 24-25, 2019
102.	Dr. Srinivasan Anandan	Development of Advanced Li-Ion Battery Materials for Electric Vehicles (EVs) Application			
103.	Dr. R. Vijay	Development of Materials and Systems for Generation, Transportation and Conversion of Energy			
104.	Dr. M. B. Sahana	Manufacturing Techniques of Electrode Materials for EV Batteries	Battery Technology for e-Vehicle	Indian Institute of Information Technology, Design and Manufacturing (IIITDM), Kancheepuram	Dec. 26-28, 2019
105.	Dr. Sanjay R. Dhage	Materials Challenges of CIGS Thin Film Solar Cell Technology	International Conference on Smart Materials and Nanotechnology (ICSMN-2020)	SKN Sinhgad College of Engineering, Maharashtra	Jan. 02-04, 2020
106.	Dr. T.N. Rao	Science and Technology for Better National Economy	Inspire Internship Programme	V.Y.T. PG Autonomous College Durg, MP	Jan. 03-04, 2020
107.	Dr. G. Padmanabham	Laser Assisted Additive Manufacturing	28th DAE – BRNS National Laser Symposium	VIT, Chennai	Jan. 08-11, 2020
108.	Dr. T.N. Rao	Role of Chemistry and Chemical Engineering in Translational Nanomaterials Research	International Conference on Recent Advances in Chemical Engineering (RACE-2020)	OU, Hyderabad	Jan. 09, 2020
109.	Dr. Sanjay Bhardwaj	ARCI's Collaborative and Technology Transfer Strategy	Faculty Development Programme	National Institute for Micro, Small and Medium Enterprises (NI-MSME), Hyderabad	Jan. 13, 2020
110.	Dr. Y. Srinivasa Rao	Issues in Technology Development and Commercialization-Few Case Studies	DST Sponsored Program on Management of Technology and Innovation	Institute of Public Entreprise (IPE), Hyderabad	Jan. 20-24, 2020
111.	Dr. S. Sakthivel	Nanofunctional Materials and Coatings for Eco-friendly Solar Thermal and PV Application	Workshop on Mechanical Engineering	Siddhartha Engineering College, Vijayawada	Jan. 25, 2020
112.	Dr. Ravi Bathe	Laser Materials Processing at ARCI	Symposium on Intense Laser Application and Innovation (SILAI2020)	Tata Institute of Fundamental Research (TIFR), Hyderabad	Jan. 27-29, 2020
113.	Dr. G. Padmanabham	Surface Engineering Technologies for Defence and Aerospace Applications	Brain Storming Session on Coatings for Armament Applications	Armament Research and Development Establishment (ARDE), Pune	Jan. 30, 2020
114.	Dr. Mani Karthik	Emerging Materials for Energy Conversion and Storage: Supercapacitor as Next Generation Energy Storage Device	2nd International Conference on Advanced Materials Chemistry at the Interfaces of Energy Environment and Medicine – AMCI 2020	Manonmaniam Sundaranar University, Tirunelveli	Jan. 30-31, 2020

S.N	Name	Title	Event	Organization, Place	Date
115.	Dr. R. Balaji	Hydrogen and Fuel Cell Technology Development Programme at ARCI-CFCT and the Way Forward for Green Energy Sector Applications	National Convention on Electrochemist-21 (NCE-21)	VIT, Chennai	Jan. 30-31, 2020.
116.	Dr. B. V. Sarada	Synthesis of Nanostructured Materials and Thin-Films by Pulse Electrodeposition for Energy Conversion and Storage Applications			
117.	Dr. G. Padmanabham	Microstructural Features in Laser Processed Materials	12th Asia Pacific Microscopy Conference (APMC)	Hyderabad	Feb. 03-07, 2020
118.	Dr. Easwaramoorthi Ramasamy	Perovskite for Next Generation Solar Cells	International Conference on Physics and Materials in Novel Engineering Applications	Kumaraguru College of Technology, Coimbatore	Feb. 06, 2020
119.	Dr. V. Raman	Electrification with Renewable Energy – An Overview of Technologies and its Societal Impact	National Workshop on Societal Responsibility for Rural Development: Role of Science and Teacher	Manonmaniam Sundaranar University, Tirunelveli	Feb. 06-07, 2020
120.	Dr. G. Padmanabham	Metal Additive Manufacturing-Technology Trends and Applications	International Welding Congress, Mumbai	Mumbai	Feb. 06-08, 2020
121.	Dr. Srinivasan Anandan	Design and Development of Advanced Nanostructured Electrode Materials for Energy Storage (Li-ion Battery and Supercapacitor) Applications	Faculty Development Workshop on Teaching and Learning Nano-Science and Technology through Hands-on Experiences	NIT, Warangal	Feb. 10- 15, 2020
122.	Dr. T. N Rao	Role of Chemical Science in Nanotechnology	National Seminar on Emerging Trends in Nanotechnology	Keshav Memorial Institute of Commerce and Science, Hyderabad	Feb. 14, 2020
123.	Dr. Sanjay Bhardwaj	Technology Commercialization in India	International Programme on Intellectual Property Management Strategies for SMEs (IPMSS)	NI-MSME, Hyderabad	Feb.17, 2020
124.	Dr. Roy Johnson	Advance Ceramic Materials – Processing and Applications	CEP on Processing and Applications of Advanced Ceramics and Composites	DMRL, Hyderabad	Feb. 18-20, 2020
125.	Dr. G. Padmanabham	Recent Trends in Powder based Technologies and Applications	International Conference on Powder Metallurgy and Particulate Materials (PM20)	Mumbai	Feb. 19-21, 2020
126.	Dr. Malobika Karanjai	Soft Magnetic PM Components in Electric Vehicles and ARCI's Contributions on Coated Fe Composites			
127.	Dr. T.N. Rao	Translational Battery Materials Research	Industry-Academia Summit 2020	SRM University, Amaravathi	Feb. 20-21, 2020
128.	Dr. S. Sakthivel	Technology Development and Demonstration of Nano Functional Coatings for Eco-Friendly Concentrated Solar Thermal and PV Applications	Advanced Materials for Energy and Environmental Applications (ICAMEA-2020)	Thiru Kolanjiappar Government Arts College, Vriddhachalam	Feb. 20-21, 2020
129.	Dr. D. B. Prabhu	Magnetism and Magnetic Materials - An Indispensable Component	National Conference on Recent Trends in Advanced Materials Research (NCRTAMR 20)	Bharath Institute of Higher Education and Research, Chennai	Feb. 21, 2020

S.N	Name	Title	Event	Organization, Place	Date
130.	Dr. S. Sakthivel	Nano Structured Materials and Coatings for Eco-Friendly Solar Thermal and PV Applications	8thNational Conference on Hierarchically Structured Materials (NCHSM 2020)	SRM Institute of Science and Technology, Chennai	Feb. 21-22, 2020
131.	Dr. B. V. Sarada	Science andTechnology for a Better World: Role of Science in Renewable Energy Conversion and Storage Applications	National Science Day Lecture	Telangana Academy of Science, Telangana	Feb. 25 , 2020
132.	Dr. M. B. Sahana	Lithium-Ion Batteries for Electric Vehicle Applications	National Science Day	PSGIT and Applied Research, Coimbatore	Feb. 28, 2020
133.		Material Science in Advanced Technologies			
134.	Ms. K. Divya	Metallurgical Aspects of Powder Bed Metal Additive Manufacturing with Case Studies	Workshop on Additive Manufacturing	NIT, Warangal	Feb. 29, 2020
135.	Dr. Gururaj Telasang	Additive Manufacturing and its Prospects			
136.	Dr. Pramod H. Borse	Material Nanostructuring for Energy Applications, a Race towards Efficient Materials	National Conference on Forays of Nanotechnology Research into Multidisciplines (FONAREM-2020)	Govt. Degree College, Ravulapalem	Mar. 03-04, 2020
137.	Dr. Sanjay Bhardwaj	Research Collaborations	General Management Programme for Scientists	ASCI, Hyderabad	Mar. 04, 2020
138.	Dr. Gururaj Telasang	Powder Bed Metal Additive Manufacturing	Short-Term Training Program on Additive Manufacturing and 3D Printing – Connotation to Indian Context	Lendi Institute of Engineering and Technology, Vizianagaram	Mar. 04, 2020
139.	P. Sudharshan Phani	High Speed Nanomechanical Property Mapping of Thermal Barrier Coatings	6th Asian Conference on Heat Treatment and Surface Engineering	ASM, Chennai	Mar.05, 2020
140.	Dr. N.Rajalakshmi	Current Status of Energy Materials and Fuel Cells for Commercial Exploitation	National Seminar on Current Status on Energy Materials and Fuel Cells	S.A. Engineering College, Chennai	Mar. 05-06, 2020
141.	Dr. R. Balaji	Overview of Hydrogen Production R&D Status in India			

E. Papers Presented at Indian Conference/Symposia

S.N	Name	Title	Event	Mode of Presentation
1.	Dr. Sanjay Bhardwaj	Up-Scaling an Idea to Technology in the Advanced Materials Domain: Review of the Methodologies to Assess the Readiness Levels	28th International Conference on Management of Technology (IAMOT-2019), Mumbai Apr. 07-11, 2019	Oral
2.		Research to Technology Transfer: Developing a Roadmap		Oral
3.	Dr. S. Sakthivel	Highly Transparent Weather Resistant Easy to Clean Coating Technology for High Performance of PV Modules in Solar PV Power Generation	14th International Conference on Surface Protective Coatings and Paint Coatings Cum Expo-2019. Mumbai, Apr. 11 -12, 2019	Oral
4.	Mr. K. V. Phani Prabhakar	Challenges in Translating Research on Dissimilar Materials Fusion Joining into Technology	International Conference on Applied Mechanical Engineering Research (ICAMER 2019), NIT, Warangal, May 02, 2019	Oral
5.	Dr. K. Suresh	Probing Nano-Heterogeneity in Metallic Materials using Small Angle X-Ray Scattering (SAXS)	Symposium and Workshop on Small Angle X-ray Scattering. IIT Bombay, Mumbai, May 06, 2019	Oral

S.N	Name	Title	Event	Mode of Presentation
6.	Ms. Anjali Kanchi (Dr. G. Ravi Chandra)	Microstructural Study of MoNbTaW Multicomponent Alloy	International Conference on Electron Microscopy and Allied Analytical Techniques (EMAAT-2019) Shimla, Jun. 07-09, 2019	Oral
7.	Mr. Aravind A B (Dr. K.Ramya)	Effect of Electrolyte Composition on Al-Air Electrochemical Cells	International Conference on Advanced Materials (ICAM) 2019, Kerala, Jun. 12-14, 2019	Oral
8.	Mr. T. Ramesh (Dr. N.Rajalakshmi)	Porous Carbon Microspheres derived Tamarind Seed Kernel for Supercapacitor Application		
9.	Dr. R. Vijay	Development of Nanostructured ODS 9Cr RAFM Steels for Fusion Reactor Applications	International Symposium on Metastable, Amorphous and Nanostructured Materials (ISMANAM 2019), Chennai Jul. 8-12, 2019	Oral
10.	Dr. S. Sudhakara Sarma	Preparation and Characterization of Nano Boron Powder by Cryo-Milling		Oral
11.	Mr. Ravi Gautam	Influence of Nanoprecipitates on the Magnetic Properties of Fe-P(Si) alloy		Oral
12.	Ms. P. Vijaya Durga	Microstructural and Mechanical Properties of Oxide Dispersion Strengthened Iron AluminidesProduced by Mechanical Milling and Hot Extrusion		Poster
13.	Mr. A. Harish Kumar (Dr. Joydip Joardar)	Development of Nanostructured 2D- Tungsten Disulfide – Aluminium/ Aluminium Alloy Matrix Composites		Poster
14.	Mr. P. Sai Karthik	Oxide Dispersion Strengthened Austenitic Steels for High Temperature Applications		Poster
15.	Mr. Imran K (Dr. K. Ramya)	Dynamic Oxygen Electrode for Robust Zinc-Air Battery	New Generation Ideation Contest, HP Green R & D Center, Bengaluru Sept. 12-2019	Poster
16.	Mr. Manish Tak	Refurbishment of High Tensile Steel using Laser Cladding Technique	ADMAT-2019, Hyderabad Sept. 23-25, 2019	Oral
17.	Dr. Gururaj Telsang	Design for Additive Manufacturing: Self-Supporting Conformal Cooling Channels by Additive Manufacturing		Oral
18.	Dr. Papiya Biswas	Transparent Magnesium Aluminate Spinel for Infrared and Thermal Imaging Applications		Oral
19.	Mr. R. Senthil Kumar	Development of Transparent Aluminum Oxynitride for Armour Applications		Oral
20.	Mr. Balaji Padya	A Novel Functionally Graded Nitrogen Enriched Carbon Uniformly – Coated on Graphene based all-Carbon Hybrid for Energy Storage		Oral
21.	Mr. S. Rajesh Kumar Reddy (Mr. Manish Tak)	Laser Assisted Machining for Improved Machinability of Hard to Machine Materials		Oral
22.	Dr. Neha Hebalkar	Silica Aerogel based Thermal Protection System for Hypersonic Vehicles		Oral
23.	Dr. Bhaskar Prasad Saha	Ballistic Performance of Silicon Carbide armour		Oral
24.	Dr. S. Kumar	Development of Cold Spray Process for Repair of Aerospace and Defense Materials		Oral
25.	Dr. Dibyendu Chakravarty	Development of Tungsten based Plates for Jet Vanes by Spark Plasma Sintering		Oral
26.	Dr. Prasenjit Barick	SiAlON Randome for Missile Application		Oral
27.	Dr. Krishna Valleti	Cathodic Arc PVD Grown Wear Resistant Thin Films/ Coatings for Strategic Applications		Oral
28.	Mr. Swapnil H. Adsul (Dr. R. Subasri)	Smart Nanocontainer based Self healing Corrosion Protection Coatings for Mg-Alloy AZ91D for Aircraft Applications		Oral
29.	Mr K.R.C. Soma Raju	Development of Transparent, Protective Coatings on Acrylic Sheets for Aircraft Applications		Poster

