इंटरनेशनल एडवांस्ड रिसर्च सेंटर
INTERNATIONAL ADVANCED RESEARCH CENTRE
FOR POWDER METALLURGY AND NEW MATERIALS
फॉर पाउडर मैटलर्जी एंड न्यू मैटीरियल्स

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ARCI

ARCI

ANNUAL REPORT

2018-19

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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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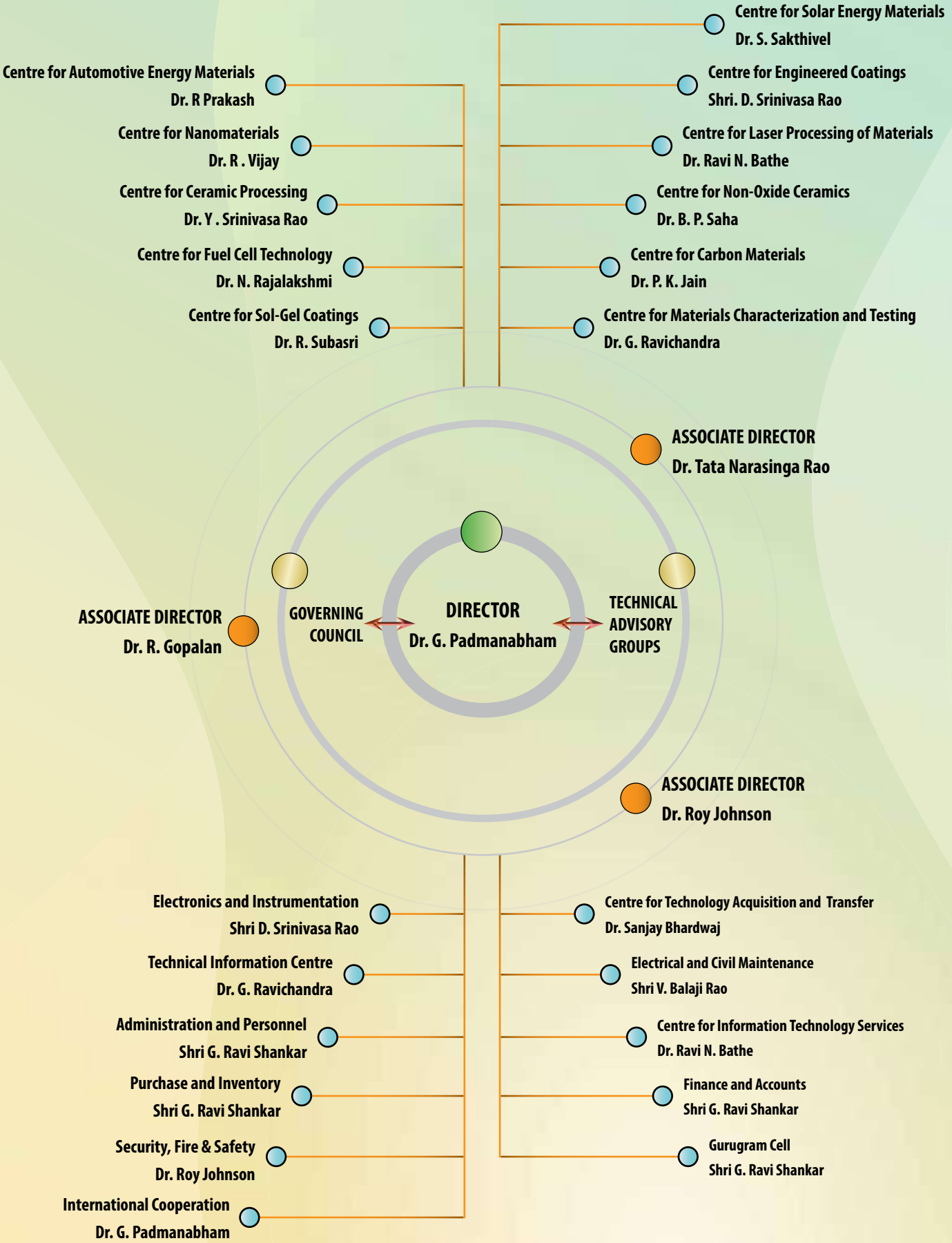
ORGANIZATIONAL STRUCTURE



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Director's Report

I am glad to present this report on accomplishments and initiatives during the year 2018-19 at ARCI. Activities have been pursued in the true spirit of ARCI's mandate viz., development of new materials, processes, products and solutions, demonstration and transfer to the industry for commercialisation. The capabilities of various centres of excellence in nanomaterials, ceramics, surface engineering, laser processing of materials, automotive energy materials, solar energy materials, carbon materials have been effectively utilised individually and jointly to realise the goals of major programmes underway.

The largest ongoing programme at ARCI is the Technical Research Centre on Alternative Energy Materials & Systems. Systematic R&D efforts and interaction with industrial partners has resulted in achieving higher technology readiness levels (TRL) and transfers. Considerable efforts were in the direction of technologies for electric mobility. In the Li-ion battery technology activity, NMC/Graphite based prismatic cells (3.6V, 20 Ah) were fabricated with an initial capacity of 19.2 Ah with remarkable capacity retention at high C rate and the cell fabrication pilot line has been geared up to produce modules for field testing on two-wheelers. At the same time, activities have been initiated to develop cost effective and environmentally friendly process for lithium/sodium ion batteries and solid-state lithium ion batteries for next generation mobility application. Indigenously developed LIB materials such as LFP and LTO have been produced at larger batch quantities and were supplied for field trials. In the supercapacitor development programme, single step process for synthesis of efficient porous carbon electrode materials from abundantly available carbon sources has been attempted. Under the magnetic materials program, a cost-effective process has been established to produce dopant free high anisotropic strontium ferrite powders with coercivity greater than 5.5 kOe. PEM Fuel Cell systems field demonstration and parallel effort to develop electrocatalysts, metallic bipolar plates and water-based electrolysers with 2.5 Nm^3 capacity were continued. On the solar energy front, a cost-effective solar receiver tube coating ($\alpha \leq 0.95$ & $\varepsilon \leq 0.14$ and good thermal stability upto 250°C in open air) technology for low and medium temperature solar thermal application has been successfully validated transferred to industry. Ambient condition curable easy to clean coating technology with high transparency and good weather stability has been successfully developed and demonstrated to NETRA, NTPC Ltd and various silicon PV module manufacturing companies. Parallel efforts on inorganic thin film solar cell research continued and efficiency of 6.1% was recorded on CIGS thin film solar cell by non-vacuum route (Electrodeposition) and a photo-conversion efficiency of 16 to 17 % has been realized by solution & vapor processes at lab-scale Perovskite Solar Cells (PSC) and prototype module (50mm x 50mm) with efficiency of 5.2 % was demonstrated.

While intensive efforts in the alternative energy materials direction is being pursued, on the other hand a major programme to establish a "National Centre for Materials and Manufacturing Technologies for Clean

NMC/Graphite based prismatic cells (3.6V, 20 Ah)

Lithium ion battery pack/ modules (48V-1KWh) field tested on two-wheeler

Li-ion battery materials

Anisotropic powder synthesized for manufacture of prototype anisotropic bonded magnet

Flexible activated carbon electrode

Supercapacitor materials

Medium temperature solar selective absorber coating for concentrated solar thermal applications

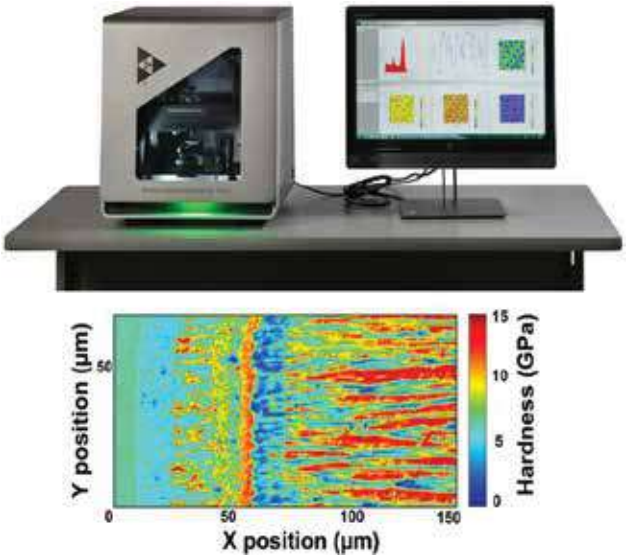
Developed and demonstrated easy-to-clean coating on solar PV panels