S.N	Name	Title	Event	Mode of Presentation
30.	Dr. Bijoy Kumar Das	Carbon coated Sodium Titanates as Ultra-Low Voltage Anode for Sodium Ion Battery	ADMAT-2019, Hyderabad Sept. 23-25, 2019	Oral
31.	Ms. G.T. Harini (Dr. N. Rajalakshmi)	Aluminium Hydride as an Advanced Propellant Ingredient : A Synthesis Perspective		Oral
32.	Ms.N.Manjula (Dr. R. Balaji)	Studies on Development of Polymer Electrolyte Membrane (PEM) based Electrochemical Hydrogen Purification Process	International Conference on Advances in Chemical Sciences and Technologies (ACST-2019), NIT Warangal, Sept. 23-25, 2019	Poster
33.	Ms. B. Divya (Dr. B. V. Sarada)	Electrodeposition of ZnO and Al-ZnO as Transparent Conducting Oxides for the CIGS Thin-Film Solar Cells		Poster
34.	Ms. Santwana H. D (Dr. M Buchi Suresh)	Impact of Particle Size Distribution of Non-Magnetic Abrasive Particles on Rheology of Magneto-Rheological Polishing Fluids		Poster
35.	Mr. Y. N. Aditya (Mr. Manish Tak)	Study the Laser Cladding of Ultra-High Strength AerMet-100 Alloy Powder on AISI-4340 steel for Repair and Refurbishment	International Conference on Advances in Minerals, Metals, Materials, Manufacturing and Modelling (ICAM5-2019), NIT, Warangal, Sept. 25-27, 2019	Oral
36.	Mr. R. Senthil Kumar	Processing and Properties of Sintered Submicron IR Transparent Yttria (Y2O3) Ceramics derived through Sol-Gel Method		Oral
37.	Ms. Pooja Miryalkar (Dr. Krishna Vellati)	Cr/ML(CrN/AlTiN)/AlSiN/AlSiO Open Air-Stable Solar Selective Coatings for CSP Applications		Oral
38.	Mr. Balaji Padya	Platelet-like Structured 2D Carbon: Solution Phase Preparation and Application for Thermal and Electrochemical Energy Storage		Oral
39.	Mr. P. Raju (Dr. Y. Srinivasa Rao)	Comparative Study on the Sintered Properties of Al2O3 produced by Pressure Slip Casting and Conventional Slip Casting		Oral
40.	Ms. S. Mubina (Dr. B.P. Saha)	Effect of Various Carbon Sources as a Sintering Additive on the Properties of Silicon Carbide		Oral
41.	Ms. D. Spandana (Dr. Kaliyan Hembram)	Study of Fe-Mn-Si Alloys for Biodegradable Implant Application		Oral
42.	Mr. Sri Harsha Swarna Kumar (Dr.R. Balaji)	Patterned Method of Coating on Flow Field Plates of PEM based Electrolyser for Hydrogen Production		Oral
43.	Dr. Sanjay Bhardwaj	ARCI Capabilities in the Engineered Coatings	Applied Materials India's Annual Engineering EventAMIND Engineering Week 2019, Mumbai Sept. 27, 2019	Poster
44.	Dr. Abha Bharti (Dr. N. Rajalakshmi)	Zeolitic Imidazolate Framework Derived Pt Free Cathode Catalyst for Proton Exchange Membrane Fuel Cell	2nd One Day Workshop on Hydrogen and Fuel Cell for Sustainable Future, IITM Research Park, Chennai, Oct. 18, 2019	Poster
45.	Mr. P.Sreeraj (Dr. V.Raman)	Recycling of Valuable Components from PEMFC		Poster
46.	Mr. Imran K (Dr. K.Ramya)	Ionomer Assisted Electrocatalysts for Oxygen Reduction Reaction		Poster
47.	Mr. Tarun Kumar (Dr. N.Rajalakshmi)	Engineering of Gas Diffusion Layer for Better Water Management of PEM Fuel Cells		Poster
48.	Mr. Uday Kiran (Dr. V.Raman)	Durable Electrocatalyst Support for PEM Fuel Cell -Ti_4O_7		Poster
49.	Mr. P. Laxman Mani Kanta	Development of Sodium Ion Batteries for Large Scale Grid Energy Storage Applications	Young Scientist Conference - India International Science Festival (IISF) 2019, Kolkata, Nov. 05-07, 2019	Oral
50.	Mr. Sumit Ranjan Sahu	Development of Indigenous Lithium-Ion Battery for Electric Mobility		Oral
51.	Mr. Manish Tak	Repair, Refurbishment and Re-manufacturing of Aerospace Components	Seminar on Aero Engine Technology: Production and Repair-Overhaul, Hindustan Aeronautics Ltd. (HAL) Koraput, Nov. 08 2019	Oral

S.N	Name	Title	Event	Mode of Presentation
52.	Ms. Minati Tiadi	Thermoelectric Properties of P-type Mg_3Sb_2	In-House Symposium, IIT Madras, Chennai, Nov. 09, 2019	Poster
53.	Ms. N. Divya (Mr. Manish Tak)	Directed Energy Deposition using Indigenously Developed Ni based Super Alloy Powder for Refurbishment of Aero-Engine Components	NMD ATM-2019, Thiruvananthapuram, Nov. 15-16, 2019	Oral
54.	Mr. M. Shiva Prasad (Dr. S. Sakthivel)	Functional Coatings for Solar Energy Applications	2nd International Conference on Surface Protective Coatings and Treatment, New Delhi, Nov. 18-19 2019	Oral
55.	Ms. T. Mitravinda (Dr. T.N. Rao)	Mass-Balancing of Electrodes to Widen the Operating Voltage Window of Carbon/Carbon based Supercapacitor in Organic Electrolyte	Conference on Carbon Materials (CCM 2019), New Delhi, Nov. 20-22, 2019	Oral
56.	Dr. Ravi Kali (Dr. P.K. Jain)	A Facile Process for Conversion of Rubber to Concentric- Shelled Carbon: As Negative Electrode for Na-Ion Battery Application		Oral
57.	Mr. N. Ravi Kiran (Dr. P.K. Jain)	Experimental Studies of Anti-Wear Behavior Of Graphene Nano-Plates in Base Oils for Al-Steel Contacts		Oral
58.	Mr. V. P. Madhurima (Dr. P.K. Jain)	Carbon based Polymeric Semiconductor for Organic Pollutant Degradation: Synthesis, Properties and Photocatalytic Performance		Oral
59.	Dr. Bijoy Kumar Das	Development of Low-Cost Sodium Ion Battery for Grid and Off-Grid Storage Applications	Industry Academia Conclave on Energy Storage, Malaviya National Institute of Technology (MNIT) Jaipur, Nov. 30, 2019	Poster
60.	Ms. P. Samhitha (Dr. B.V. Sarada)	Electrodeposited $NiCo_2O_4$ with Enhanced Oxygen Vacancies as Effective Electrode Material for High-Performance Pseudocapacitor	IIT-EV International Workshop – Dawn of New Era for Indian Automotive Industry, IIT- Hyderabad Nov. 30, 2019	Poster
61.	Dr. D. B. Prabhu	The Effect of Post Sinter Annealing on the Zn bonded Sm-Fe-N Magnets	National Conference-STAR 2019 BARC, Mumbai, Dec. 05-07, 2019	Oral
62.	Mr. M B Siva Kumar	Microstructural Investigation of Ce-La-Fe-B Permanent Magnet		Poster
63.	Mr. G.Vijayaragavan	Development of Low Melting Alloys for Consolidation of Isotropic Sm-Fe-N Powders		Poster
64.	Mr. Imran K (Dr. K.Ramya)	Engineering of O_2 Electrodes by Surface Modification for Corrosion Resistance in Zinc-Air Batteries	7th International Conference on Advances in Energy Research (ICAER-2019), IIT-Bombay, Mumbai Dec. 10-12, 2019	Oral
65.	Mr. M. Shiva Prasad (Dr. S.Sakthivel)	Novel Synthesis of Al2O3 Nanoflakes for Ni-Al_2O_3 Composite Solar Selective Coatings		Oral
66.	Dr. Pandu Ramavath	Single-Step Hot Isostatic Pressing of Magnesium Aluminate ($MgAl_2O_4$) Spinel Powder to Dense Ceramic Parts	83rd Annual Session of Indian Ceramic Society and National Conference on Innovations and Technologies for Ceramics (InTeC-2019), Thiruvananthapuram Dec. 11-12, 2019	Oral
67.	Ms. M. Swathi (Dr. Roy Johnson)	Shaping of $MgAl_2O_4$ Spinel Ceramics through Compaction and Colloidal Shaping Process: Comparative Evaluation		Poster
68.	Dr. Prasenjit Barick	Effect of Starting Boron Carbide Particle Size on Microstructure and Mechanical Properties of Reaction Bonded Boron Carbide		Oral
69.	Ms. S. Mamatha (Dr. Roy Johnson)	Mechanical Behaviour of 3D Extrusion Printed Alumina Specimens		Poster
70.	Mr. Kezil Mathew Varghese (Dr. YS Rao)	Aqueous Slip Casting of Magnesium Oxide Porous Ceramics with Engineered Porosity		Poster
71.	Dr. Abha Bharti (Dr. N. Rajalakshmi)	Development of Proton Exchange Membrane Fuel Cells for Sustainable Energy	XIV Triennial National Conference of IWSA National Institute of Nutrition (NIN), Hyderabad, Dec. 11-13, 2019.	Oral
72.	Dr. B. V. Sarada	Nanostructured Materials and thin Films by Electrochemical Synthesis for Energy and Biomedical Applications		Oral

S.N	Name	Title	Event	Mode of Presentation
73.	Mr. V. V. N. Phanikumar	Tamarind Kernel Powder as a Novel Aqueous Binder for Graphite Anode in Lithium-Ion Batteries	13th National Conference on Solid State Ionics (NCSSI-13), IIT Roorkee, Dec. 16-18, 2019	Poster
74.	Ms. B. Gowreeswari	Semi-Transparent Metal Cathode (DMD) for Perovskite Solar Cells	6th International Conference on Advanced Nanomaterials and Nanotechnology, Guwahati, Dec. 18-21, 2019	Poster
75.	Dr. Prashant Misra	A Multi-Layer Cu-InGa Precursor Sputtering Approach for Improving Structural Quality of Selenized CIGS Absorber Layer	3rd International Conference on Solar Energy Photovoltaics (ICSEP), Bhubaneswar, Dec. 19-21, 2019	Poster
76.	Dr. Sreekanth M	Economic Pulse Electrodeposition for Flexible CuInSe2Solar Cells		Poster
77.	Mr. Brijesh Singh Yadav (Dr. Sanjay Dhage)	Drop on Demand Inkjet Printing of Aqueous Ink for $CuInGaSe_2$Thin Film Solar Cell		Oral
78.	Ms. Reshma K. Dileep (Dr. Ganapathy Veerappan)	Highly Stable, Low Temperature Curable Carbon based Triple Cation-Mixed Halide Perovskite Solar Cells		Oral
79.	Ms. B Ramya Krishna (Dr. Easwaramoorthi Ramasamy)	Impact of Hole Transporting Materials on the Performance and Stability of Perovskite Solar Cells		Oral
80.	Dr. Sanjay R. Dhage	Materials Challenges of CIGS Thin Film Solar Cell Technology	ICSMN-2020, SKN Singhad College of Engineering, Pandharpur Jan. 02-04, 2020	Oral
81.	Dr. K. Suresh	Small Angle X-ray Scattering (SAXS) for Microstructural Studies		Oral
82.	Mr. S. Yasodhar (Dr. R. Balaji)	Optimization of Flow Distribution in PEMFC Stack by Computational Fluid Dynamics	International Conference on Recent Advances in Chemical Engineering (RACE 2020). Hyderabad Jan. 20, 2020.	Oral
83.	Dr. M. Sreekanth	Pulse Electrodeposited CIS/CIGS Absorbers for Photovoltaic and Photoelectrochemical Applications	International Conference on Electrochemistry in Industry Health and Environment(EIHE-2020) Mumbai, Jan. 21-25,2020	Oral
84.	Ms. B. Divya (Dr. B. V. Sarada)	Electrodeposition: An Effective and Economic Technique for the Fabrication of CIGS Thin Film Solar Cells		Oral
85.	Ms. P. Samhitha (Dr. B. V. Sarada)	Electrochemically Exfoliated High Quality Graphene Oxide-$NiCo_2O_4$ Nanocomposite Electrode Material for Supercapacitors		Oral
86.	Ms. J. Prithi (Dr. N. Rajalakshmi)	Experimental and Theoretical Study on SO_2 Tolerance of Pt Electrocatalysts: Role of Carbon Support		Oral
87.	Dr. Sanjay Bhardwaj	Advanced Materials Technology Domain: Analysis of the Commercialization Process	5th International Conference on 'Management of Intellectual Property Rights and Strategy' (MIPS) 2020, Mumbai, Jan. 24-25, 2020	Oral
88.	Mr. Surabattula Yasodhar	A Three Dimensional CFD Simulation of PEMFC with the Modified-Parallel Flow Field Design	NCE-21, VIT, Chennai Jan. 30, 2020.	Oral
89.	Mr. Ravi Gautam	Microstructure-Magnetic Properties Correlation of Fe-P(Si) Aged Alloys	12thAPMC-2020, Hyderabad Feb. 03-07, 2020	Oral
90.	Dr. L. Venkatesh	Characterization of NiCr-Cr_3C_2 Composite Coatings Engineered by Cold Spraying		Oral
91.	Mr. M. Tarun Babu (Dr. K. Suresh)	Microstructure and Mechanical Properties of Cold-Sprayed Al6061 Alloy Coatings		Poster
92.	Ms. K. Anjali (Dr. G. Ravi Chandra)	Microstructural Study of MoNbTaW Multicomponent Alloy		Poster
93.	Dr. G. Ravi Chandra	Study of Recovery and Recrystallization using Electron Backscatter Diffraction		Oral

S.N	Name	Title	Event	Mode of Presentation
94.	Dr. Raman Vedarajan	Eco-Friendly Synthetic Methods for Fuel Cell Electro Catalysts	14th International Conference on Ecomaterials (ICEM-14), Trivandrum Feb. 05-07, 2020	Oral
95.	Dr. Rahul B. Mane (Dr. Dibyendu Chakravarty)	Sintering and Oxidation Behavior of Ti_3GeC_2 MAX Phase Material	International Conference on Powder Metallurgy and Particulate Materials (PMAI-2020), Mumbai, Feb. 19-21, 2020	Oral
96.	Mr. Mahender Peddi	Processing of Lithium Ion Battery Electrodes for Electric Vehicle Applications	2nd Indo Japan Bilateral Symposium on Futuristic Materials and Manufacturing for Next Generation, Electric Vehicles and High Speed Railway, IIT Madras, Chennai, Mar.02-03, 2020	Oral
97.	Dr.D. Prabhu	Fe-P Soft Magnetic Material for Automotive Application	11th Bengaluru India Nano Bengaluru Mar. 02-04, 2020	Poster
98.	Mr. Ravi Gautam	Development of Nanostructured Fe-P based Soft Magnetic Alloys with High Saturation Induction and Low Core Loss for Motor Applications		Poster
99.	Dr. P. Sudharshan Phani	High Speed Nanomechanical Property Mapping of Thermal Barrier Coatings	6th Asian Conference on Heat Treatment and Surface Engineering, IIT Madras, Chennai Mar. 05-07, 2020	Oral
100.	Dr. P. Suresh Babu	Influence of Phase Proportion on the Tribological Performance of Al_2O_3-TiO_2 Ceramic Composite Coatings Deposited by Detonation Spray Technique		Oral
101.	Mr. Rahul Alroy Jude (Dr. G. Sivakumar)	Development of Plasma Sprayed Rare Earth Zirconate Based Thermal Barrier Coatings for Enhanced CMAS/VA Infiltration Resistance		Oral
102.	Ms. Vijaya Lakshmi (Dr. P. Suresh Babu)	Electrochemical Corrosion and Erosion Wear Behavior of FeAlCr Intermetallic Coatings Deposited by Detonation Spray Technology		Oral
103.	Mr. Ratnesh Pandey (Dr. G. Sivakumar)	Effect of Laser Clad Parameters on Microstructure of Cr_3C_2-NiCr Coatings Designed for Elevated Temperature Erosion Resistant Applicants		Oral
104.	Ms. K. Anjali (Dr. G. Ravi Chandra)	Microstructural Study of Medium Entropy Refractory Multicomponent Alloy	International Workshop on High Entropy Alloys, IIT Kanpur Mar. 07-08, 2020	Poster

F. Participation in Indian Conferences/Symposia/Seminars/Workshops/Exhibitions

S.N	Name	Event	Place and Date	Sponsor (s)/ Organisor (s)
1.	Mr.G. Gopal Rao	Workshop on Reservation in Services for SC / ST / OBC	New Delhi, Apr. 08-11, 2019	Institute of Secretariet Training & Management (ISTM)
2.	Mr. K. R. C. Soma Raju	Workshop on Environmental Challenges in Metal Finishing – 2019	Bengaluru, Apr. 12-13, 2019	Electrochemical Society of India (ECSI), Bengaluru
3.	Dr.L. Rama Krishna	International Conference on Applied Mechanical Engineering Research	Warangal, May 02, 2019	NIT, Warangal
4.	Mr. Narendra Kumar Bhaktha	Workshop on GeM	New Delhi, June 04, 2019	DST
5.	Mr. Sudheendra	Workshop on Recruitment Rules and Reservation in Services	New Delhi, June 27-29, 2019	Integrated Training and Policy Research (ITPR)
6.	Dr. K. Hari Gopi	ANSYS Innovation Conference	Chennai, June 12, 2019	Ansys
7.	Dr. K. Suresh	ISMANAM-2019 Pre-Conference Workshop on Advances in Nano-Scale Materials Characterization	Chennai, July 07, 2019	IIT-Madras
8.	Mr. G.Vijayaragavan			
9.	Mr. M. B. Sivakumar			
10.	Dr. S. Kavita			
11.	Mr. Sumit Ranjan Sahu			

S.N	Name	Event	Place and Date	Sponsor (s)/ Organisor (s)
12.	Dr. Ravi Bathe	Indo-South Korea (INAE-NAEK) Joint Workshop	Hyderabad, July 15-16, 2019	INAE-NAEK
13.	Dr. R. Vijay			
14.	Mr. Arun Seetharaman	E-Mobility Event	Park Hyatt Hyderabad, July 17, 2019	Indian Chamber of Commerce
15.	Dr. Sanjay Bharadwaj			
16.	Dr. Pramod H. Borse	Workshop on Electronic and Photonic Packaging	Hyderabad, Jul. 20, 2019	IEEE CAS/EDS Society, Hyderabad Chapter and IEEE Photonics Society, Hyderabad Chapter
17.	Dr Ravi Bathe			
18.	Dr. Sanjay Dhage			
19.	Dr. Prasenjit Barick			
20.	Ms S. Nirmala			
21.	Dr.L. Rama Krishna	Modernisation and Sustenance Plans of the Indian Air Force	New Delhi, Aug. 19-20, 2019	Confederation of Indian Industry- New Delhi in Association with Indian Air Force
22.	Mr. Arun Seetharaman	36th DAE Saftey & Occupational Health Professionals Meet-2019	NFC, Hyderabad, Aug. 21-23, 2019	NFC, Hyderabad
23.	Ms. N. Aparna Rao	National Science Communication Orientation Programme	CSIR-AMPRI, Bhopal, Aug. 22-23, 2019	NISCAIR, New Delhi
24.	Dr. Sanjay Dhage	Workshop on Advanced Sensor Material Development ASMD-2019	Hyderabad, Aug. 23, 2019	Indian Ceramic Society and Sensor Research Society of India
25.	Dr. Kaliyan Hembram	CEP on Processing of Advanced Powder Metallurgy Alloys	Hyderabad, Aug. 26-28, 2019	DMRL
26.	Mr. K. V. Phani Prabhakar	Workshop on Emerging Trends in Welding and Non-Destructive Evaluation [WNDE-2019]	NFC, Hyderabad, Aug. 30, 2019	The Indian Institute of Welding, Hyderabad
27.	Mr. N Venkata Rao			
28.	Mr. Anbu Rasu			
29.	Dr. K. Hari Gopi	ANSYS Academic Innovation Conference	Chennai, Sept. 06, 2019	Ansys
30.	Mr. M. Rajkumar			
31.	Dr. Sanjay Bhardwaj	Telangana All-Incubator Meet 2019 on the Innovation and Entrepreneurship Ecosystem	Hyderabad, Sept. 24, 2019	Govt. of Telangana
32.	Ms. Priya Anish Mathews	International Conference on Advances in Minerals , Metals, Materials, Manufacturing and Modelling – 2019 (ICAM5)	Warangal, Sept. 25-27, 2019	NIT, Warangal
33.	Dr. Ravi Bathe	First Consultative Meeting on National Mission on Quantum Technologies	Pune, Oct. 01, 2019	DST and IISER
34.	Dr. M. Buchi Suresh	Hydrogen and Fuel Cells for Sustainable Future	Chennai, Oct. 18, 2019	ARCI, Chennai
35.	Dr. Sanjay Bhardwaj	Brainstorming Session on Hyderabad City Knowledge and Innovation Cluster	Hyderabad, Oct. 18, 2019	Office of Principal Scientific Advisor to Govt. of India, Govt. of Telangana and Research and Innovation Circle of Hyderabad (RICH)
36.	Dr. R. Vijay	National Conference on Advanced Ultra Super Critical Technology [AUSC-2019]	Hyderabad, Oct. 30-31, 2019	BHEL, IGCAR and NTPC
37.	Dr. Ravi Bathe			
38.	Mr. K.V. Phani Prabhakar			
39.	Dr. S.M.Shariff			
40.	Dr. P. Suresh Babu			
41.	Dr. K.Murugan			
42.	Dr. Pramod H. Borse	Workshop on Sense Indent and Intelligence	Hyderabad, Nov .08, 2019	DRDO, India
43.	Dr. Manjusha Battabyal	In-house Symposiumof IIT Madras,	Chennai, Nov. 09, 2019	IIT Madras

S.N	Name	Event	Place and Date	Sponsor (s)/ Organisor (s)
44.	Ms. Minati Tiadi	Workshop on Advanced in EDS, EBSD and TKD	Madras, Nov. 11-12, 2019	IIT Madras
45.	Dr. P. K. Jain	India Graphene Camp 2019	Hyderabad, Nov. 28, 2019	Department of International Trade, UK and the RICH
46.	Dr. Sanjay Bhardwaj			
47.	Dr. B. V. Sarada			
48.	Dr. S. Anandan	IIT-H and itsEV International Workshop	Hyderabad, Nov. 30, 2019	Japan International Cooperation Agency
49.	Mr. Arun Seetharaman	Indian International Innovation Fair (IIF)	NSIC, Hyderabad, Dec. 01-03, 2019	Indian Innovators Association
50.	Dr. Neha Hebalkar	International Exhibition and Conference on WaterEx South World Expo 2019	Hyderabad, Dec. 05, 2019	Chemtech Foundation
51.	Dr. Pandu Ramavath	3rd International Conference on Advanced Functional Materials (ICAFM-2019)	Thiruvananthapuram, Dec. 09-10, 2019	Indian Ceramic Society, Kerala Chapter
52.	Dr. Y. Srinivasa Rao	Programme on Strategic R & D Management	Hyderabad, Dec. 09-11, 2019	DST-ASCI, Hyderabad
53.	Dr. G. Siva Kumar			
54.	Mr. Srinivasa Rao Atchuta	7th International Conference on Advances in Energy Research (ICAER 2019) Exhibition	Mumbai, Dec. 10-12, 2019	ARCI/IIT Bombay
55.	Mr. V. SaiKrishna			
56.	Dr. Neha Hebalkar	XIV Triennial National Conference of IWSA on Women Led Science, Technology and Innovation	Hyderabad, Dec. 11-13, 2019	IWSA
57.	Mr. Arun Seetharaman	Annual Sesion of National Academy of Sciences (NASI) and Symposia cum Exhibition on Science and Technology based Entrepreneurship development	NAARM, Hyderabad, Dec. 21-23, 2019	NASI and ICAR, NAARM
58.	Mr. L. Babu	NuGen Mobility Summit 2019	New Delhi, Dec. 27-29, 2019	ICAT
59.	Ms. N. Aparna Rao	Project Vigyan Samachar's Workshop	New Delhi, Jan. 14, 2020	Vigyan Prasar in association with Ministry of S&T and Ministry of Earth Sciences, New Delhi
60.	Dr. Malobika Karanjai	Workshop on World Hindi Diwas	Hyderabad, Jan. 28, 2020	TOLIC- INCOIS
61.	Dr. Rambha Singh			
62.	Ms. Priya Anish Mathews	12th Asia Pacific Microscopy Conference (APMC)	Hyderabad, Feb. 03-07, 2020	Electron Microscope Society of India (EMSI)
63.	Dr. R. Subasri	IUPAC Global Women Scientists' Breakfast Programme	Hyderabad, Feb. 12, 2020	IICT, IWSA, Hyd Chapter
64.	Dr. Shiv Prakash Singh	Processing and Applications of Advanced Ceramics and Composites	Hyderabad, Feb. 18-20, 2020	Continuing Education Programme of DRDO-DMRL
65.	Dr. Ravi Bathe	Presentation on Draft National Policy and Strategy Paper on Additive Manufacturing	New Delhi, Feb. 19, 2020	Ministry of Electronics and Information Technology (MeitY)
66.	Dr. R. Vijay	International Conference on Powder Metallurgy and Particulate Materials (PM 20)	Lalit Mumbai, Mumbai, Feb. 19-21, 2020	Powder Metallurgy Association of India (PMAI)
67.	Mr. Srinivasa Rao Atchuta	11th Bengaluru INDIA NANO 2020 Exhibition	LaLiT Ashok, Bengaluru, Mar. 02-03, 2020	ARCI 11th Bengaluru INDIA NANO 2020
68.	Mr. Nanaji Katchala			
69.	Mr. V. Sai Krishna			
70.	Mr. Arun Seetharaman	International Engineering Sourcing Show (IESS 2020)	Codissia Exhibition Center, Coimbatore, Mar. 04-06,2020	Industrial Product India and Engineering Export Promotion Council
71.	Dr. P. Sudharshan Phani	6th Asian Conference on Heat Treatment and Surface Engineering	Chennai, Mar.05-07, 2020	ASM Chennai and IIT Madras

G. Participation in Training Programmes in India

S.N	Name (s)	Training Programme	Place and Date	Sponsor (s)/ Organisor (s)
1.	Mr. S. Ramakrishnan	Transmission Electron Microscopy	Chennai, May 06 - 10, 2019	IIT Madras
2.	Dr. Kaliyan Hembram	Hands-on-Training Programme on Electron Microscopy-Why, How and What	New Delhi, May 22- June 01, 2019	CSIR-National Physical Laboratory (NPL)
3.	Ms. K. Divya,	A Course on Integrated Computational Materials Engineering for Metals (ICME)	Hyderabad, July 08-13, 2019	MHRD – Global Initiative on Academic Network (GIAN)
4.	Dr. B. Bolla Reddy			
5.	Mr. K. K.Phani Kumar	A Short Course on Metallurgy for Non – Metallurgists: Industrial Practices (MNM-2019)	Hyderabad, Jul. 12-13, 2019	Indian Institute of Metals (IIM)
6.	Mr. K Srinivasa Rao			
7.	Dr. Gururaj Telasang	Emotional Intelligence at Workplace for Scientists/Technologists	Hyderabad, Aug. 05-09, 2019	DST- Centre for Organization Development (COD)
8.	Dr. D. Prabhu			
9.	Mr. P. Sankar Ganesh	Network Administration: Configuring and Securing LANs and WANs	Hyderabad, Sept. 16-20, 2019	Engineering Staff College of India (ESCI)
10.	Mr. A. Srinivas	14th Annual Convention of Central Information Commission	New Delhi, Oct. 12, 2019	Central Information Commission
11.	Mr. K. R. C. Soma Raju	Short Course on Spectroscopic Ellipsometry	Bengaluru, Nov. 04-05, 2019	Sinsil International Private Limited
12.	Mr.K.R.C.Soma Raju	ABB Industrial Robot Programing Training	Bengaluru, Nov. 18-20, 2019	ABB Industrial robotics
13.	Dr K.Murugan			
14.	Dr P. Suresh Babu			
15.	Dr Naveen M C			
16.	Mr. Vasantha Rayadu			
17.	Ms. Priya Anish Mathews	Programme on Socio-Economic Impact Assessment of S&T Outcomes for Women Scientists/Technologists	Ghaziabad, Nov. 18-22, 2019	DST
18.	Dr. G. Ravi Chandra	National Programme for Scientists and Technologists on Enhancing Accountability and Responsiveness in Scientific Organizations	Hyderabad, Dec. 02-06, 2019	DST-OU
19.	Mr. B. Laxman	Hindi Training on Computer	Secunderabad, Dec. 09, 2019	Ministry of Home Affairs (MHA)
20.	Dr. R. Vijay	Training Programme on Science and Technology: Global Developments, Perspectives	Bengaluru, Dec. 09-20, 2019	DST- NIAS
21.	Ms. S. Nirmala	Proficiency Improvement Programme (PIP) on Automotive Sensors and Actuators	Pune, Dec. 19-20, 2019	Automotive Research Association of India (ARAI)
22.	Dr. Rambha Singh	Memory based Translation Tool	New Delhi, Jan. 21, 2020	MHA
23.	Dr. Malobika Karanjai	Programme for Women Scientists on Social Responsibility of Scientists: Pathways and Outcomes	Bengaluru, Feb. 10-14, 2020	DST-NIAS
24.	Dr. Kaliyan Hembram	Emotional Intelligence at Workplace for Scientists/Technologists	Hyderabad, Feb. 17-21, 2020	DST-COD
25.	Dr. R. Balaji			
26.	Mr. S. Ramakrishnan	All India Training Programme on Industrial Metal Finishing Electroplating Technologies and Aerospace Chemical Process 2020	Bengaluru, Mar. 05-07, 2020	IISc- Electrochemical Society of India
27.	Ms. N. Aruna	Awareness Programme on Sexual Harassment at Work Place- Act of 2013	Hyderabad, Mar. 06, 2020	Commissionerate Rachakonda Police
28.	Ms. K. Divya			