50mm X 50mm semi-transparent perovskite solar cell

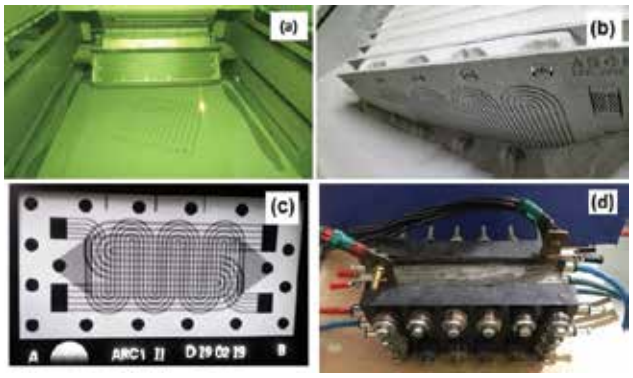
Coal Energy Generation" has been initiated with the support of DST's Clean Energy Research Initiative. This is an ARCI-led consortium project involving several premier institutions such as NML Jamshedpur, IIT Madras, BHEL Trichy, NITs. The aim is to improve the performance and life of thermal power plants by applying high performance coatings on components subjected to severe fire-side and steam side conditions, development of advanced fabrication technologies for improved productivity and development of cheaper high temperature materials.

Providing advanced surface engineering solutions to a wide range of applications and coating equipment development has been a unique capability of ARCI over the years. Several critical solutions were provided, including development of Cathodic Arc Physical Vapour Deposition (CA-PVD) coatings for life improvement of minting dies and wear resistant coatings for aeroengine compressor blades. Academic version of Micro Arc Oxidation (MAO) systems were designed, fabricated and commissioned at NIT-Tiruchirappalli. Development of advanced detonation spray coating and cold spray coating systems has been progressed

30 kVA custom-built MAO control system installed and commissioned at Materials and Metallurgical Engineering Department, NIT-Tiruchirappalli



Advanced nanomechanical characterization facility along with a high speed hardness map across various layers of an EBPVD TBC



Photographs showing (a) Process of additive manufacturing (AM) of MBP, (b) AM built plates, (c) X-ray radiography image of MBP and (d) stack of fuel cell with AM built MBP

Laser refurbishment of Aerospace components (pinion)

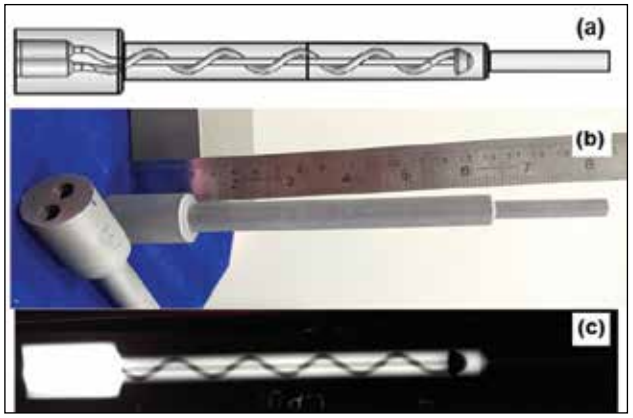


Fig. 2 PDC core with conformal cooling channel showing (a) 3D model (b) Core pin built by AM and (c) X-ray radiography

Photograph of a road stud with sol-gel coated lenses

Energy efficient sanitary napkin incinerator

to higher technology readiness levels. In order to support the coating evaluation at microscale, a high speed nanoindentation technique has been adopted and a mapping and data deconvolution tool, NanoBlitz 3D+, jointly developed with M/s Nanomechanics Inc, USA was globally launched. Surface engineering solutions using wet-chemical sol-gel route have been focused on developing scratch/abrasion resistant coatings on transparent plastics, superhydrophobic coatings for antibiofilm formation and room temperature curable solar control coatings on glass for architectural and automotive applications.

Laser based additive manufacturing (AM) technology was pursued intensively during the year. Apart from attempting applications such as die inserts for pressure die casting (PDC) and metallic bipolar plate for PEM fuel cell, several aerospace components were designed for AM. In an effort to indigenise AM powders, IN718 powder was indigenously produced with alloy supplied by MIDHANI and used for building components by

AM. Static mechanical properties were found to be similar to that of parts made of commercial AM powders. Laser direct energy deposition technology was demonstrated for repair of aerospace components.

Good progress has been achieved in the area of ceramic processing. Limited production of transparent spinel profiles for trials by users was carried. Environmentally friendly sanitary napkin incinerators technology developed jointly with M/s Sowbal Aerothemics Ltd and CSIR-NEERI was commercialized. Advancing the capabilities in complex shaping of advanced ceramics, especially the extrusion expertise, 3D extrusion printing of ceramics such as alumina (Al_2O_3), spinel ($MgAl_2O_4$) and cordierite ($Mg_2Al_4Si_5O_{18}$) has been established using an indigenously made facility. Several limited production works were taken up for supply of porous magnesia discs and protypes of sodium beta alumina. Initiatives have been taken up to develop SiC-based thrust bearing components for applications at elevated temperature under highly oxidative and corrosive environments, corrosion, wear and abrasion resistant nozzles and seals.

In line with the mandate of transferring technologies and solutions to industry, intense marketing efforts resulted in over 60 new leads through participation in relevant exhibitions, making presentation and direct marketing. An MoU with a company who has taken several ARCI technologies in the past was concluded to establish a joint centre for coatings for aerospace applications. This is a public-private-partnership (PPP) aimed at successfully addressing the needs of aerospace components.

Overall, it has been a fruitful year in terms of technology development, patenting publications in reputed journals, human resource development and outreach.

My thanks are due to all scientists and staff of ARCI whose enthusiasm, scientific passion and dedication contributed to the accomplishments as mentioned above.

Performance Indicators

Parameters	***2018-19***
Papers in Refereed Journals	*115@*
Chapters in Books	*9@*
Papers presented in Conferences and Invited Lectures	*233*
No. of Ph.Ds. Produced	*2*
Foreign Patent Applications (inventions awaiting grant)	*4**
Foreign Patents Granted	*15*#*
Indian Patent Applications (awaiting grant)	*71**
Indian Patents Granted	*47**

Parameters	***2018-19***
No. of Technologies/ Designs and other IP Commercialized	*26*
Number of Technology Leads Awaiting Transfer	*34*
Research Manpower Trained (other than PhDs)	*19*
Technical Manpower Trained	*68*
B. Tech/ UG Projects Guided	*97*
M. Tech./ M. Sc./ M. Phil Projects Guided	*37*

** Cumulative figures up to the end of the financial year*
@ Calendar year 2018
 # includes same inventions granted in multiple countries

(G. Padmanabham)

Research and Technology Highlights

Centre for Automotive Energy Materials

The Centre of Automotive Energy Materials (CAEM) located at Indian Institute of Technology Madras Research Park, Chennai is one of the Centres of Excellence of ARCI. The primary objective of the centre is to develop and demonstrate materials and components processing technology to Indian automotive industries as well as provide technical supports to their potential problems. The Centre has five major activities: (i) development of materials and engineering the process technology of lithium-ion battery (LIB) for electric mobility as well as energy storage applications; (ii) development of low-cost materials for sodium-ion battery for grid/off-grid storage application; (iii) development of soft and hard magnetic materials for motors and alternators in automotive application; (iv) development of thermoelectric materials and device for waste heat recovery and conversion of automobile exhaust heat into power; and (v) development of rare-earth free magnetocalorimetric materials for magnetic refrigeration.

The major achievements in the LIB activity during 2018-19 was the fabrication of NMC/Graphite based prismatic cells (3.6V, 20 Ah), which exhibited an initial capacity of 19.2 Ah with remarkable capacity retention at high C rate cycling. In the sodium ion battery program an electrolyte system with good ionic conductivity and wide electrochemical stability window has been developed. Under the magnetic materials program, a cost-effective process has been established to produce dopant free high anisotropic strontium ferrite powders with coercivity greater than 5.5 kOe. The prototypes using ARCI materials technology is currently being undertaken in collaboration with various industries.

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 products are the main focus. In addition to the above, two more new activities have also been initiated, viz. solid state lithium ion batteries for next generation mobility application and aqueous binder development for cost effective and environmental friendly process for lithium/sodium ion batteries. During the last one year, the centre has also established new facilities such as formation cycler for LIB, four port glovebox for Na-ion battery and physical property measurement system (PPMS) for materials characterization.