H. Panel Discussion: Invited Speakers

S.N	Name	Title	Technical Session Topic	Name of the Event, Place and Date
1.	Dr. R. Vijay	Development of LTO Material Technology at ARCI	LTO Battery Storage System - its Suitability for Various Applications and the Potential for Enhancing Demand and Manufacturing in India	Round Table on Battery Storage New Delhi, Aug. 06 2019
2.	Dr. S. Anandan			
3.	Dr. Sanjay Bhardwaj	-	IP Contracts Drafting for IP Professionals – Do's / Don'ts and Best Practices	International IP Skills Summit (IIPSS) Hyderabad, Aug. 13-14, 2019
4.			Plenary Session on Innovation Trends and Approach to Novelty Protection of Advanced Materials	STEM Annual Summit 2019 Hyderabad, Dec. 06-07, 2019
5.	Mr. Srinivasa Rao Atchuta	Cost Efficient Functional Coating Technologies for Eco-Friendly Concentrated Solar Thermal and PV Application	Industry Innovations in Energy	7th International Conference on Advances in Energy Research (ICAER 2019), IIT Bombay, Mumbai, Dec.10, 2019.
6.	Dr. N. P. Wasekar	Mechanism of Metal Matrix Composite Electrodeposition		Electrodeposition of Composite Coatings Workshop, Tata Steel, Jamshedpur, Dec. 16-17, 2020
7.	Dr. N.Rajalakshmi	ARCI's Fuel Cell Programme	Status Update on Hydrogen Storage, Fuel Cell and Electricity	Deakin University-GE Power-TER sponsored 'Integrated Energy Program', India Habitat Centre Complex, New Delhi, July 12, 2019.
8.	Dr. Sanjay Bhardwaj	-	Threats, Opportunities and Challenges for Chemical Engineering and its Allied Braches	RACE- 2020, Hyderabad, Jan. 08-09, 2020
9.	Dr. G. Sivakumar	Thermal Spray Coatings		Discussion Meeting on Thermal Spray Trends in India IIT Bombay, Jan. 24, 2020
10.	Dr. Sanjay Bhardwaj	-	Round Table on Challenges and Way Forward for IP in the Emerging Technology Ecosystem	5th MIPS-2020 Mumbai, Jan. 24-25, 2020
11.	Dr. N.Rajalakshmi	Country Perspective about Hydrogen	Country Perspectives- Sustainable Hydrogen Economy	DST sponsored Industry-Academia conclave on Hydrogen and Fuel Cells IISER, Thiruvananthapuram, Feb. 27, 2020
12.	Dr. Sanjay Bhardwaj	-	Drafting IP Contracts: A Primer for IP Professionals	IIPS-2020, Hyderabad, Feb. 27-28, 2020
13.	Mr. D. Srinivasa Rao	ARCI's contributions to the sustenance of Aerospace sector	Defense Private Sector on the Technologies to Focus	Aerospace and Defence Summit GMR Aero Park, Hyderabad, Feb. 28, 2020
14.	Dr. L. Rama Krishna			
15.	Dr. N.Rajalakshmi	Round Table Discussion on Hydrogen and Fuel Cells		Indo-Japan workshop on Hydrogen and Fuell cell 2020, India Habitat Centre, New Delhi, Mar. 03, 2020

Patents' Portfolio

National Patents Granted

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
1.	A Solar Drier	184674	23/09/2000	487/MAS/1994	08/06/1994
2.	A Solar Cooker	184675	25/05/2001	498/MAS/1994	13/06/1994
3.	An Indirect Heated Catalytic Converter for use with Vehicles	185433	10/08/2001	809/MAS/1994	25/08/1994
4.	A Process for the Preparation of Short Ceramic Fibres	186751	07/06/2002	537/MAS/1994	20/05/1994
5.	A Process of Producing Chemically Treated Expanded Graphite and a Device having Such Graphite	187654	05/12/2002	562/MAS/1994	07/06/1995
6.	A Process for Preparation of Reaction Bonded Silicon Carbide Components	195429	31/08/2006	1886/MAS/1996	28/10/1996
7.	New Composite Material Having Good Shock Attenuating Properties and a process for the Preparation of Said Material	194524	02/01/2006	976/MAS/1998	06/05/1998
8.	Improved Process for the Preparation of Magnesium Aluminate Spinel Grains	200272	02/05/2006	29/MAS/1999	07/01/1999
9.	Ceramic Honey Comb Based Energy Efficient Air Heater	200787	02/06/2006	30/MAS/1999	07/01/1999
10.	A Process for the Preparation of Improved Alumina Based Abrasive Material, an Additive Composition and a Process for the Preparation of the Composition	198068	16/02/2006	122/MAS/2000	18/02/2000
11.	A Process for the Production of Dense Magnesium Aluminate Spinel Grains	198208	16/02/2006	520/MAS/2000	06/07/2000
12.	An Improved Method for Making Honeycomb Extrusion Die and a Proc ess for Producing Ceramic Honeycomb Structure using the Said Die	198045	13/01/2006	538/MAS/2001	03/07/2001
13.	Device for Gas Dynamic Deposition of Powder Materials	198651	25/01/2006	944/MAS/2001	22/11/2001
14.	An Evaporation Boat useful for Metallization and a Process for the Preparation of Such Boats	201511	01/03/2007	882/CHE/2003	31/10/2003
15.	Process for Carbothermic Reduction of Iron Oxide in an Immiscible Flow with Constant Descent in Vertical Retort of Silicon Carbide	205728	16/04/2007	546/CHE/2003	01/07/2003
16.	A Process for Preparing Ceramic Crucibles	207700	20/06/2007	806/MAS/2000	26/09/2000
17.	A Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	209817	06/09/2007	945/MAS/2001	22/11/2001
18.	A Method and a Device for Applying a Protective Carbon Coating on Metallic Surfaces	211922	13/11/2007	719/MAS/1999	08/07/1999
19.	An Improved Boronizing Composition	220370	27/05/2008	289/MAS/2001	03/04/2001
20.	Titanium Based Biocomposite Material useful for Orthopedic and other Implants and a Process for its Preparation	228353	03/02/2009	2490/DEL/2005	14/09/2005
21.	An Improved Method of Forming Holes on a Substrate using Laser Beams	239647	29/03/2010	3205/DEL/2005	29/11/2005
22.	A Method of and an Apparatus for Continuous Humidification of Hydrogen Delivered to Fuel Cells	247547	19/04/2011	670/CHE/2007	30/03/2007
23.	An Improved Process for the Preparation of Doped Zinc Oxide Nanopowder useful for the Preparation of Varistors	254913	03/01/2013	1669/DEL/2006	20/07/2006
24.	A Device for Controlling the On & Off Time of the Metal Oxide Semi Conductor Field Effect Transistor (MOSFET), A Device for Spark Coating the Surfaces of Metal Workpiece Incorporating the said Control Device and a Method of Coating Metal Surfaces using the said Device	262189	05/08/2014	1610/DEL/2005	21/06/2005
25.	An Improved Catalyst Ink useful for Preparing Gas Diffusion Electrode and an Improved PEM Fuel Cell	277778	30/11/2016	680/DEL/2008	18/03/2008

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
26.	An Improved Process for the Preparation of Exfoliated Graphite Separator Plates useful in Fuel Cells, the Plates Prepared by the Process and a Fuel Cell Incorporating the Said Plates	281504	20/03/2017	1206/DEL/2006	17/05/2006
27.	Improved Method of Producing Highly Stable Aqueous Nano Titania Suspension	282988	28/04/2017	730/DEL/2009	09/04/2009
28.	A Process for the Preparation of Nanosilver and Nanosilver-Coated Ceramic Powders	284812	30/06/2017	2786/DEL/2005	19/10/2005
29.	An Improved Method for Preparing Nickel Electrodeposited having Predetermined Hardness Gradient	285178	14/07/2017	1455/DEL/2009	15/07/2009
30.	An Improved Method for the Generation of Hydrogen from a Metal Borohydride and a Device Therfor	285257	17/07/2017	1106/DEL/2007	23/05/2007
31.	Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	289543	14/11/2017	1835/DEL/2010	04/08/2010
32.	Improved Method for Producing Carbon Containing Silica Aerogel Granules	290370	07/12/2017	2406/DEL/2010	08/10/2010
33.	An Improved Composition for Coating Metallic Surfaces, and a Process for Coating Such Surfaces using the Composition	290592	14/12/2017	620/DEL/2010	17/03/2010
34.	Improved Catalyst Ink for Catalyst Coated Membrane of Electrode Membrane Assembly and the Process Thereof	290765	18/12/2017	631/DEL/2008	13/03/2008
35.	Improved Process for the Preparation of Bi-Functional Silica Particles useful for Antibacterial and Self Cleaning Surfaces	291408	04/01/2018	3071/DEL/2010	22/12/2010
36.	A Hydrophilic Membrane based Humidifier useful for Fuel Cells	291871	18/01/2018	95/DEL/2007	16/01/2007
37.	An Improved Method for Producing ZnO Nanorods	293775	05/03/2018	2759/DEL/2010	19/11/2010
38.	Improved Scratch and Abrasion Resistant Compositions for Coating Plastic Surfaces, a Process for their Preparation and a Process for Coating using the Compositions	295221	28/03/2018	2427/DEL/2010	12/10/2010
39.	An Improved Abrasion Resistant and Hydrophobic Composition for Coating Plastic Surfaces and a Process for its Preparation	297072	24/05/2018	1278/DEL/2011	02/05/2011
40.	Improved Fuel Cell having Enhanced Performance	301158	19/09/2018	606/DEL/2007	21/03/2007
41.	An Improved Process for Preparing Nanotungsten Carbide Powder useful for Fuel Cells	303338	22/11/2018	81/DEL/2007	12/01/2007
42.	An Improved Solar Selective Multilayer Coating and a Method of Depositing the Same	303791	30/11/2018	1567/DEL/2012	22/05/2012
43.	An Improved Method of Preparing Porous Silicon Compacts	304349	12/12/2018	912/DEL/2011	31/03/2011
44.	An Improved Coating Composition to Provide Flame Retardant Property to Fabrics and Process of Preparing the Same	305214	01/01/2019	201611040091	23/11/2016
45.	An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	305898	18/01/2019	2141/DEL/2015	15/07/ 2015
46.	Novel Copper Foils having High Hardness and Conductivity and a Pulse Reverse Electrodeposition Method for their Preparation	306501	29/01/2019	1028/DEL/2009	20/05/2009
47.	A Process for Preparing Nanocrystalline Olivine Structure Transition Metal Phosphate Material	310620	31/03/2019	405/DEL/2012	14/02/2012

National Patent Applications Awaiting Grant

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
1.	Novel Ceramic Materials Having Improved Mechanical Properties and Process for their Preparation	3396/DEL/2005	19/12/2005

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
2.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	1829/DEL/2008	01/08/2008
3.	An Improved Gas and Coolant Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	1449/DEL/2010	22/06/2010
4.	An Improved Method for Making Sintered Polycrystalline Transparent Sub-Micron Alumina Article	1358/DEL/2011	10/05/2011
5.	An Improved Composition for Solar Selective Coatings on Metallic Surfaces and a Process for its Preparation and a Process for Coating using the Composition	3324/DEL/2011	22/11/ 2011
6.	A Process and a Multi-Piston Hot Press for Producing Powder Metallurgy Component, such as Cerametallic Friction Composite	3844/DEL/2011	28/12/ 2011
7.	A Device for and A Method of Cooling Fuel Cells	1408/DEL/2012	08/05/2012
8.	An Improved Aqueous Method for Producing Transparent Aluminium Oxy Nitride (ALON) Articles	1409/DEL/2012	08/05/2012
9.	A Multi Track Laser Beam Process of Surface Hardening of a Full size Steel Blank of Low Carbon Steel for Producing Automotive Components	600/KOL/2012	25/05/2012
10.	Enhanced Thermal Management System for Fuel Cell Applications Using Nanofluid Coolant	1745/DEL/2012	07/06/2012
11.	Electronically and Ionically Conducting Multi-Layer Fuel Cell Electrode and a Method for Making the Same	2198/DEL/2012	17/07/2012
12.	A Polymer Electrolyte Membrane (PEM) Cell and a Method of Producing Hydrogen from Aqueous Organic Solutions	3313/DEL/2012	29/10/2012
13.	An Improved Test Control System useful For Fuel Cell Stack Monitoring and Controlling	269/DEL/2013	31/01/2013
14.	A Novel Laser Surface Modification Technique for Hardening Steel	337/DEL/2013	06/02/2013
15.	An Improved Solar Selective Absorber Coating with Excellent Optical Absorptance, Low Thermal Emissivity and Excellent Corrosion Resistance Property and a Process of Producing the Same	1129/DEL/2013	16/04/2013
16.	An Improved Composition for Coating for Anodizable Metal Surfaces and a Process of Coating the Same	1310/DEL/2013	03/05/2013
17.	A Method of Preparation of Supported Platinum Nano Particle Catalyst in Tubular Flow Reactor Via Polycol Process	1571/DEL/2013	24/05/2013
18.	An Improved Composition for Antireflective Coating with Improved Mechanical Properties and a Process of Coating the Same	2330/DEL/2013	05/08/2013
19.	Process for Producing Anti-Reflective Coatings With Anti-Fogging (Super Hydrophilic), UV, Weather and Scratch Resistance Properties	2919/DEL/2013	03/10/2013
20.	An Improved Process for Obtaining a Transparent, Protective Coating on Bi-Aspheric / Plano-Convex Lenses made of Optical Grade Plastics for use in Indirect Ophthalmoscopy	3072/DEL/2013	17/10/2013
21.	Exfoliated Graphite Separator based Electrolyzer for Hydrogen Generation	3073/DEL/2013	17/10/2013
22.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	1411/KOL/2013	13/12/2013
23.	A Super Hydrophobic Coating with High Optical Properties having Easy to Clean Property, UV and Corrosion Resistance Properties, a Process of Preparation and Application of the Same	402/DEL/2014	12/02/2014
24.	High Temperature Polymer Electrolyte Membrane Fuel Cells with Exfoliated Graphite based Bipolar Plates	494/DEL/2014	20/02/2014
25.	Method of Deposition of Double Perovskite of Sr-Fe Niobium Oxide Film on a Substrate by Spray Coating Technique and the Coated Substrate Thereof	1151/DEL/2014	29/04/2014
26.	An Improved Process to Make Coating Compositions for Transparent, UV Blocking on Glass and a Process of Coating the Same	1152/DEL?2014	29/04/2014
27.	Method of Producing Multifunctional Self Assembled Mixed Phase Titania Spheres	3777/DEL/2014	19/12/2014
28.	Method of Producing Porous MgF2 Nanoparticles, Antireflection Coating Suspension and Coatings for Solar Optical UV and IR Transparent Window Applications	4041/DEL/2014	31/12/2014

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
29.	A Novel Electrochemical Method for Manufacturing CIGS Thin Film Containing Nanomesh Like Structure	426/DEL/2015	16/02/2015
30.	An improved performance of Nanocomposite Oxide Selective Absorber Coating with excellent optical and thermal resistant properties and method of manufacturing the same	1111/DEL/2015	22/04/ 2015
31.	Process and apparatus for protection of structural members from wear, corrosion and fatigue damage	1839/DEL/2015	22/06/ 2015
32.	A Method of Preparing of Anti Tarnishing Organic-Inorganic Hybrid Sol-Gel and Coating The Same	2049/DEL/2015	07/07/2015
33.	Solar Selective Coating For Solar Energy Collector / Absorber Tubes with Improved Performance and a Method of Producing the Same	2142/DEL/2015	15/07/ 2015
34.	Production of Graphene-Based Materials by Thermal Spray	2626/DEL/2015	25/08/2015
35.	Methods of preparation of high Performance ZnO varistors and improved compositions	2765/DEL/2015	03/09/2015
36.	An Improved Coating Composition to Provide Prolonged Corrosion Protection to Anodizable Metal Surfaces and Process of Preparing the Same	3082/DEL/2015	28/09/ 2015
37.	A Method and an Apparatus for Preparing Nickel Tungsten based Nanocomposite Coating Deposition	201611001190	13/01/2016
38.	A Process for In-Situ Carbon Coating on Alkali Transition Metal Oxides	201611007451	03/03/2016
39.	An Improved Process for the Preparation of Stable Nano Silver Suspension having Antimicrobial Activity	201611027145	09/08/2016
40.	A Laser-based Surface Processing Apparatus and a Method to Process Metallic Materials and Components	201611034362	07/10/2016
41.	An Improved Process of Carbon - Metal Oxide Composites Prepared by Nano Casting of Wood and the Product thereof	201611034531	07/10/2016
42.	A method for producing inorganic bonded silica based eco-friendly artificial marble articles and the product thereof	201611036479	25/10/2016
43.	Method of producing Hollow MgF_2 nanoparticles, anti-reflection coating sols and coatings for optical and solar applications	201611041804	07/12/2016
44.	A method of producing high performance lithium titanate anode material for lithium ion battery applications	201711006147	21/02/2017
45.	Method of producing graphene like structured nanoporous carbon material from Jute stick based bio-waste for Energy Storage applications and the product thereof	201711006697	24/02/2017
46.	An improved gas dynamic cold spray device and method of coating a substrate	201711006749	26/02/2017
47.	A Novel Equipment to Accomplish Power Metallurgy Processing Starting From The 'Raw Materials' to Finished Product	201711011552	30/03/2017
48.	An Improved Process for Preparing Durable Multifunctional Coatings On Metal/Alloy Substrates	201711020529	12/06/2017
49.	A System for treating a surface of bearing components and a process thereof	201711046511	23/12/2017
50.	Method of Producing Nano Structured C-TIO_2 Composite Material For Visible Light Active Photocatalytic Self-Cleaning Applications	201811011478	28/03/2018
51.	An Ecofriendly Incinerator To Dispose Of The Used Sanitary Napkins and Bio Medical Waste	201821021430	07/06/2018
52.	Process for Preparing Durable Solar Control Coatings on Glass Substrates	201811024034	27/06/2018
53.	Laser Based Clad-Coatings For Protecting The Power Plant Components for Life Enhancement	201811039663	19/10/2018
54.	Process of Electroless Nickel/Nickel Phosphide (EN) Deposition on Graphite Substrates	201811041418	01/11/2018
55.	A Grid Independent Fuel Cell System With A Unitized (DC & AC) Power Conditioner	201911006700	20/02/2019
56.	Refurbishment of Aircraft Components Using Laser Cladding	201911007994	28/02/2019
57.	Microwave Assisted Sol-Gel Process For Preparing In-Situ Carbon Coated Electrode Materials and the Product there of	201911008004	28/02/2019
58.	Ambient Condition Curable Transparent Super Hydrophobic Coating for Easy to Clean Applications and Method of Producing the Same	201911009429	11/03/2019

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
59.	Method of fabricating tungsten based composite sheets by spark plasma sintering technique for making components	201911014933	13/04/2019
60.	Transition metal-based solar selective absorber coated substrate and method of manufacturing the same	201911019139	14/05/2019
61.	Process for producing the nano Boron by cryo-milling	201911025690	27/06/2019
62.	Method of preparing gas diffusion layer for the electrode of ECMR cell for hydrogen generation Method of preparing gas diffusion layer for the electrode of ECMR cell for hydrogen generation	201911030852	31/07/2019
63.	Antimicrobial Aqueous Based Sol-Gel Composition for Coating on Substrate and Process of Preparing the Same	201911045386	07/11/2019
64.	A method of preparing the thermoelectric module for power generation from automotive exhaust and the thermoelectric module thereof	201911045857	11/11/2019
65.	Method of Producing Nanoporous Graphene Sheet-like Structured High and Low Surface Area Carbon Sheets from Petroleum Coke	20201100739	20/02/2020

International Patents Granted and Awaiting Grant

Sl. No.	Title of Patent	Country	Patent Number / Application Number	Date of Grant	Date of filing with patent office
1.	Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	USA	US6893551B2	17/05/2005	02/08/2002
2.	A Device for Controlling the On & Off Time of the Metal Oxide Semi Conductor Field Effect Transistor (MOSFET), A Device for Spark Coating the Surfaces of Metal Workpiece Incorporating the said Control Device and a Method of Coating Metal Surfaces using the said Device	USA	US8143550B2	27/03/2012	20/03/2006
3.	A Process for the Preparation of Nano Silver and Nano Silver-Coated Ceramic Powders	South Africa	2006/8591	30/04/2008	13/10/2006
		Sri Lanka	14258	02/11/2011	17/10/2006
		Indonesia	IDP000044402	06/02/2017	18/10/2006
4.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	South Africa	2009/06786	26/05/2010	30/09/ 2009
		UK	2464378	15/05/2013	02/10/2009
		USA	8486237	16/07/2013	14/10/2009
		Japan	2009-237921	27/12/2013	15/10/2009
		France	2937342	18/12/ 2015	12/10/2009
5.	Method of Depositing Electrically Conductive Electrode Material onto the Surface of an Electrically Conductive Work Piece	USA	US8674262B2	18/03/2014	12/08/2011
6.	Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	United Kingdom	GB2496089	18/06/2014	19/07/2011
7.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	USA	US9365945B2	14/06/2016	14/06/2016
8.	An Improved Hybrid Methodology for Producing Composite, Multilayered and Graded Coatings by Plasma Spraying Utilizing Powder and Solution Precursor Feedstock	South Africa	2012/02480	28/11/2012	05/04/2012
		Canada	2784395	16/09/2014	31/07/2012
9.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	USA	15/103343	---	10/12/2014
		Australia	AU2014362928A	---	10/12/2014
		Europe	EP3080313A1	---	10/12/2014

Sl. No.	Title of Patent	Country	Patent Number / Application Number	Date of Grant	Date of filing with patent office
10.	An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	UAE	P6000095/2018	-	11/01/2018
		Saudi Arabia	518390733	-	11/01/2018
		Mexico	MX/a/2018/000480	-	11/01/2018
		Russia	2017128112	-	07/08/2017
		Indonesia	P00201800182	-	09/01/2018
		China	201680041762.3	-	12/01/2018
		Malaysia	PI2018700103	-	08/01/2018
		Brazil	BR1120180007030	-	12/01/2018
		USA	15/744011	-	12/01/2018
		Korea	1020187003173	-	01/02/2018
11.	A Method of Producing High Performance Lithium Titanate Anode Material for Lithium Ion Battery Applications	Japan	2019-520394	-	10/04/2019
		Germany	112018000205.5	-	28/06/ 2019
		USA	16/463088	-	22/05/2019
		China	201880004507.0	-	22/05/2019
		Korea	10-2019-7019218	-	02/07/2019
12.	An Improved Gas Dynamic Cold Spray Device and Method of Coating a Substrate	China	201880013832.3	-	26/08/2019
		Russia	2019129866	-	24/09/2019
		Canada	3054112	-	09/09/2019
13.	Microwave assisted sol-gel process for preparing in-situ carbon coated electrode materials and the product thereof	Yet to Choose	PCT/IN2020/050143	-	

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2. Y.Ikuma, M. Yamana, S. Yogose, K. Niwa, S. Anandan, D. Kuroda, H. Tajiri and O. Sakata, "Surface X-ray diffraction study of annealed single crystal rutile TiO2 (001) surface", Ionics, Vol. 25(4), p 1879–1886, 2019.

3. V. Manikandan, V. Kuncser, Bogdan Vasile, S. Kavita, S. Vigneselvan and R.S.Mane, "Enhancement in magnetic and dielectric properties of the ruthenium-doped copper ferrite (Ru-CuFe2O4) nanoparticles", Journal of Magnetism and Magnetic Materials, Vol.476, p 18-23, 2019.

4. M. Sreekanth, S.R. Dey, S.V. Joshi and B.V. Sarada, "Two-dimensional CuIn1-x GaxSe2 nano-flakes by pulse electrodeposition for photovoltaic applications", Solar Energy, Vol. 181, p 396-404, 2019.

5. M. Sreekanth, Prashant Misra, B. V. Sarada and T.N. Rao, "Copper chalcopyrites for solar energy applications", Transactions of Indian Institute of Metals, Vol. 72 (2), p 271-288, 2019.

6. Ho Soon Min, M. Sreekanth, R. Chandran, A.Mallik, M. A. Sobhan Bhuiyan and K.G. Deepa, "Preparation of CuInSe2thin films by using various methods", Oriental Journal of Chemistry, Vol. 35 (1), 2019.

7. B.S. Yadav, S. R. Dey and Sanjay R Dhage, "Effective ink-jet printing of aqueous ink for Cu (In, Ga) Se2 thin film absorber for solar cell application", Solar Energy, Vol. 179, p 363-370, 2019.

8. N.S. Anas, M. Ramakrishna, R. K. Dash, Tata N. Rao and R. Vijay, "Influence of process control agents on microstructure and mechanical properties of Al-Cu-Mg alloy produce by mechanical alloying", Materials Science and Engineering A, Vol. 751, p 171-182, 2019.

9. P. Chapala, P. S. Kumar, J. Joardar, V. Bhandari andS. Ghosh Acharyya, "Effect of alloying elements on the microstructure, coefficient of friction, in-vitro corrosion and antibacterial nature of selected Ti-Nb alloys," Applied Surface Science, Vol. 469, p 617-623, 2019.

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11. Tejassvi, E. Hari Mohan, Neha Y. Hebalkar, A. Jyothirmay, B. V. Sarada, S. Anandan, M. Krishna Mohan and Tata N. Rao, "Flexible and free-standing carbon nanofiber matt derived from electrospun polyimide as an effective interlayer for high performance lithium sulfur batteries", Journal of Material Science, Vol. 54(12), p. 9075-9087, 2019.

12. Papiya Biswas, S. Mamatha, S. Naskar, Y. Srinivas Rao, Dr. Roy Johnson and Dr. G. Padmanabham, "3D extrusion printing of magnesium aluminate spinel ceramic parts using thermally induced gelation of methyl cellulose",

Journal of Alloys and Compounds, Vol. 770, p 419-423, 2019.

13. K. Nanaji, U. V. Varadaraju, Tata N. Rao and S. Anandan, "One step synthesized hierarchical spherical porous carbon as an efficient electrode material for lithium ion battery", Materials Letters, Vol. 237,p 156-160, 2019.

14. E. Hari Mohan, K Nanaji, S. Anandan, B.V. Sarada, M. Ramakrishna, A Jyothirmayi, B.

V. Appa Rao and T.N. Rao, "One-step induced porous graphitic carbon sheets as supercapacitor electrode material with improved rate capability", Material Letters, Vol. 236, p 205-209, 2019.

15. K. Nanaji, U. V. Varadaraju, Tata N. Rao and S. Anandan, "Robust, environmentally benign synthesis of nanoporous graphene sheet from bio-waste for ultrafast supercapacitor application", ACS Sustainable Chemistry and Engineering, Vol.7, p. 2516-2529, 2019.

16. A. K. Mallik, M. Das, S. Ghosh and D. Chakravarthy, "Spark plasma sintering of Ti-diamond composites", Ceramic International, Vol. 45, p. 11281-11286, 2019.

17. E. Hari Mohan, S. Anandan, B. V. Appa Rao and T.N. Rao, "Neem leaves-derived micro and mesoporous carbon as an efficient polysulfide inhibitor for sulfur cathode in a Li-S battery", Chemistry Letters, Vol. 48(1), p 62-64, 2019.

18. P.M. Prathekha, J. Sri Rajeshwari, D. Paul Joseph, T. N. Rao and S. Anandan, "Investigation of in-situ carbon coated LiFePO4 as superior cathode materials for lithium ion batteries", Journal of Nanoscience and Technology, Vol. 19, p. 3002-3011, 2019.

19. M. Vijayakumar, D. Sri Rohita, T. N. Rao and Mani Karthik, "Electrode mass ratio impact on electrochemical capacitor performance", Electrochimica Acta, Vol. 298, p. 347-359, 2019.

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23. S. Bhuvaneswari, U.V.Varadaraju, R.Gopalan and RajuPrakash, "Structural stability and superior electrochemical performanceof Sc-doped LiMn2O4spinel as cathode for lithium ion batteries", Electrochimica Acta, Vol. 301, p 342-351, 2019.

24. V.V.N. Phanikumar, V. R. Rikka, Bijoy Das, R. Gopalan, B. V. Appa Rao and R. Prakash, "Investigation on polyvinyl alcohol and sodium alginate as aqueous binders for lithium-titanium oxide anode in lithium-ion batteries", Ionics, Vol. 25(6), p 2549–2561, 2019.

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26. L. Rama Krishna, Y. Madhavi, T. Sahithi, D. Srinivasa Rao, Vijay K. Ijeri, Om Prakash and S.P. Gaydos, "Enhancing the high cycle fatigue life of high strength aluminum alloys for aerospace applications", Fatigue and Fracture of Engineering Materials and Structures, Vol. 42, p 698-709, 2019.

27. P. Sudharshan Phani and W.C. Oliver, "A critical assessment of the effect of indentation spacing on the measurement of hardness and modulus using instrumented indentation testing", Materials and Design, Vol. 164, Article no. 107563, 2019.

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33. A. R. Dilipan, A. K. Srinithi, Ravi Gautam, U. Gowtham, D. Prabhu, V. Chandrasekaran and R. Gopalan, "Microstructure and magnetic properties of anisotropic strontium hexaferrite powders", IEEE Transactions on Magnetics, Vol. 55(8), Article No. 2101705, 2019.