Formation cycler for LIB

Lithium-Ion Cell (3.6V, 20 Ah)

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NMC-Graphite based Lithium-ion battery for electric mobility

Electrical vehicle (EV) plays a key role in the transportation sector for minimization of the greenhouse gas emissions like CO_2 and NOx. In this context, development of high performance and low-cost lithium-ion batteries (LIBs) greatly accelerates the battery driven trend for automobile industry. After the recent announcement of the FAME 2 scheme by Government of India to promote the use of EVs in India, there is an urgent need of indigenously developed LIBs to meet the demand. Under make-in-India approach, the indigenous development of LIB is anticipated to reduce cost of the battery by ~20%.

ARCI has set-up a pilot plant facility for the fabrication of large format lithium-ion cells, along with a comprehensive testing facility at Centre of Automotive Energy Materials (CAEM) for EV application. After the successful demonstration of on-road trials of the indigenously developed LIB module (48V-850 Wh) using $LiFePO_4$/Graphite cells for e-two-wheelers, we are currently developing $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ (NMC532) based cells due to its high gravimetric and volumetric energy density as compared to that of LFP-based cells. We have fabricated NMC electrode with uniform thickness and loading (20 mg/cm^2) with an active material content >85%. The electrodes exhibited excellent peel strength and displayed a specific discharge capacity of 160 mAh/g vs. Li/Li$^+$ at 0.1C with good cyclic stability. Prototype prismatic cells (15 Ah) have been fabricated using the NMC cathode and graphite anode in a polypropylene casing (Fig. 1a). The cells were subjected to multi-step formation cycles under CC/CV mode. A discharge capacity of 17 Ah was obtained after the formation cycles at 0.1 C (Fig. 1b). Further, the charge/discharge cycling was carried out at 1C under CC mode. An initial capacity of 14.5 Ah was obtained with a capacity retention of 80% (for EV requirement) after 200 cycle (Fig. 1c). In addition, prismatic cells of 20 Ah have been fabricated using stainless steel casing with the same internal dimensions as that of the prototype cell (Fig. 1d). The formation cycles for the cells were optimized to get the enhanced cell capacity as well as cyclic stability. A discharge capacity of 20.3 Ah was achieved after the formation cycles at 0.1C (Fig. 1e). The cell offered an initial capacity of 19.2 Ah at 1C with a capacity retention of 93% after 100 cycles which is better than that of the prototype ones after 100 cycles (88%) (Fig. 1f). Presently, the rate capability, life cycle, and high temperature cycling stability studies are underway.

Carbon coated NMC532 cathode for Lithium ion battery

One of the main reason for the poor cyclic stability of Lithium ion battery is the parasitic reaction of the electrolyte with the surface of the electrode materials. Especially the unavoidable moisture traces in the electrolyte give rise to the HF formation, which attacks the surface of the cathode material. It is well known that surface coating on active cathode electrodes improves the cycle life of Lithium ion battery. We have developed an in-situ carbon coating on layered oxide cathode of $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ materials. The cycle life test for carbon coated $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ (333) both at half cell and full cell level shows 80 % capacity retention. Since the practical capacity in the operating voltage, of $LiNi_{1-}$

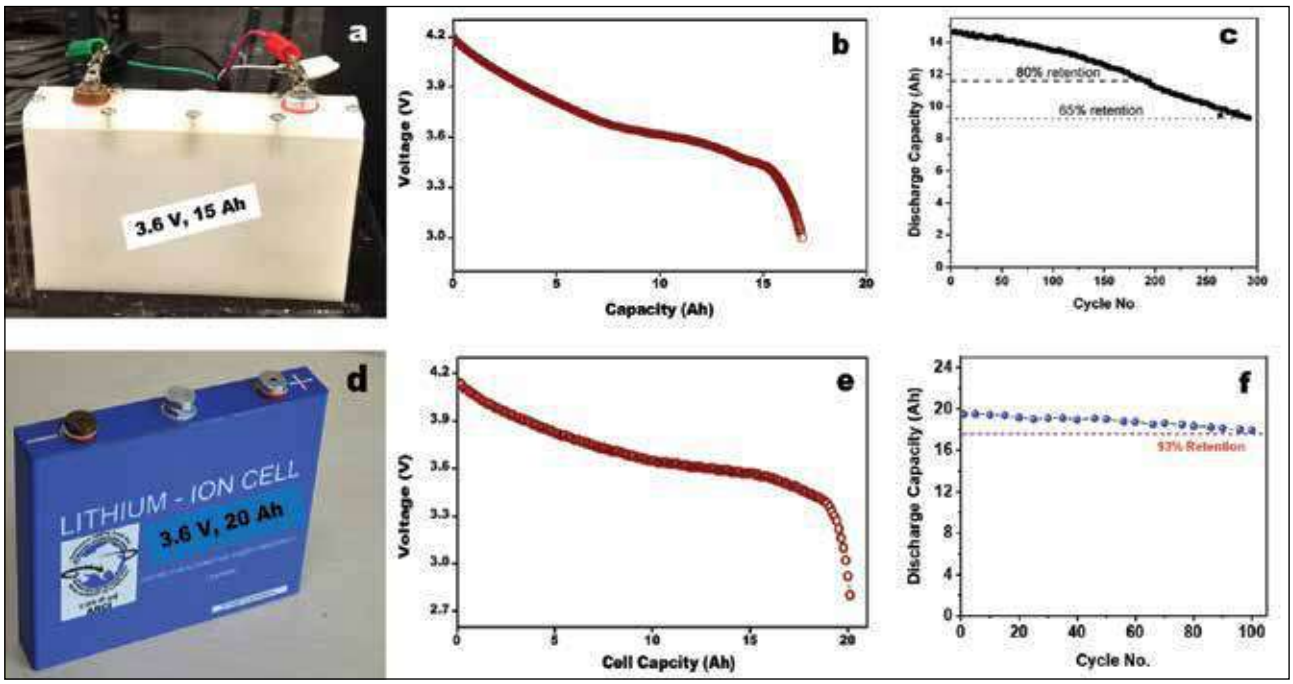

Fig. 1 (a) 3.6V, 15 Ah prototype prismatic cell; (b) Discharge curve after formation cycle at 0.1C; (c) Cyclic stability test at 1C; (d) 3.6V, 20 Ah prismatic cell; (e) Discharge curve after formation cycle at 0.1C; (f) Cyclic stability test at 1C.

$_{x-y}Mn_xCo_y$, is determined by the nickel content in NMC the achieved specific capacity at 0.5 C was only around ~ 150mAhg^{-1}. The possible increase in the achievable capacity of LIB with lithium layered transition metal oxide (LMO2, M= Ni, Co, Mn, Al) cathode and graphite as anode are given in Fig. 2.

Therefore, in order to increase the specific capacity of the layered oxide materials, increasing the nickel concentration to 50% along with carbon coating has been tried. However, due to high sensitivity of $LiNi_{1-x-y}Mn_xCo_y$ (with Nickel content greater than Mn percentage) to CO_2 Li_2CO_3 secondary phases are observed in C-NMC532 in contrast to pristine NMC532 (Fig. 3a). The reactivity of $LiNi_{1-x-y}Mn_xCo_y$ with CO_2 decrease with decrease in Ni content. Therefore, if the concentration of Nickel is less or equal to Mn at the surface of the particle, the possibility of Li_2CO_3 formation is minimum. Therefore a core shell structured NMC 532 with nickel rich core and Mn rich shell has been synthesised along with the carbon encapsulation. From the XRD, (Fig. 3b) it can be confirmed that the formation of Li_2CO_3 can be prevented using compositionally graded NMC. The electrochemical characterisation of the carbon coated compositionally graded NMC 532 are being carried out.

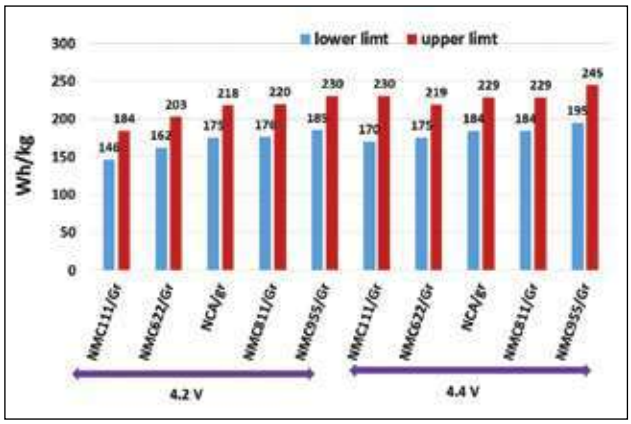

Fig. 2 The predicted increase in the capacity of two scenarios with increase in the Nickel content in NMC

In situ/ex situ investigations on the formation of the mosaic solid electrolyte interface layer on graphite anode for Lithium ion batteries

In the ongoing pursuit towards high-performance lithium ion battery (LIB), understanding of the solid electrolyte interface (SEI) layer is important to enhance the performance and lifetime of LIB. Graphite is used extensively as an anode material for LIB due to its high structural stability and low-cost. Due to the thermodynamic instability of the aprotic electrolyte at low working potential, a solid electrolyte interface layer (SEI) forms on the graphite anode during initial formation cycles. The formation of a stable SEI layer, prevents continuous degradation of the electrolyte in the subsequent cycles, which is critical to ensure the high Coulombic efficiency, rate capability, cycle life, calendar life and safety of the LIB. In-spite of its important role in determining the safety and performance of LIBs, the SEI layer remains as the least understood component due to insufficient characterization tools for direct measurement of its physical and chemical properties. Here, we have experimentally established the formation and growth process of the mosaic SEI layer as a function of different lithium intercalation stages. In our study, we have used a specially designed cell (Fig. 4) which has enabled us to confirm the structure and chemical composition of the SEI layer by sequential in situ (FTIR and EIS) and ex situ (TEM, SEM and XPS) characterizations without causing significant damages to the SEI layer. TEM studies revealed a clear evolution of the SEI layer during first lithiation with formation of polyhetero microphases. Moreover, these sequential in situ and ex situ characterizations revealed that the organic and inorganic compounds on the graphite surface as a mosaic structure of the SEI layer. These findings open up a promising technique to investigate the electrolyte–electrode interface in advanced battery systems.

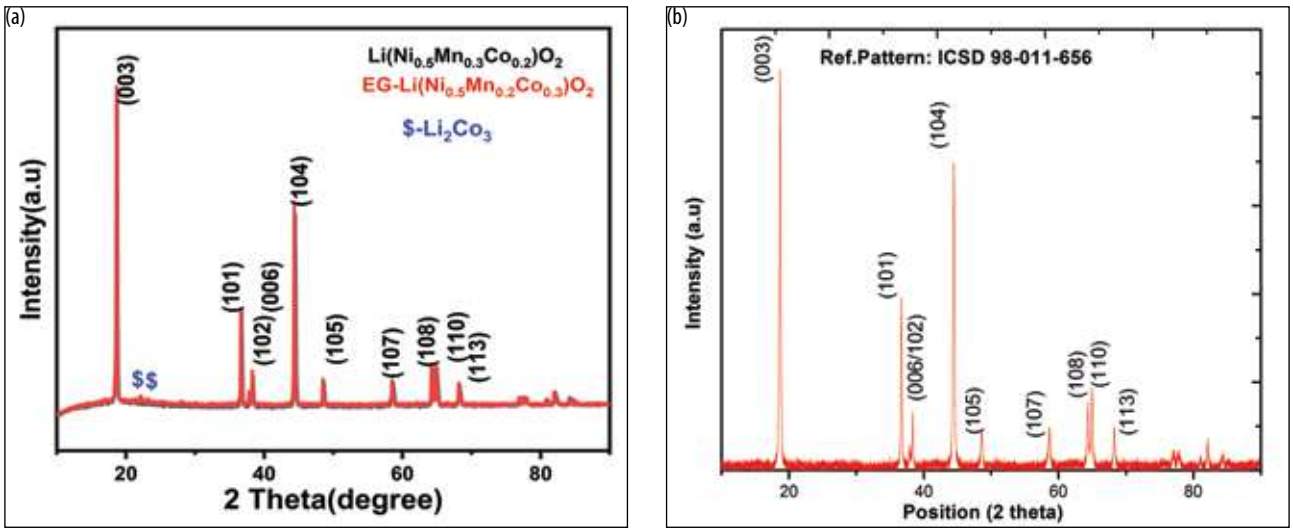

Fig. 3 (a) The XRD pattern of pristine NMC 532 and C-NMC 532; (b) The XRD pattern of compositional graded C- NMC 532

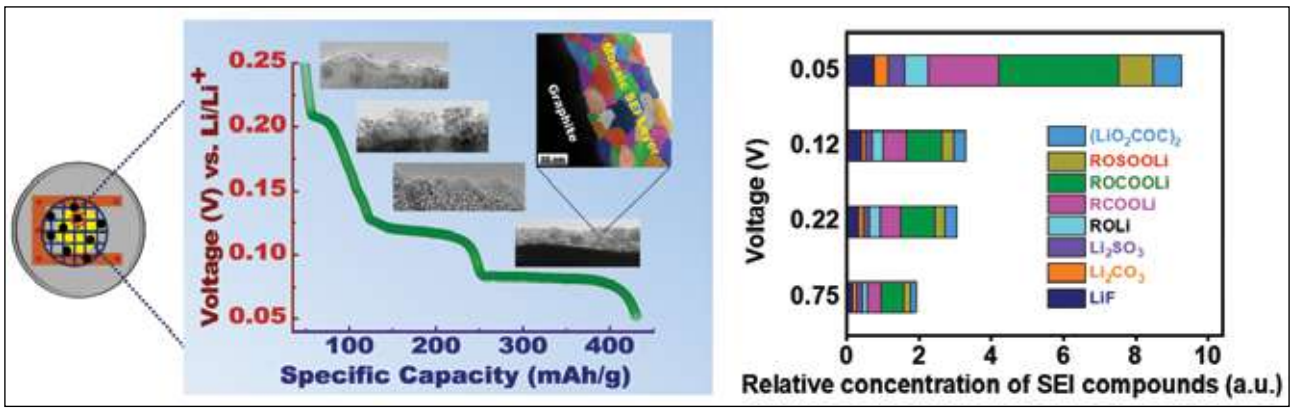

Fig. 4. Formation of mosaic SEI layer on graphite surface and the relative concentration of SEI compounds

Development of low-cost electrode materials for Sodium-ion battery for energy storage

Sodium ion batteries (SIBs) are currently taking a boost as an alternative to presently used lithium ion batteries (LIBs) for large scale, such as grid storage and electric vehicle (EV) applications due to their on par energy density and low-cost. Various industries world-wide, such as Faradion, AGM batteries, Aquion and WMG etc. are currently working on the commercialization of sodium ion battery technology. Recently, ARCI has started the research and development of SIBs, where its main focus is on the development of high energy density electrode materials as well as electrolytes for sodium ion battery. In this respect, different electrode materials are selected based on their promising electrochemical properties, such as transition metal layered oxides with high specific capacity and polyanionic compounds with long cycle life as cathodes; whereas hard carbon and sodium titanates with low sodium insertion potential and high specific capacity as anodes for sodium ion batteries. So far, ARCI has successfully developed suitable electrolyte with excellent ionic conductivity and electrochemical stability window (Fig. 5(a)) on par with commercial electrolyte based on lithium salt; electrode materials with excellent storage performance and cycle life. Layered type transition metal oxide Na_xMnO_2, has shown drastic improvement in the electrochemical performance of 80% capacity retention at the end of 60 cycles (Fig. 5(b)) with the co-doping of Co and Fe into Mn sites. Hard carbon (HC) is being explored as a potential anode material for sodium ion batteries and the optimization of calcination temperatures to achieve desired porosity and surface area is under progress. The HC calcined at 1000°C showed a high and stable specific capacity of ~270 mAh/g (Fig. 5(c)). In-situ carbon coated polyanionic electrode materials have been developed as potential cathodes for sodium ion batteries with excellent electrochemical performance. The symmetric and asymmetric sodium ion full cells have been fabricated using polyanionic cathodes, which showed excellent cycle life at very high current rates (cycle life >1000 cycles at 1 A/g). The synthesis of potential electrode materials in large scale and demonstration of proto-type sodium ion battery are under progress.