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18. A chapter on "Transparent ceramics for ballistic armor applications" authored by R. Senthil Kumar, Papiya Biswas, Roy Johnson, and Y. R. Mahajan in the 'Handbook of Advanced Ceramics and Composites' (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature, ISBN978-3-319-73255-8,2020 (published online)

19. A chapter on "New generation ceramic coatings for high-temperature applications by liquid feedstock plasma spraying" authored by S. Joshi, N. Markocsan, P. Nylén, and G. Sivakumar in the 'Handbook of Advanced Ceramics and Composites, (ed.)Y. R. Mahajan and Johnson, Springer Nature, ISBN978-3-319-73255-8,2020 (published online)

20. A Chapter on "Recent developments in electrode materials for lithium-ion batteries for energy storage

application" authored by M. B. Sahana and R. Gopalan in the 'Handbook of Advanced Ceramics and Composites' (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature, ISBN978-3-319-73255-8,2020 (published online)

21. A chapter on "Applications of sol-gel coatings: Past, present and future" authored by R. Subasri, K.R.C. Soma Raju and K. Samba Sivudu in the 'Handbook on Modern Coating Technologies: Applications, V4', (ed) M. Aliofkhazraei, Elsevier Publishers. (In Press)

Other Articles in Magazines and News Letters

1. Tata. N. Rao and V. Pavan, "Journey of lithium-ion batteries to nobel destiny", Nano Digest, p 14-18, 2019.
2. E. Anusha, A. Kumar, G. Padmanabham and S. M. Shariff, "Novel technique of controlling heat input for core retention and reduction in distortion in laser surface treatment of bearing racer", Kiran – A Bulletin of ILA, Vol.29, p 35-45, 2019.
3. Nitin P. Wasekar, L. Ramakrishna, D. S. Rao and G. Padmanabham, "Novel nanostructured coatings by pulsed electrodeposition", Indian Engineering Exports, 12(7), 2019, p 16-24.
4. Sanjay Bhardwaj, "Commercialization of advanced material technologies: Challenges, opportunities and invention protection", Srujan - ARCI Hindi Magazine, (2), p.14-15 (Issue of 2018-19) published 2019-2020.
5. K. Swati, Priya Anish Mathews and Sanjay Bhardwaj, "Intellectual property rights", Srujan - ARCI Hindi Magazine (2), p 16-17 (Issue of 2018-19) published 2019-2020.

Awards and Honours

1. Dr. G. Padmanabham was awarded the 'Abdul Kalam Technology Innovation National Fellowship' by Indian National Academy of Engineering (INAE) 2019.
2. Mr. K. Nanaji, was selected for the 'DST-DFG Awards for Participation in the '69th Meeting of NOBEL Laureates and Student' to be held at Lindau, Germany in 2020.
3. Dr. Pramod H. Borse selected as Fellow of Telangana Academy of Sciences for the year 2019.
4. Dr. Srinivasan Anandan has been selected as Associate Fellow of Telangana Academy of Sciences for the year 2019.
5. Dr. N. P. Wasekar was awarded with 'Best Reviewer Award' for the year 2019 by Editorial Board of Transaction of Indian Institute of Metals.
6. Dr. Sanjay Bhardwaj was nominated as Member of IIChE's National Industry - Institute Interaction Committee for 2020.
7. Dr. Easwaramoorthi Ramasamy received "Bhaskara Advanced Solar Energy Fellowship' from Indo-US Science and Technology Forum on April 01, 2019.
8. Dr. S. Sakthivel and Dr. Easwaramoorthy Ramasamy were inducted as the Members of the Royal Society of Chemistry, Cambridge, U.K. on May 03, 2019.
9. Mr. K. Nanaji, received the 'Young Scientist Award in Chemistry for the year 2018-19' from Dr. K.V. Rao Scientific Society, Hyderabad on May 11, 2019.

Mr. K. Nanaji receiving the 'Young Scientist Award' in Chemistry from Dr. K. V. Rao Scientific Society

10. Dr. Sanjay Bhardwaj received the 'Certificate of Recognition' for achievements and contributions in the field of Intellectual Property during Questel Executive IP Summit held at Bengaluru on June 27, 2019.
11. Dr. R. Vijay received 'FTCCI Excellence Award' for individual achievement in Science and Engineering (Chelikani Atchut Rao Award) from Federation of Telangana Chamber of Commerce and Industry (FTCCI) on July 12, 2019 at Hyderabad.

Dr. R. Vijay receiving the 'FTCCI Excellence Award' for individual achievement in Science and Engineering

12. Dr. Sakthivel received the 'Best Paper Award' for presenting a paper on "Cost efficient receiver tube technology for eco-friendly concentrated solar thermal application" at the International Conference on Energy Conversion Technologies for Space Power held at Berlin, Germany during on July 22-23, 2019.
13. Mr. Ravi Gautam received the 'Second Best Poster Award' for the poster presentation on "Influence of microstructure on the magnetic properties of Fe-P based soft magnetic alloy" at the 24th Soft Magnetic Materials Conference held at Poznan, Poland during September 04-07, 2019.

Mr. Ravi Gautam receiving the 'Second Best Poster Award' at the 24th Soft Magnetic Materials Conference, Poland

14. Ms. Pooja Miryalkar (Dr. Krishna Valleti) received the 'Best Paper Award' for paper presentation on "Cr/ML(CrN/AlTiN)/AlSiN/AlSiO Open Air-Stable Solar Selective Coatings for CSP Applications" at the 'International Conference on Advances in Minerals, Metals, Materials, Manufacturing and Modelling' held at Warangal during September 25-27, 2019.
15. Dr. G. Padmanabham was awarded the 'Fellow of the National Academy of Sciences, India (NASI)' during October 2019.
16. Mr. M. Shiva Prasad (Dr. S. Sakthivel) secured the 'Best Ph.D. Award' at the '2nd International Conference on Protective coatings and Surface treatment' held at New Delhi during November 18-19, 2019.

Mr. M. Shiva Prasad receiving the 'Best Ph.D. Award' at the 2nd International Conference on Protective Coatings and Surface Treatment

17. Dr. Bijoy Kumar Das, received the 'Second Best Poster Award'for the poster presentation on "Development of low-cost sodium ion battery for grid and off-grid storage applications" at the Industry Academia Conclave on Energy Storage held at MNIT, Jaipur during November 30, 2019.
18. Mr. G. Vijayaragavan received 'Best Poster Award' for the poster presentation on "Development of low meting alloys for consolidation of isotropic Sm-Fe-N powders" at the STAR 2019 held at BARC, Mumbai during December 05-07, 2019.
19. Mr. M. B. Sivakumar received the 'Best Poster Award' for the poster presentation on "Microstructural investigation of Ce-La-Fe-B permanent magnet"at the STAR 2019 National Conference held at BARC, Mumbai during December 05-07, 2019.
20. Dr. Bhaskar P. Saha received the 'Malaviya Award-2019' by the 'Indian Ceramic Society' during the '83rd Annual Session of Indian Ceramic Society' held on December 11-12, 2019, at NIIST, Thiruvananthapuram, Kerala, India for co-authoring the paper on 'Spark plasma sintering of silicon carbide with Al_2O_3 and CaO: densification behavior, phase evolution and mechanical properties' published in the Transaction of Indian Ceramic Society, 77 (4), 1-7 (2018), that was selected as the best paper.
21. Ms. M. Swathi (Dr. R. Johnson) received the 'Best Poster Award' for the poster presentation on "Shaping of $MgAl_2O_4$ spinel ceramics through compaction and colloidal shaping process: Comparative evaluation" at the National Conference on Innovations and Technologies for Ceramics (InTeC-2019) held at NIIST, Thiruvananthapuram during December 11-12, 2019.

Ms. M. Swathi receiving the 'Best Poster Award' at the National Conference on Innovations and Technologies for Ceramics

22. Mr. V. V. N. Phanikumar received the 'Best Poster Award' for the poster presentation on "Tamarind kernel powder as a novel aqueous binder for graphite anode in Lithium ion batteries" at the 13th National Conference on Solid State Ionics (NCSSI-13) held at IIT Roorkee during December 16-18, 2019.
23. Ms. J. A. Prithi received the 'Best Oral Presentation Award' for the paper on "Experimental and theoretical study on SO_2 tolerance of Pt electrocatalysts: Role of carbon support" at the International Conference on Electrochemistry in Industry, Health and Environment (EIHE-2020) held at BARC, Mumbai during January 21-25, 2020.
24. Dr. R. Prakash was awarded the 'International Distinguished Scientist' by IJRULA and World Research Council and United Medical Council at Trichy on January 26, 2020 for his work on Lithium-ion battery.
25. Dr. R. Gopalan was elected the 'Fellow of the Electron Microscope Society of India'. The award was conferred on February 04, 2020 during the 12th Asia Pacific Microscopy Conference (APMC12) held in Hyderabad.
26. Dr. G. Ravi Chandra was elected the 'Fellow of the Electron Microscope Society of India'. The award was conferred on February 04, 2020 during the 12th Asia Pacific Microscopy Conference (APMC12) held in Hyderabad.

Dr. R. Gopalan receiving the 'Fellow of the Electron Microscope Society of India' Award during the 12th Asia Pacific Microscopy Conference

27. The following Research Fellows/Associates/Students received Awards in the Science Flash Talk-Creativity Unleashed, organized at ARCI, Hyderabad, on the occasion of National Science Day 2020, held on February 28, 2020:
    - Mr. Imran Karanjagi and V. Sri Harsha Swarna Kumar (Dr. N. Rajalakshmi) received First Prize for the presentation entitled "Recyclables for Energy"
    - Mr. D. Nazeer Basha (Dr. Ravi Bathe) received Second Prize for the presentation entitled "Ultrafast Laser Surgery - A Ray of hope for new life in Cancer Patients"
    - Mr. Kigozi Moses (Dr. P. K. Jain) received Third Prize for the presentation entitled "Use of Piezoelectric material effect on the metro stations and Bus stops for street lighting or in car tyres for automobile support"
    - Mr. Jaijeet Singh Rathore (Dr. P. Sudharshan Phani) received consolation prize for the presentation entitled "Sustainable Energy Storage for Future"
    - Ms. Nirogi Aamani (Dr. S. Anandan) received consolation prize for the presentation entitled "Smart Control of Electrical Applicances using Cloud Technology"
    - Ms. G. Nivetha (Dr. P. H. Borse) received consolation prize for the presentation entitled "Piezoelectrically Self Powered Hearing Aid Generated by Jaw Movement"
    - Ms. V. P. Madhurima & Mr. Allen John (Dr. P. K. Jain) received consolation prize for the presentation entitled "CNT Reinforced Composite Sheet for Lightning Strike Protection"
    - Ms. S. Manasa, (Dr. R. Subasri) received consolation prize for the presentation entitled "Orange Diaper-A Happy Diaper"
28. Dr. S. Kavita received the RULA award 2020 for 'Magnetocaloric work on Heusler alloys' at Trichy, January 26, 2020.
29. Ms. K. Anjali (Dr. G. Ravi Chandra), received '1st prize' for the poster presentation on "Microstructural studies on medium entropy refractory multicomponent alloys" at the International Workshop on High Entropy Alloys (IWHEA-2020) held at IIT Kanpur on March 07-08, 2020.

Contribution to Professional Societies / Bodies as Office Bearers

S.N	Name	Contribution/Role
1.	Dr. Sanjay Bhardwaj	Elected as Chairman, Indian Institute of Chemical Engineers-Hyderabad Regional Centre (IIChE-HRC) for 2019-2020
2.		Secretary, Organizing Committee, Seminar on 'Innovations in Chemical Sector' was organized by IIChE-HRC at Hyderabad on May 10, 2019 at NFC Hyderabad to celebrate the IIChE Foundation Day
3.		Secretary, Organizing Committee,12th M.P. Chary Memorial Lecture on 'Industry 4.0' by Dr. Vilas Tathavadkar, Senior Vice President, Aditya Birla Science and Technology Co. Ltd on June 18, 2019 organized by IIChE-HRC at Hyderabad
4.		Chairman, Organizing Committee, Seminar on 'Understanding Industry 4.0 and its Applications' organized by IIChE- HRC at NFC, Hyderabad on September 20, 2019
5.		Best Regional Centre (BRC) Award-2019 was conferred on the IIChE – Hyderabad Regional Centre (IIChE-HRC) at 72nd Annual Session of IIChE / CHEMCON 2019 Conference held at Indian Institute of Technology (IIT) Delhi during December 15-19, 2019. Dr. Sanjay Bhardwaj, has been Chairman of IIChE-HRC during 2019-2020 and Honorary Secretary of IIChE-HRC during 2017-2019.
6.		Co-convener, International Conference on 'Recent Advances in Chemical Engineering (RACE - 2020)' organized by University College of Technology, Osmania University in association with IIChE-HRC during January 08-09, 2020
7.		Chairman, Organizing Committee a) 'Design Thinking Workshop' organized by IIChE- HRC and IIT Bombay Alumni Association (IITBAA) - Hyderabad Chapter in association with Department of Chemical Engineering, Anurag University, Hyderabad; b) IIChE – HRC Inter-College Competitions (Scientific Model Making, Technical Quiz, Essay Writing, and Elocution) on February 25, 2020
8.		Elected as President, IIT-Bombay Alumni Association (IITBAA) - Hyderabad Chapter for 2019-2020
9.	Dr. L. Ramakrishna	Joint Secretary - Indian Institute of Metals (IIM), Hyderabad Chapter
		Executive Council Member - Materials Research Society of India (MRSI), Hyderabad Chapter
		Editor - Transactions of Indian Institute of Metals (TIIM) Journal, Publisher: Springer
10.	Dr. Gururaj Telasang	Secretary, SAEINDIA Hyderabad Division Organizing Committee, State level Student Convention (Tier 2) - technical events competition for Engineering Students, at Matrusri Engineering College, at Hyderabad on February 10, 2019

PERSONNEL
(as on March 31, 2020)

DIRECTOR

Dr. G. Padmanabham

REGIONAL DIRECTOR

Dr. Raghavan Gopalan

ASSOCIATE DIRECTORS

Dr. Tata Narasinga Rao
Dr. Roy Johnson

DISTINGUISHED ARCI CHAIR

Prof. P. Rama Rao

DISTINGUISHED EMERITUS SCIENTIST

Prof. G. Sundararajan

SCIENTISTS

D. Srinivasa Rao, Scientist 'G'
Dr. G. Ravi Chandra, Scientist 'G'
Dr. Pawan Kumar Jain, Scientist 'G'
Dr. N. Rajalakshmi, Senior Scientist
Dr. R. Vijay, Scientist 'G'
V. Balaji Rao, Scientist 'F'
Dr. R. Subasri, Scientist 'F'
Dr. Bhaskar Prasad Saha, Scientist 'F'
Dr. Pramod H. Borse, Scientist 'F'
Dr. L. Rama Krishna, Scientist 'F'
Dr. Y. Srinivasa Rao, Scientist 'F'
Dr. Sanjay Bhardwaj, Scientist 'F'
Dr. S. Sakthivel, Scientist 'F'
Dr. N. Ravi, Scientist 'F'
Dr. I. Ganesh, Scientist 'F'
Dr. Joydip Joardar, Scientist 'F'
Dr. Malobika Karanjai, Scientist 'F'
Dr. Ravi N. Bathe, Scientist 'F'
Dr. G. Siva Kumar, Scientist 'F'
Dr. R. Prakash, Scientist 'F'
Dr. S. M. Shariff, Scientist 'F'
Dr. D. Siva Prahasam, Scientist 'F'
Dr. B. V. Sarada, Scientist 'F'
K. V. Phani Prabhakar, Scientist 'F'
Dr. S. B. Chandrasekhar, Scientist 'E'
Dr. Neha Y. Hebalkar, Scientist 'E'
Dr. K. Suresh, Scientist 'E'
Dr. P. Sudharshan Phani, Scientist 'E'
Dr. Sanjay R. Dhage, Scientist 'E'
Dr. Nitin P. Wasekar, Scientist 'E'
Dr. Dibyendu Chakravarty, Scientist 'E'
Dr. Kaliyan Hembram, Scientist 'E'
Dr. K. Murugan, Scientist 'E'
Dr. Dulal Chandra Jana, Scientist 'E'
Dr. K. Ramya, Senior Scientist
Dr. Srinivasan Anandan, Scientist 'E'
Ms. S. Nirmala, Scientist 'E'
Dr. P. Suresh Babu, Scientist 'E'
Dr. Krishna Valleti, Scientist 'E'
Dr. M. Buchi Suresh, Scientist 'E'
Manish Tak, Scientist 'E'
Dr. Papiya Biswas, Scientist 'E'
Dr. Gururaj Telasang, Scientist 'E'
Dr. R. Easwaramoorthi, Scientist 'E'
R. Senthil K umar, Scientist 'E'
S. Sudhakara Sarma, Scientist 'D'
Dr. S. Kumar, Scientist 'D'
Ms. Priya Anish Mathews, Scientist 'D'
Dr. Prasenjit Barick, Scientist 'D'
Dr. Naveen Manhar Chavan, Scientist 'D'
M. Ramakrishna, Scientist 'D'
Balaji Padya, Scientist 'D'
R. Vijaya Chandar, Scientist 'D'
Dr. Pandu Ramavath, Scientist 'D'
Ms. J. Revathi, Scientist 'D'
Arun Seetharaman, Scientist 'D'
Dr. M. B. Sahana, Senior Scientist
Dr. D. Prabhu, Scientist 'D'
Dr. R. Balaji, Senior Scientist
Dr. Raman Vedarajan, Scientist
Dr. Shiv Prakash Singh, Scientist
Dr. L. Venkatesh, Scientist 'C'
Ms. K. Divya, Scientist 'C'
Amit Das, Scientist 'B'