High coercive anisotropic Sr-ferrite powders for bonded magnet applications

At Centre for Automotive Energy Materials under the magnetic materials program a cost-effective method to produce dopant free high anisotropic strontium ferrite powders with coercivity greater than 5.5 kOe has been developed. Currently La and Co addition is required to produce powders with enhanced magnetic properties making them costly. Microstructural engineering can yield high coercive powders without the requirement of dopants which result in increased cost. Bonded magnets are cost effective magnets which are widely used in many automotive applications like throttle sensors,

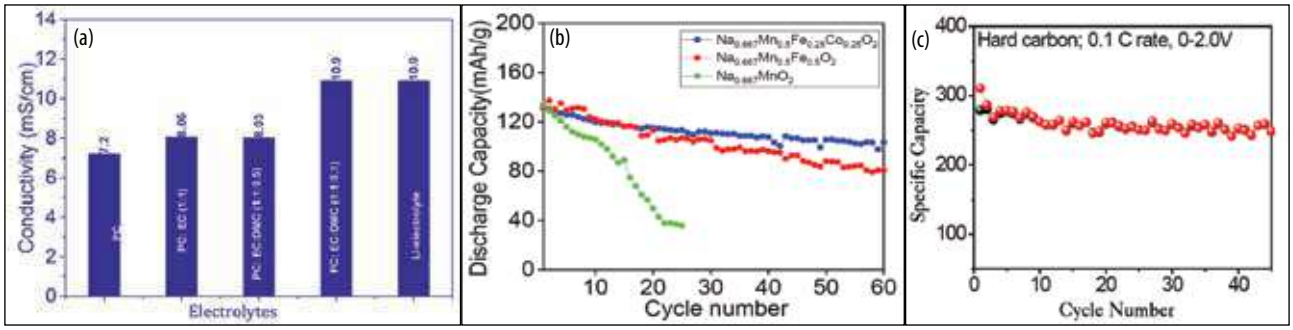

Fig. 5 (a) Ionic conductivity of non-aqueous electrolyte with 1M $NaClO_4$ in different organic solvents; (b) Capacity vs. cycle number plots for pristine and doped P2-Na_xMnO_2; (c) Capacity vs. cycle number for hard carbon calcined at 1000°C.

dashboard gauges, fuel filters, etc. The bonded magnets also have the advantage that complex shaped magnets can be produced in near net shapes by techniques like injection moulding. In order to demonstrate the feasibility of using the powders for manufacture of bonded magnets the synthesis was scaled up to produce 4 kg of powders (Fig. 6). A collaboration has been initiated with one of the local industries to produce prototype magnets using the powders synthesied at ARCI.

Fig. 6 A batch of anisotropic powder synthesized for manufacture of prototype anisotropic bonded magnet

At ARCI we have synthesized aniostropic strontium ferrite powders using the commercially viable solid state synthesis process. Stronitum carbonate and ferric oxide in suitable weight ratios were thoroughly mixed using high energy mill for 1 hour. The mixed powders were calcined at 1200°C/7h and was subzequently micronized thereafter. The micronized powders were annealed to relieve the stress. The final powders obtianed exhibited superior magnetic properties with a magnetization of 64 emu/g (Fig. 7a) and remanance ratio of about 0.9 and a coercivity greater than 5.5 kOe (Fig. 7b). The properties were better than the commercial powder used in industry for anisotropic bonded magnets which exhibited a coercivity of 3.5 kOe. The sample also exhibited a better positive temperature coefficient of coercivity of 0.13%/K compared to 0.11%/K of the commercial sample making them suitable for opertation at elevated temperatures.

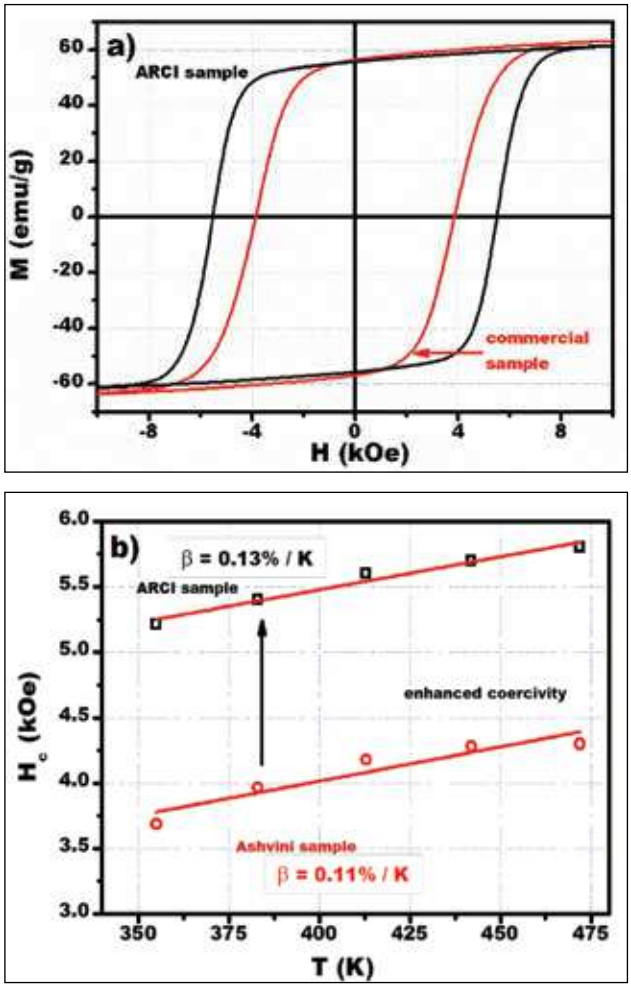

Fig. 7. Magnetic properties of the synthesized powders showing a) enhanced coercivity from hysteresis measured at room temperature and b) higher positive temperature of coefficient of coercivity determined from measuring coercivity at elevated temperatures.

$Mg_2Si_{1-x}Sn_x$–$Pb_{1-y}Sn_yTe$ based thermoelectric module for mid-temperature waste heat recovery applications

Thermoelectrics (TE) deal with direct energy conversion from heat to electricity. $Mg_2Si_{1-x}Sn_x$ (n-type) and $Pb_{1-y}Sn_yTe$ (p-type) are mid-temperature (200-500°C) thermoelectric materials with figure of merit >1 at 327°C (600 K). A thermoelectric module generating 0.3-0.5 W power using these materials consists of several uni-couples connected electrically in series by Cu electrodes and thermally in parallel by sandwiching between ceramic substrates has been successfully developed. The device performance is tested up to 400°C. Since both materials have a nearly the same thermal coefficient of expansion and thermoelectric properties, thus making them highly compatible above ~375°C (650 K) the typical operating temperature for these modules (Figure 1). This combination overcomes the major drawback of high materials cost by using $Mg_2Si_{1-x}Sn_x$ for n-type legs makes these devices highly noteworthy over conventional Bi_2Te_3 based devices. The cost/Watt, as well as weight/Watt, can be brought down without compromising the power output density for these devices.

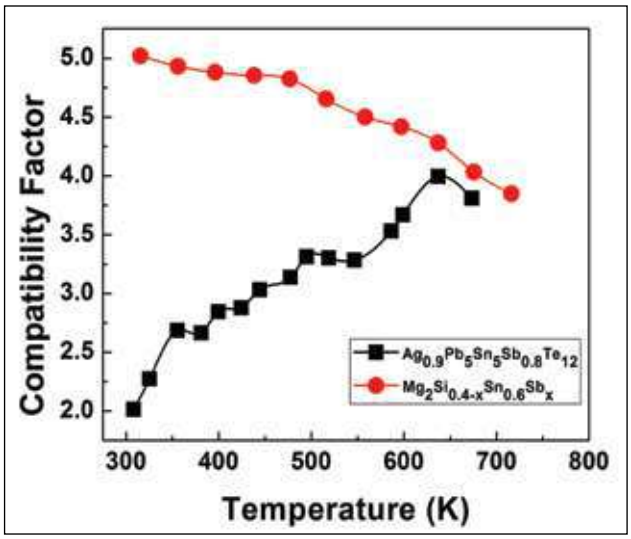

Fig. 8 Compatibility Factor

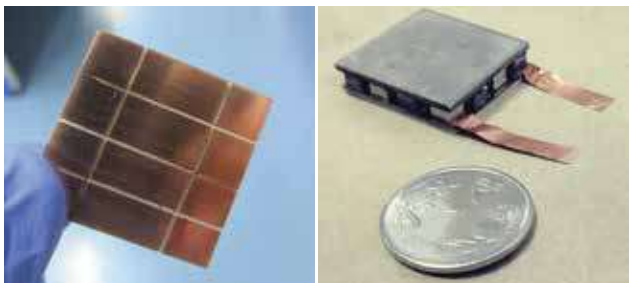

Fig. 9 Cu electrode patterned to Al_2O_3 substrate and assembled TE device

Skutterudite Thermoelectrics for Waste Heat Recovery

The growing demand for an alternative energy source has led to renewed interest in thermoelectric (TE) technology that can convert waste heat directly into electricity. The TE materials used in thermoelectric modules must have figure of merit (ZT) more than 1 at the operating temperature range. Skutterudites are considered one of the efficient TE materials for waste heat recovery applications in automobiles and heavy industries due to their flexibility of fabrications and cost effectiveness.

To fabricate indigenous TE modules at ARCI, Ni doped Dy filled $CoSb_3$ skutterudite samples ($Dy_{0.4}Co_{4-x}Ni_xSb_{12}$ (x=0, 0.4, 0.8)) have been processed using powder metallurgy route. The nanocrystalline n-type skutterudite samples show the enhancement of the power factor due to the substantial reduction in electrical resistivity with increase in Ni concentration. Lattice thermal conductivity is drastically reduced to 0.3 W/mK at 773 K in $Dy_{0.4}Co_{3.2}Ni_{0.8}Sb_{12}$ sample due to the enhanced phonon scattering from Ni induced point defects and grain boundaries. As a result, a huge increase in figure of merit (ZT~ 1.4 ± 0.14) at 773 K is observed for $Dy_{0.4}Co_{3.2}Ni_{0.8}Sb_{12}$ sample, the highest among the single elemental filled $CoSb_3$ skutterudites reported so far at this temperature. The upscalling processing of n-type skutterudites is initiated. P-type skutterudite samples are developed with ZT ~ 1 at 773 K to make the skutterudite TE modules. The skutterudite based TE module is under fabrication.

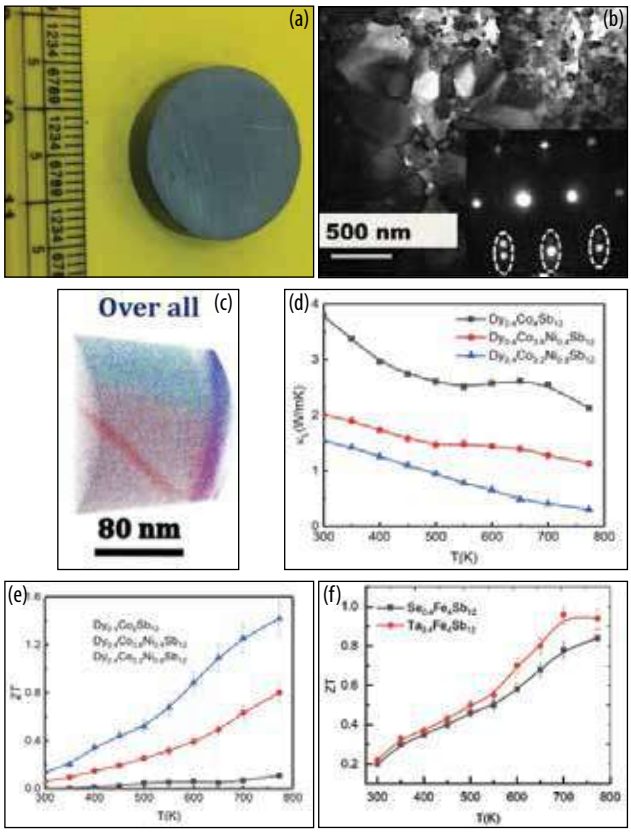

Fig. 10 (a) Processed skutterudite pellet at ARCI, (b) microstructure, (c) atom probe study and (d) lattice thermal conductivity and (e) (ZT) of Ni doped$CoSb_3$ skutterudite, (f) ZT of p-type skutterudite thermoelectrics developed at ARCI

Magnetocaloric materials for magnetic refrigeration

Magnetocaloric refrigeration is a cooling technology expected to offer significant energy savings. For optimal performance, magnetic materials close to a first-order magneto-structural transition such as such as $Gd_5Ge_2Si_2$, $LaFe_{13-x}Si_x$, and $MnFeP_{1-x}As_x$ are employed for this application. The high price of rare earth elements, and the toxicity of As element make them unsuitable for the practical applications. At our center we are exploring various magnetocaloric materials, among them Mn-Fe-P-Si alloys show many distinct advantages, e.g. giant magnetocaloric effect, tuneable TC near room temperature, excellent corrosion resistance and low cost.

$Mn_{1.15}Fe_{0.85}P_{0.65}Si_{0.13}Ge_{0.2}B_{0.02}$ was prepared by mechanical alloying followed by SPS. All the raw materials were mixed and ball milled for 8 h under an Ar atmosphere in a high energy Pulverisette ball mill at a speed of 220rpm and then spark plasma sintered into a 10 mm diameter cylindrical sample at 900°C at a heating rate of 100°C/min under 50 MPa using the technique. The sintered sample was homogenized at 920°C for 72 h. The phase purity of the sintered sample and the annealed samples were examined using X-ray diffraction (XRD) with Cu Kα radiation. Magnetic measurements were performed using Physical Property Measurement System.

XRD of the SPS sintered (Fig. 11 (a)) and sintered annealed sample (not shown here) of $Mn_{1.15}Fe_{0.85}P_{0.65}Si_{0.13}Ge_{0.2}B_{0.02}$ confirms the hexagonal Fe_2P-type (space group $P\bar{6}2m$) main phase. Fig. 11 (b) shows the thermomagnetic curve of the SPS sintered and sintered annealed sample. It has been found that the magnetization of the annealed sintered sample increases with respect to the sintered sample, which could be due to the homogeneity obtained in the system after annealing the sintered sample. It has been also noticed that the thermal hysteresis reduces from 18 K to 9 K in the annealed and sintered sample. Fig. 11 (c) magnetic entropy change of the annealed sample and sintered sample calculated from the magnetization measurements. There is a huge enhancement in the

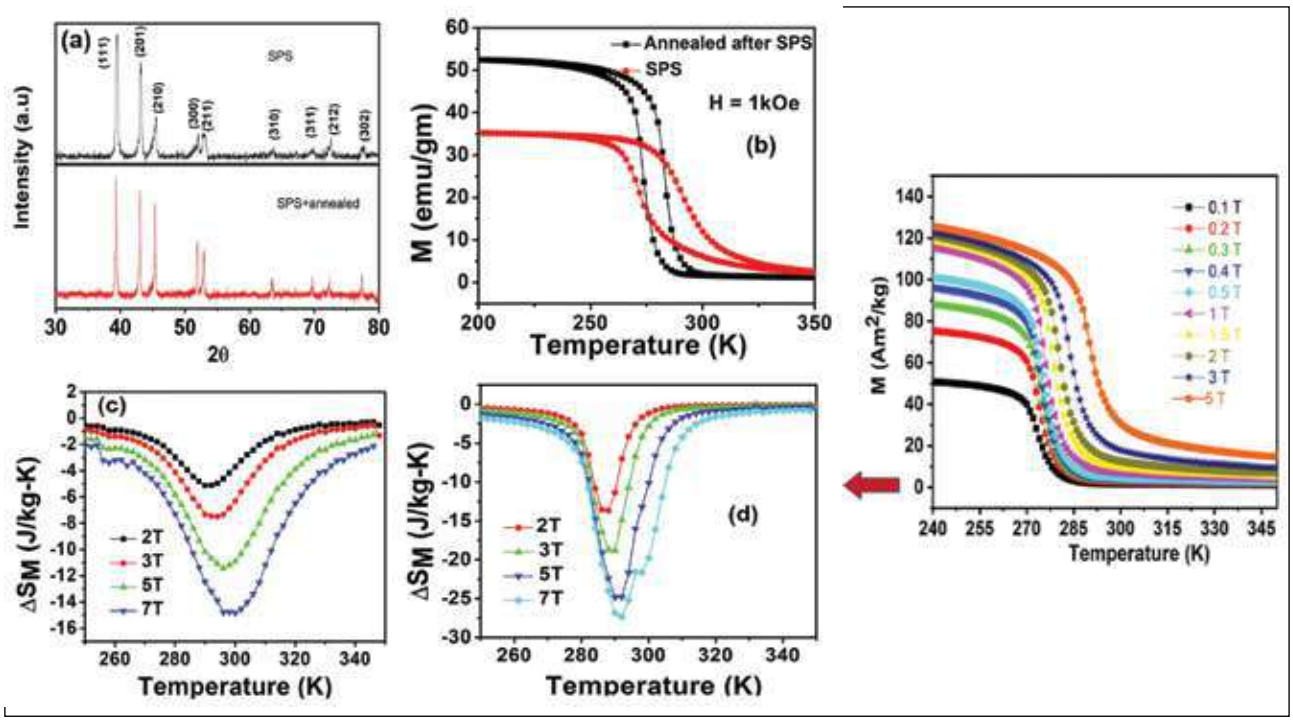

Fig.11. (a) XRD of sintered sample (b) thermomagnetization curve, magnetic entropy versus temperature of (c) sintered and (d) annealed sample

magnetic entropy to 19 J/kg-K at 290 K of the annealed sintered sample when compared to the magnetic entropy of 7.4 J/kg-K at 294 K of the sintered sample at 3T. The huge magnetocaloric effect at room temperature and low fields indicates that these alloys are suitable for magnetic refrigeration.