TECHNICAL OFFICERS

Debajyoti Sen, Technical Officer 'E'
K. R. C. Somaraju, Technical Officer 'E'
Ms. A. Jyothirmayi, Technical Officer 'D'
Ms. V. Uma, Technical Officer 'D'
G. Venkata Ramana Reddy, Technical Officer 'D'
V. C. Sajeev, Technical Officer 'D'
P. Rama Krishna Reddy, Technical Officer 'D'
V. Mahender, Technical Officer 'C'
K. Srinivasa Rao, Technical Officer 'C'
Ch. Sambasiva Rao, Technical Officer 'C'
D. Sreenivas Reddy, Technical Officer 'C'
C. Karunakar, Technical Officer 'C'
M. Srinivas, Technical Officer 'C'
Ms. B. V. Shalini, Technical Officer 'C'
N. Venkata Rao, Technical Officer 'C'
M. Srihari, Technical Officer 'C'
J. Nagabhushana Chary, Technical Officer 'B'
A. Raja Shekhar Reddy, Technical Officer 'B'
A. R. Srinivas, Technical Officer 'B'
E. Anbu Rasu, Technical Officer 'B'
S. Sankar Ganesh, Technical Officer 'B'
K. Naresh Kumar, Technical Officer 'B'
M. Ilaiyaraja, Technical Officer 'B'
P. V. V. Srinivas, Technical Officer 'B'
K. Ramesh Reddy, Technical Officer 'B'
Ms. N. Aruna, Technical Officer 'B'
R. Anbarasu, Technical Officer 'B'
M. R. Renju, Technical Officer 'A'

TECHNICAL ASSISTANT

J. Shyam Rao, Technical Assistant 'A'

TECHNICIANS

D. Krishna Sagar, Technician 'E'
K. V. B. Vasantha Rayudu, Technician 'E'
G. Venkata Rao, Technician 'E'
E. Konda, Technician 'D'
A. Sathyanarayana, Technician 'D'
B. Venkanna, Technician 'D'
G. Venkat Reddy, Technician 'D'
P. Anjaiah, Technician 'D'
A. Ramesh, Technician 'D'
D. Kutumba Rao, Technician 'D'
B. Subramanyeswara Rao, Technician 'D'
Kona Vigneswara Rao, Technician 'D'
A. JayaKumaran Thampi, Technician 'D'
B. Hemanth Kumar, Technician 'D'
J. Venkateswara Rao, Technician 'D'
A. Praveen Kumar, Technician 'D'
K. Satyanarayana Reddy, Technician 'D'
D. P. Surya Prakash Rao, Technician 'D'
Kurra Venkata Ramana, Technician 'D'
Govinda Kumar, Technician 'D'
A. Janga Reddy, Technician 'D'
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A. Jagan, Technician 'C'
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Prabir Kumar Mukhopadhyay, Technician 'C'
Shaik Ahmed, Technician 'C'
K. Ashok, Technician 'C'
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I. Prabhu, Technician 'C'
Ch. Jangaiah, Technician 'C'
S. Narsing Rao, Technician 'B'
Mothe Lingaiah, Technician 'B'
Aan Singh, Technician 'A'
Gaje Singh, Technician 'A'

SENIOR FINANCE & ADMINISTRATIVE OFFICER

G. Ravi Shankar

SENIOR STAFF OFFICER TO DIRECTOR

P. Nagendra Rao

SENIOR FINANCE & ACCOUNTS OFFICER

N. Srinivas
(on deputation to NIT, Warangal w.e.f. 30.10.2019)

STORES & PURCHASE OFFICER

Anirban Bhattacharjee

ADMINISTRATIVE OFFICER

A. Srinivas

ACCOUNTS OFFICER

G. M. Rajkumar

COMMUNICATIONS AND PUBLIC RELATIONS OFFICER

N. Aparna Rao

SECURITY, FIRE & SAFETY OFFICER

D. Ramesh

OFFICERS

Y. Krishna Sarma, Officer 'B'
Poduri Venugopal, Officer 'B'
Ms. P. Kamal Vaishali, Officer 'B'
Pothuri Venkata Ramana, Officer 'B'
P. Dharma Rao, Officer 'A'
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B. Laxman, Officer 'A'
Ravi Singh, Officer 'A'

ASSISTANTS

Ms. Rajalakshmi Nair, Assistant 'B'
Ms. K. Madhura Vani, Assistant 'B'
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Boorgu Venkatesham, Assistant 'A'
Ramavathu Ranga Naik, Assistant 'A'

Pokalkar Sai Kishore, Assistant 'A'
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Ch. Venugopal, Assistant 'A'
Edunuri Ramesh, Assistant 'A'
A. Balraj, Assistant 'A'

JUNIOR HINDI TRANSLATOR

Dr. Rambha Singh

DRIVERS

Md. Sadiq, Driver 'C'
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T. Satyanarayana, Driver 'B' (MACP)
M. A. Fazal Hussain, Driver 'B' (MACP)

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PROJECT SCIENTISTS

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Golu Kumar Jha (TRC)
Krishna Kumar Pathak (TRC)
K. Velmurgan (TRC)
U. Gowtham (TRC)
K. Shanmugam (TRC)
T. P. Sarangan (TRC)
A. Sivaraj (TRC)
D. Vigneshwaran (TRC)
N. Ramesh (TRC)
Nenavath Raju (TRC)
K. Sudalaiyandi (TRC)
M. Nandhagopal (TRC)
Sambhunath Jana (TRC)
Abdul Khalad (TRC)

TRC: Technical Research Centre on 'Alternate Energy Materials and Systems'
SPHD: Sponsored Technology Development Programme

Financial Report

M.BHASKARA RAO & CO
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6-3-652, SOMAJIGUDA,
Hyderabad - 500 004
email : mbr_co @ mbrc.co.in

Date: 15/09/2020

To

Members of Governing Council
International Advanced Research Centre for
Powder Metallurgy and New Materials (ARCI)
Hyderabad

INDEPENDENT AUDITORS' REPORT

Qualified Opinion

We have audited the accompanying financial statements of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad ("the Entity"), which comprise the Balance Sheet as at March 31, 2020, and the Income and Expenditure Account and Receipts and Payments Account for the year then ended, and notes to the financial statements, including a summary of significant accounting policies and explanatory notes of:

* Consolidated Fund
* Operational Fund
* Sponsored Fund
* Technology Demonstration and Transfer Fund

In our opinion, except for the possible effects of the matters described in the 'Basis for Qualified Opinion' paragraph below, the accompanying financial statements give a true and fair view in conformity with the accounting principles generally accepted in India (GAAP), of the financial position of the Entity as at March 31, 2020, of its financial performance and of its cash flows for the year then ended in accordance the Accounting Standards issued by the Institute of Chartered Accountants of India (ICAI).

Basis for Qualified Opinion

We draw attention to:

a. Note 5 to the Schedule 25 to the consolidated financial statements and Note 3 to the Operational Fund Financial Statements regarding long pending items in classified under Capital Work in Progress:

   Capital work in progress as at March 31,2020, as per the accompanying financial statements aggregate to Rs 32,79,77,840. This amount includes Rs. 29,00,42,043, incurred prior to three years by the entity and pending for capitalization. Management informed us that it is making efforts for resolving the pending issues related to capital expenditures incurred in earlier years and capitalize during the financial year 2020-21 once they can be put to use for their intended purposes. Pending final adjustment entries, we are unable to comment on the impact on the financial statements of the entity.

   We conducted our audit in accordance with the Standards on Auditing (SAs) issued by the Institute of Chartered Accountants of India (ICAI). Our responsibilities under those standards are further described in the Auditor's Responsibilities for the Audit of the Financial Statements section of our report. We are independent of the Entity in accordance with the ethical requirements that are relevant to our audit of the financial statements and we have fulfilled our other ethical responsibilities in accordance with these requirements. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our opinion.

Emphasis of Matter:

a. Note 6 to the Schedule 25 to the consolidated financial statements regarding certain unreconciled items appearing in the Bank Reconciliation Statements.
b. Note 7 to the Schedule 25 to the consolidated financial statements regarding reconciliation of certain advances to vendors, aggregating to Rs 78,50,000 in Operating fund and Rs 32,98,302 in Sponsored fund which are long pending. Further, no confirmation of balances from the vendors were on record.

Responsibilities of Management for the Financial Statements

Governing Council of the Entity is responsible for the preparation of these standalone financial statements that give a true and fair view of the financial position, financial performance, and cash flows of the Entity in accordance with the Accounting Standards issued by ICAI. This responsibility also includes maintenance of adequate accounting records for safeguarding of the assets of the Company and for preventing and detecting frauds and other irregularities; selection and application of appropriate accounting policies; making judgments and estimates that are reasonable and prudent; and design, implementation and maintenance of adequate internal financial controls, that were operating effectively for ensuring the accuracy and completeness of the accounting records, relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatement, whether due to fraud or error.

In preparing the financial statements, management is responsible for assessing the Entity's ability to continue as a going concern, disclosing, as applicable, matters related to going concern and using the going concern basis of accounting unless management either intends to liquidate the Entity or to cease operations, or has no realistic alternative but to do so.
The above Governing Council is also responsible for overseeing the company's financial reporting process.

Auditor's Responsibilities for the Audit of the Financial Statements

Our objectives are to obtain reasonable assurance about whether the financial statements as a whole are free from material misstatement, whether due to fraud or error, and to issue an auditor's report that includes our opinion. Reasonable assurance is a high level of assurance, but is not a guarantee that an audit conducted in accordance with SAs will always detect a material misstatement when it exists. Misstatements can arise from fraud or error and are considered material if, individually or in the aggregate, they could reasonably be expected to influence the economic decisions of users taken on the basis of these financial statements.

As part of an audit in accordance with SAs, we exercise professional judgment and maintain professional skepticism throughout the audit. We also:

- Identify and assess the risks of material misstatement of the financial statements, whether due to fraud or error, design and perform audit procedures responsive to those risks, and obtain audit evidence that is sufficient and appropriate to provide a basis for our opinion. The risk of not detecting a material misstatement resulting from fraud is higher than for one resulting from error, as fraud may involve collusion, forgery, intentional omissions, misrepresentations, or the override of internal control.
- Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by management.
- Conclude on the appropriateness of management's use of the going concern basis of accounting and, based on the audit evidence obtained, whether a material uncertainty exists related to events or conditions that may cast significant doubt on the entity's ability to continue as a going concern. If we conclude that a material uncertainty exists, we are required to draw attention in our auditor's report to the related disclosures in the financial statements or, if such disclosures are inadequate, to modify our opinion. Our conclusions are based on the audit evidence obtained up to date of our auditor's report. However, future events or conditions may cause the entity to cease to continue as a going concern.
- Evaluate the overall presentation, structure and content of the financial statements, including the disclosures, and whether the financial statements represent the underlying transactions and events in a manner that achieves fair presentation.

Materiality is the magnitude of misstatements in the financial statements that, individually or in aggregate, makes it probable that the economic decisions of a reasonably knowledgeable user of the financial statements may be influenced. We consider quantitative materiality and qualitative factors in (i) planning the scope of our audit work and in evaluating the results of our work; and (ii) to evaluate the effect of any identified misstatements in the financial statements.

Report on Other Matters:

1. We report that:
   a. We have sought and obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purpose of our audit.
   b. In our opinion proper books of account as required by law have been kept by the entity so far as appears from our examination of those books.
   c. The Balance Sheet, the Income and Expenditure Account and Receipts and Payments Account dealt with by this Report are in agreement with the books of account.
   d. In our opinion, the aforesaid financial statements comply with the Accounting Standards issued by ICAI.

For **M Bhaskara Rao & Co**
Chartered Accountants
Firm's Registration No. 000459S

Sd/-
V K Muralidhar
Partner
Membership No. 201570
UDIN: 20201570AAAAGI3900

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
ARC INTERNATIONAL FUND (OPERATIONAL) BALANCE SHEET AS AT 31.03.2020

(Amount in Rs.)

GRANTS-IN-AID: FUND AND LIABILITIES	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
GRANTS- IN- AID	1	1,32,42,37,747.49	1,41,75,00,015.46
RESERVES AND SURPLUS	2	8,09,09,471.89	4,04,14,760.35
EARMARKED /ENDOWMENT FUNDS	3	0.00	0.00
SECURED LOANS AND BORROWINGS	4	0.00	0.00
UNSECURED LOANS AND BORROWINGS	5	0.00	0.00
DEFERRED CREDIT LIABILITIES	6	0.00	0.00
CURRENT LIABILITIES AND PROVISIONS	7	36,74,00,313.53	32,77,00,247.17
TOTAL		**1,77,25,47,532.91**	**1,78,56,15,022.98**
ASSETS			
FIXED ASSETS	8	1,26,38,31,878.55	1,32,49,28,670.93
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUND	9	0.00	0.00
INVESTMENTS - OTHERS	10	0.00	0.00
CURRENT ASSETS, LOANS, ADVANCES ETC.	11	50,87,15,654.36	46,06,86,351.55
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)		0	0
TOTAL		**1,77,25,47,532.91**	**1,78,56,15,022.98**
SIGNIFICANT ACCOUNTING POLICIES	24		
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25		

AS PER OUR REPORT OF EVEN DATE

Sd/-
G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Sd/-
Dr. G Padmanabham
Director

for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S

Sd/-
V.K.Muralidhar
Partner, Membership No. 201570

Date: 15-09-2020
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INCOME AND EXPENDITURE ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2020

(Amount in Rs.)