Visit of Prof. Ashutosh Sharma, Secretary, Department of Science and Technology to ARCI-Chennai

Centre for Solar Energy Materials

Centre for Solar Energy Materials (CSEM) strives to work on constructive ideas and innovative approaches to develop new materials, processes and components for solar energy conversion technologies. The center is committed to achieve excellence in various key research areas such as CIGS thin film solar cells, Perovskite solar cells, Solar absorber tubes, functional coatings (Easy to Clean, Antireflective and Antifogging) for power generation through Photovoltaic (PV) and concentrated solar thermal power (CSP). Knowledge sharing and collaboration with different companies has always been principle objective. Characterization facilities available at CSEM furnish the research activities for analyzing the performance and operational stability of various photovoltaic and solar thermal components. Cost-efficient solar receiver tube technology for low and medium temperature solar thermal application along with high optical properties ($\alpha \leq 0.95$ & $\varepsilon \leq 0.14$), good thermal stability ($\leq 250°C$) in open air atmospheric condition and superior corrosion resistance has been successfully validated under std test and field conditions and technology transferred to Greenera Energy Private Ltd. Ambient condition curable easy to clean coating technology with high transparency and good weather stability has been successfully developed and demonstrated to NETRA, NTPC Ltd and various PV module manufacturing companies. This novel technology will provide a solution for the easy to cleaning of solar (PV panels & CSP reflectors), optical and other expensive devices. Technology transfer is being progressed with few industries (PV panel manufacturing and power plants). Apart from solar thermal technology, CIGS thin film solar cells may tussle with the traditional Si solar cells to showcase its performance and cost advantages in field of Photovoltaic. The center's CIGS pilot line operates on 'sputtering + selenization' concept to fabricate 300 mm x 300 mm size mini-modules on glass substrate complements to the research facilities available at CSEM. Development of CIGS absorber layer by non-vacuum electrodeposition route and ink-based method are also being explored as low-cost alternative to the established processes. A maximum efficiency of 8.2% has been achieved by CIGS thin film solar cell by vacuum route (sputtering process) and 6.1% by non vacuum route (Electrodeposition). Moreover, Perovskite Solar Cell (PSC) rapidly developed as alternative technology due to their high performance and low-cost. Photo-conversion efficiency of 16 to 17% has been realized by solution & vapor processes in lab-scale PSCs and prototype module (50 mm x 50 mm) with efficiency of 5.2% was demonstrated. Development of earth abundant, non-toxic and intrinsically-stable perovskites (Quasi 2D structure and Single crystalline) is also actively carried out and achieved 12% efficiency. Current efforts are being focused on the scale-up of PSC technology to 100 mm x 100 mm with targeted efficiency.

Technology demonstration and transfer to the industry

New facilities established

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Technology of cost-efficient solar receiver tube for low and medium temperature solar thermal applications

Solar thermal technology has attracted a substantial renewed interest due to its diversity and compatibility in applications such as water heaters, industrial heating, and electricity generation. In solar thermal system, spectrally selective absorber coatings play a vital role in the efficiency of the system. Development of cost-effective solar selective receiver tube in a solar thermal system not only improves the energy conversion efficiency, also directly reduces the cost of it because of selective solar absorption while minimizing heat losses simultaneously. In this regard, solar thermal group in the centre developed a highly selective tandem absorber through an easy wet chemical route using a combination of novel chemical oxidation, sol-gel, and nanoparticle coating methods. The developed tandem absorber with three graded refractive index layers on stainless steel exhibits high optical properties ($\alpha \leq 0.95$ & $\varepsilon \leq 0.14$), good thermal stability up to 250°C in open air atmospheric condition and superior corrosion resistance (withstands >200h in salt spray test (ASTM B117)) in low cost compared to most of the commercially available solar selective coatings. The developed receiver tube with excellent uniformity and high mechanical stability is attracting many industries and recently this novel technology has been transferred successfully to an Indian industry (Greenera Energy India Pvt. Ltd).

Fig. 1 Technology demonstration and transfer to the industry

Fig. 2 1m prototype receiver tube for low and medium temperature applications

Technology of easy clean coating for dust cleaning of pv panels

Self-clean (easy to clean) coating technology is generally related to protecting the solar devices from dust/ dirt, corrosion and all sorts of weather conditions. PV panels are very important solar devices traditionally mounted outdoors on rooftops or in wide open spaces where they can maximize their exposure to sunlight. Unfortunately, this type of outdoor placement of the devices is subjected to substantially constant weather and moisture exposure. Due to this constant and extended exposure to the devices are preferably designed for using many years of stable and reliable operation without failure due to moisture damage. A general challenge is finding one protective coating (single layer) that has best-in-class qualities of self-clean property (easy to clean), high weather and mechanical stabilities, no loss in transmittance / power conversion efficiency after deposition on PV panels and curable by ambient conditions. ARCI has developed the real field technology for the PV dust mitigation. The nanocoating can be easily applied on the PV panel by simple spray and wipe technique. This coating reduces the amount of dust deposited on the panel and cleans itself by action of water on the modules. Moreover, it has many other potential advantages like room temperature or sunlight curable and high weather stability (IEC-61215) and high mechanical stability and the coating is validated under STD test and field conditions at CPRI, Bangalore, NETRA, NTPC, Noida, Renewsys Pvt. Ltd, Hyderabad. Technology transfer is under progress to few Indian Industries.

Fig. 3 Coating performance evaluation and validation under STD test and field conditions and field performance result

Design and development of cost-efficient solar receiver tube for medium and high temperature solar thermal applications (DST-SERI)

Medium & high temperature stable solar selective coatings are an essential component for increasing energy efficiency in concentrated solar thermal power (CSP) applications. Cost-effective development of coatings with high selectivity can reduce the cost of the entire system which can boost the usage of solar energy which in turn reduces environmental pollution. Globally, there are no commercial selective coatings for high-temperature (≤500°C) application to work in ambient conditions. In order to meet the challenge, we have

incorporated highly dispersible zirconia nanoparticles in a transition metal-based composite (CoCuMnOx) sol by cost-effective wet chemical method. The ZrO_2 nanoparticles were synthesized by the solvothermal method to obtain high crystallinity and dispersibility. The developed nanocomposite (CoCuMnOx+ ZrO_2) with tandem layer exhibited $\alpha > 0.95$ & ε=0.17 @500°C in open air atmosphere on SS 304 substrate. The coatings exhibited an excellent adhesion, and uniformity in terms of optical properties at lab and prototype scale. We have also developed multiple numbers of prototype receiver tubes to validate and measure the photothermal conversion efficiency in the parabolic trough. The nanocomposite based solar receiver exhibited excellent optical properties and thermal stability can be an attractive candidate for CSP applications.

Fig. 4 1 meter prototype absorber tube with and without AR layer

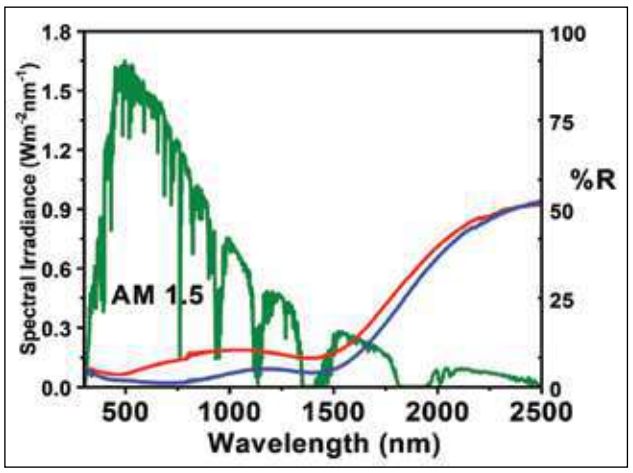

Fig. 5 Optical properties of single and tandem absorber tubes

Screen printed large-area carbon cathode perovskite solar module with enhanced operational stability

Organic inorganic halide based perovskites possess unique properties (high absorption coefficient, solution processable and tunable band-gap); which makes them to grow rapidly and also as an alternative for silicon and other thin-film solar cells by reaching efficiency more than 24 % in a short period of time. In perovskite solar cells (PSC), perovskite films are traditionally fabricated by solution process due to its simplicity and low cost. In spite of achieving high power conversion efficiency, it is challenging to make uniform and large area perovskite films with reproducibility. Quasi-vapor process considered as a promising alternative to solution process for fabricating uniform perovskite films with reproducibility. Here, we fabricated perovskite films by solution and quasi-vapor process. Perovskite films fabricated by quasi-vapor deposition have shown full film conversion and highly crystallinity with large grain size of 454 nm. Due to the large grains and pin-hole free film; quasi-vapor processed device has shown high power conversion efficiency (PCE) of 16.8%.