	SCHEDULE		CURRENT YEAR		PREVIOUS YEAR
INCOME					
Income from Sales/Services	12		0.00		0.00
Grants/Subsidies	13		40,41,99,000.00		42,60,55,000.00
Fees/Subscriptions	14		98,766.95		4,37,639.15
Income from Investments (Income on Investments from earmarked/endowment funds)	15		0.00		0.00
Income from Royalty, Publications etc.	16		0.00		0.00
Interest Earned	17		2,75,80,776.89		2,67,91,130.99
Other Income	18		2,42,63,025.38		1,95,23,759.99
Increase/(decrease) in stock of finished goods and work-in-progress	19		0.00		0.00
TOTAL (A)			**45,61,41,569.22**		**47,28,07,530.13**
EXPENDITURE					
Establishment Expenses	20		32,61,63,672.37		32,10,25,846.60
Other Expenses	21		18,05,22,937.65		17,05,01,432.01
Expenditure on Grants/Subsidies	22		0.00		0.00
Interest	23		87,03,670.00		80,26,234.00
Depreciation (Net Total at the year-end: corresponding to Schedule 8)			14,99,27,557.17		16,13,38,863.05
TOTAL (B)			**66,53,17,837.19**		**66,08,92,375.66**
Balance being excess of Income over Expenditure (A-B) Transfer to Special Reserve [specify each] Transfer to/from General Reserve			-20,91,76,267.97		-18,80,84,845.53
BALANCE being Excess of Expenditure over Income - Transfer to Grants-in-Aid			**-20,91,76,267.97**		**-18,80,84,845.53**
SIGNIFICANT ACCOUNTING POLICIES	24				
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25				

AS PER OUR REPORT OF EVEN DATE

Sd/-
G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Sd/-
Dr. G Padmanabham
Director

for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S

Sd/-
V.K.Muralidhar
Partner, Membership No. 201570

Date: 15-09-2020
Place: Hyderabad

INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

BALAPUR POST. HYDERABAD

ARCI (OPERATIONAL) FUND

SCHEDULE – 24 SIGNIFICANT ACCOUNTING POLICIES

1. **Basis of preparation of financial statements :**
The financial statements of Operation Fund of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI/Society), Hyderabad, have been prepared on historical cost convention and on accrual basis unless otherwise stated.

2. **(1) Grants:**
(a) Grants are recognized on receipt.
(b) Grants received from Department of Science & Technology (DST) are treated as Income.
(c) Expenditure incurred by the Society towards operations, maintenance and depreciation have been adjusted against these grants.
(d) Grants received from DST and earmarked for special projects by ARCI are grouped under Sponsored Project Fund.
(2) Reserves & Surpluses:
(a) Net Surplus / Deficit generated from Technology Demonstration & Transfer Fund (TDT Fund) are appropriated as under: 50% Transferred to ARCI Operational Fund & Balance 50% Remains in TDT Fund

3. **Fixed Assets:**
Fixed assets are stated at cost. Cost includes duties, taxes, freight, insurance etc., attributable to acquisition and installation of asset.

4. **Depreciation and Amortization:**
Depreciation on fixed assets (except Lease Hold building) is provided on written down value method as per rates stated in Income Tax Act,1961
Non -Refundable advance towards Lease Hold Building is amortized over lease period.

5. **Revenue Recognition:**
Grants are recognized on cash basis. Interest income from bank balances/deposit is recognized on accrual basis.

6. **Research and Development (R&D) Expenditure:**
R&D expenditure including cost of raw materials, consumables, other inputs etc. is charged off as revenue expenditure. Raw materials, consumables, stores spares and other inputs are procured on need basis and issued to end users soon after they are received. Hence values of closing stock of these materials is not recognized in the accounts.

7. **Foreign Exchange Transactions:**
Foreign exchange transactions during the year are recorded at the exchange rate prevailing on the date of transaction.

8. **Retirement Benefits:**
Contributions to Provident Fund and New Pension Scheme (Defined Contribution Plans) are charged to income and expenditure account as per applicable rules/statutes. Provision towards gratuity and leave encashment (Defined benefit Plan) is made on actuarial valuation carried out by Life Insurance Corporation of India as stated in AS-15 (Revised) – "Accounting for Retirement Benefits". The Society has covered its gratuity and leave encashment liability with Life Insurance Corporation of India (LIC) and contributions are made to LIC on yearly basis.

9. **Margin Money Deposits:**
Margin Money Deposits placed with Banks towards Letters of Credit issued in favour of ARCI are grouped under Loans and Advances- Advances Recoverable in Cash/Kind.

AS PER OUR REPORT OF EVEN DATE
for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S
Sd/-
V.K.Muralidhar
Partner, Membership No. 201570

Sd/-
G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Sd/-
Dr. G Padmanabham
Director

Date: 15-09-2020
Place: Hyderabad

INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

BALAPUR POST, HYDERABAD

ARCI (OPERATIONAL) FUND

SCHEDULE – 25 NOTES TO THE ACCOUNTS

1. Department of Science and Technology (DST) sanctioned and released during the year Rs:40,41,99,000/ towards revenue and Rs: 11,59,14,000/- as capital grant-in-aid under Plan (Previous year Rs. 42,60,55,000/ and Rs. 10,60,20,000/- towards revenue and capital respectively under Plan grant-in-aid). Under Non-Plan, Grant-in-aid sanctioned was nil.

2. During the year, the provision for Gratuity Liability & Leave Encashment was made based on the accrued liability furnished by LIC of India.

3. Capital Work in Progress of Rs 32,79,77,840/- pending capitalization as stated in Schedule 8 to the financial statements include Rs: 29,00,420,043/- classified as Capital Work in Progress pending capitalization for more than three years. In the opinion of the management of the Society all these capital works are capable being used for the purpose for which these assets were procured and capitalization will be carried out in the financial year 2020-2021. Further, Management is also of the opinion that theses capital works do neither require any impairment nor provisioning.

4. The figures of previous year have been regrouped/reclassified wherever necessary.

AS PER OUR REPORT OF EVEN DATE
for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S
Sd/-
V.K.Muralidhar
Partner, Membership No. 201570

Sd/-
G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Sd/-
Dr. G Padmanabham
Director

Date: 15-09-2020
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
RECEIPTS AND PAYMENT ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2020

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
I. **Opening Balances**			I. **Expenses**		
a. Cash in hand	25,800.00	30,559.00	a. Establishment expenses	29,70,55,121.00	30,04,75,401.74
b. Bank Balances			b. Other expenses	16,51,66,372.00	13,95,95,046.46
i) In Current accounts	0.00	0.00			
ii) In Deposit accounts	7,00,00,000.00	0.00	**Total: Expenses**	**46,22,21,493.00**	**44,00,70,448.20**
iii) Savings accounts	80,23,632.22	5,73,43,711.47			
Total: Opening Balances	**7,80,49,432.22**	**5,73,74,270.47**			
II. **Grants Received**			II. **Payments made against various projects**		
a. From Government of India	52,01,13,000.00	53,20,75,000.00			
b. From State Governments	0.00	0.00	Rheological characterisation of $LiFeP0_4$ (IIT-MUMBAI)	0.00	0.00
c. From other source [details]	0.00	0.00			
d. Fund received on closed Projects	0.00	0.00			
Total: Grants Received	**52,01,13,000.00**	**53,20,75,000.00**	**Total: Payments made Against Projects**	**0.00**	**0.00**
III. **Income on Investments From**			III. **Investments and deposits made**		
a. Earmarked/Endowment Funds	0.00	0.00	a. Out of Earmarked/Endowment funds	0.00	0.00
b. Own funds (other investments)	0.00	0.00	b. Out of own funds (investments-others)	0.00	0.00
Total: Income on Investment	**0.00**	**0.00**	**Total: Investments and Deposits**	**0.00**	**0.00**
IV. **Interest Received**			IV. **Expenditure on Fixed Assets & Capital Work-in-Progress**		
a. On bank deposits	85,63,318.00	78,33,724.00			
b. Interest from sponsored projects	0.00	0.00	a. Purchase of fixed assets	16,32,78,943.14	10,35,00,843.64
c. Loans, Advances to staff etc.	1,40,352.00	1,92,510.00	b. Expenditure on capital work-in progress	0.00	0.00
Total: Interest Received	**87,03,670.00**	**80,26,234.00**			
			Total: Expenditure on Fixed Assets & Capital WIP	**16,32,78,943.14**	**10,35,00,843.64**
V. **Other Income**	3,66,10,732.11	2,76,04,797.15	V. **Refund of surplus money/loans**		
			a. To Government of India	0.00	0.00
			b. To State Government	0.00	0.00
			c. To other providers of funds	0.00	0.00

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
VI. **Amount Borrowed**	0.00	0.00	VI. **Finance charges (Interest)**	0.00	0.00
VII. **Any Other Receipts**			VII. **Other Payments**		
a) EMD & Security Deposits	62,53,429.00	0.00	(a) Advance to Staff -HBA	0.00	37,50,000.00
b) Sales of Fixed Assets	22,81,609.98	23,90,090.44	(b) Deposit Gratuity to LIC	0.00	13,01,427.00
c) Advances from Suppliers- Buildings	2,74,347.00	0.00	(c) Deposit EL Encashment to LIC	0.00	78,37,071.00
d) TDT Fund contribution for Manpower Usages	5,85,403.00	17,03,697.00	(d) TDS receivables	0.00	300.00
			(e) Interest - DST	80,26,234.00	0.00
e) TDT Fund Contribution for Equipment Usages	24,11,726.00	53,35,433.00			
			Total : Other Payments	**80,26,234.00**	1,28,88,798.00
			VIII. **Closing Balances**		
Total : Any Other Receipts	**1,18,06,514.98**	**94,29,220.44**	a) Cash in hand	30,126.00	25,800.00
			b) Bank balances		
			i) In Current accounts	0.00	0.00
			ii) In Deposit accounts	1,00,00,000.00	7,00,00,000.00
			iii) In Savings accounts	1,17,26,553.17	80,23,632.22
			Total : Closing Balances	**2,17,56,679.17**	**7,80,49,432.22**
TOTAL	**65,52,83,349.31**	**63,45,09,522.06**	**TOTAL**	**65,52,83,349.31**	**63,45,09,522.06**

AS PER OUR REPORT OF EVEN DATE

Sd/-
G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Sd/-
Dr. G Padmanabham
Director

for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S

Sd/-
V.K.Muralidhar
Partner, Membership No. 201570

Date: 15-09-2020
Place: Hyderabad

OUR COLLABORATORS

FOREIGN

- Applied Materials, USA
- Belarusian State University of Informatics and Radio Electronics
- Ballard Power Systems Inc., USA
- Bromine Compounds Ltd., Israel
- Corning Incorporated, USA
- DesignTech Systems Limited
- Duracell US Operations Inc., USA
- Deakin University, Australia
- Fraunhofer Institutions, Germany
- Industrial Materials Institute of National Research Council of Canada (NRC-IMI), Canada
- Institute for Problems of Materials Science (IPMS), Ukraine
- International Centre for Electron Beam Technologies, Ukraine
- Li-ion Technologies Limited, Russia
- MPA Industrie, France
- Nanomechanics, USA
- SLM Solutions Singapore Pvt. Ltd.
- The Boeing Company, USA
- Techno Takatsuki Co. Ltd., Japan
- Zoz GmbH, Germany
- The ExOne Company, Pennsylvania

INDIAN

- 3 BL Business Solutions LLP
- Ariston Filtration Systems Pvt. Ltd.
- Advanced Manufacturing Technology Development Centre
- Andhra Pradesh Mineral Development Corporation Ltd.
- Aditya Birla Science and Technology Pvt. Ltd.
- Allox Minerals Pvt. Ltd.
- Bharat Electronics Limited
- Bharat Heavy Electricals Limited
- Bhabha Atomic Research Centre
- Central Scientific Instruments Organization
- Central Institute of Plastics Engineering and Technology
- Central Electronics Limited
- CSIR-Institute of Minerals and Materials Technology
- Carborundum Universal Limited
- CSIR-Central Glass & Ceramic Research Institute (CGCRI)
- Defense Research and Development Organization
- Ducom Instruments
- Deem Roll Tech Ltd.
- Ecogreen Cleantech Pvt. Ltd.
- enArka India Pvt. Ltd.
- Enerzi Microwave Systems Pvt. Ltd.
- Fourth Energy Partner Pvt. Ltd.
- Global Medical Education and Research Foundation
- GE India Industrial Pvt. Ltd.
- Gujrat Borosil Ltd.
- Hindustan Aeronautics Limited
- Hulikkal Electro (India) Pvt. Ltd.
- Hyderabad Eye Research Foundation
- Hindustan Petroleum Corporation Limited
- h2e Power Systems
- Hyderabad Electroplating Works
- Indian Institute of Chemical Technology
- Indian Airforce
- Indian Space Research Organization
- Indira Gandhi Centre for Atomic Research
- Indian Institute of Technology-Bombay
- Indian Institute of Technology-Madras
- Indian Institute of Technology-Kanpur
- Indian Institute of Technology-Kharagpur
- Indian Institute of Technology-Hyderabad
- ITI Ltd
- Indian Institute of Astrophysics
- Imake
- Log 9 Materials Scientific Pvt. Ltd.
- LeeP eDrive Pvt Ltd.
- Las Engineers and Consultants Pvt. Ltd.
- Lithium Power Technologies LLP
- Mahindra and Mahindra
- Marichin Technologies LLP
- Mishra Dhathu Private Limited
- MVS Engineering Pvt. Ltd.
- Manideep Techno Coats
- Magni5 Technologies
- National Institute of Technology-Warangal
- National Institute of Technology-Thiruchirapalli
- National Institute of Technology-Nagpur
- National Research and Development Corporation
- National Institute of Design
- Navyug Namdhari Enterprises
- Osmania University
- Pi Beams Labs Pvt. Ltd.
- Renewable Energy Systems Limited
- Resil Chemicals Pvt. Ltd.
- Rensol Power Pvt. Ltd.
- Scitech Patent Art Services Pvt. Ltd.
- Silcarb Recrystallized Pvt. Ltd.
- Sri Chitra Tirunal Institute for Medical Sciences and Technology
- Siemens Limited
- Saffrongrid Limited
- Tata Steel Limited
- TVS Lucas
- Titan Company Limited
- Translational Health Science and Technology Institute
- TVS Motor Company Limited
- Toyota Tshusho India Pvt. Ltd.
- Uppal Ferrocast Pvt. Ltd
- University of Hyderabad
- Vrinda Li-ion Batteries
- Valtree Global Pvt. Ltd.
- Wissenkraft Labs Pvt. Ltd.
- Yash Lenses

ADDRESS

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Chennai Cell

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Centre for Fuel Cell Technology
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arci

INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY AND NEW MATERIALS (ARCI)

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