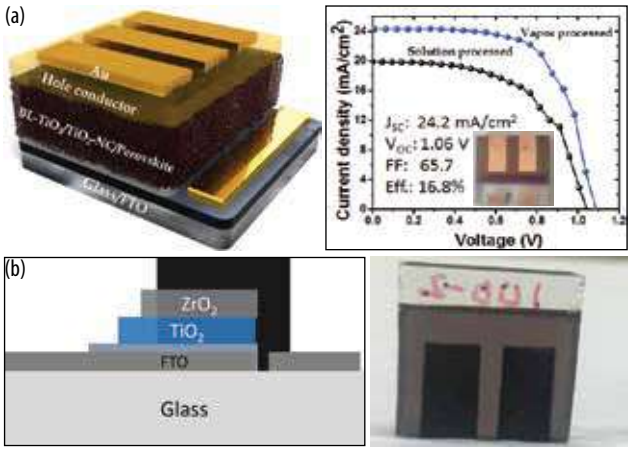

Fig. 6 (a) J-V characteristics of the vapor and solution processed devices, (Inset image showing the respective digital photograph of the typical PSC) and (b) Schematic diagram of lab-scale screen-printed carbon-based PSC (15mm x15 mm), corresponding digital photograph of the typical carbon-based PSC

State-of the-art laboratory scale PSC prepared in FTO/TiO_2/$MAPbI_3$/Spiro/Au configuration achieved record PCE; but prompted efforts on developing stable materials and upscaling of PSC technology for practical applications. Main problem in taking PSC for the market is due to the expensive organic hole-conductor (HTM) and the metal cathode (Au). A major portion of the PSCs cost was borne by HTM (33.9%) and metal cathode (18.3%). Another bottleneck in state-of-the-art PSC is the complexity in depositing large area, glove box processing and stability. It drives the research community to come up with the use of carbon-based PSC. Hole-conductor free carbon cathode monolithic integration is being identified as suitable approach for the industry viable fabrication of PSC modules on large size substrates. Herein, we first developed the device design for the proof-of-concept of successive screen-printing method for depositing all the layers on lab-scale carbon-based PSC (FTO/TiO_2/TiO_2/$MAPbI_3$/Carbon) and achieved reasonable photovoltaic performance around 10.9 % (Fig.7). Then, the same method was conceptualized to develop large area (64cm^2) carbon-based PSC. Fabrication of large area devices by screen printing is simple, reproducible and economically cheap. And the same can also be easily extended for developing flexible PSCs. Fig.9 shows the photograph of 100mm x100mm size carbon-based PSC module fabricated by successive screen printing of mesoporous TiO_2, ZrO_2 and carbon layers on patterned FTO glass substrate followed by $MAPbI_3$ absorber loading through infiltration of perovskite precursor solution. Complete solar cell fabrication was done in ambient conditions (36±1°C, 35%RH). The module consists of 10 numbers of monolithically integrated 7mm x 92mm unit

cells and obtained a VOC of 5.98V indicating minimum resistive losses. A measured photocurrent of 30 mA under 1 sun condition is lower than that of our lab-scale device and attributed to incomplete infiltration of perovskite precursor into the triple layer porous stack and poor crystallization kinetics of $MAPbI_3$. Module was tested for stability by storing the samples in ambient conditions. As expected, the device doesn't show any degradation, since the thick hydrophobic carbon layer acted as a self-encapsulation from moisture. Improving the perovskite loading by electrode thickness/porosity optimization and perovskite composition engineering is underway to realize 10% power conversion efficiency.

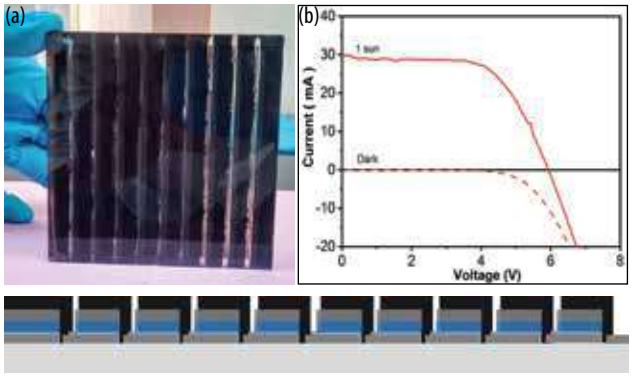

Fig. 7 (a) Photograph and schematic diagram of 100 x 100 mm large area carbon-based perovskite solar module fabricated by screen printing and (b) Current-voltage characteristics of the corresponding device measured in dark and 1 sun illumination conditions

CIGS Thin-film solar cells by non-vacuum routes for BIPV applications (TRC-B6)

CIGS is a well-proven material, with its superior optoelectronic properties and long-term stability, among thin films photovoltaic technologies with demonstrated commercial maturity. Non-vacuum approaches including electrodeposition and nano-ink processes have been the most explored for CIGS absorber fabrication and have produced commercial products. Solution-based economic methods are potentially ideal to achieve low-cost CIGS modules even with a slight compromise on efficiency, considering the small-scale energy needs that arise with the world looking forward to smarter technologies. Development of CIGS solar cells on rigid and flexible substrates by electrodeposition route is one of the primary aspects of interest. To simplify the process of optimization in electrodeposition, initially CIS absorbers are prepared through a novel attempt wherein absorbers are prepared in a Cu/In precursor approach followed by selenization. A combination of direct current (DC) and pulse electrodeposition (PED) approaches are utilized for the Cu/In precursor films preparation. With the individual layer thickness and compositional optimization, a near-stoichiometric CIS absorber of nearly 1 µm thickness is prepared which resulted in a power conversion efficiency of 6.1%.

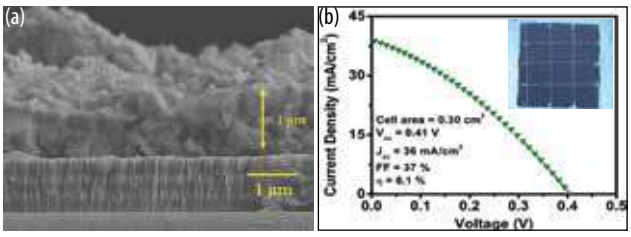

Fig. 8 Pulse electrodeposited CIS solar cells: (a) Cross-sectional morphology of absorber and (b) J-V characteristics of solar cell (Inset: CIS device)

CIGS thin film absorbers are also being prepared using printing of CIG precurosr/CIGS nanocrystal ink on conductive substrate followed by either thermal/photonic post-treatment. Two air-stable and non-toxic inks are employed, one comprising of facile benign aqueous metallic salt precursors and second, aqueous dispersion of CIGS nanocrystals. A high-quality CIGS absorber is obtained by non-vacuum atmospheric pressure selenization of ink jet printed metal salt precursors; the fabricated solar cell adapting this approach exhibited a power conversion efficiency of 4.7% despite having bilayer CIGS structure and thick $MoSe_2$ at Mo-CIGS interface, (Figure 8 (a)). In the second approach, application of synthesized CIGS nanocrystals by ambient sonochemical route is adapted to make thin film solar cell by employing atmospheric pressure thermal selenization or laser post treatment on spray casted film ensuing to improve the optoelectronic properties and performance of solar cell, comparison in (Figure 8 (b)). The solar cells with laser treated and selenized CIGS nanocrystal films have demonstrated an efficiency of 1.11% and 3.47%, respectively. Above mentioned non-vacuum routes are scalable and have advantage of high material utilization which eventually has important implications in cost-effective fabrication of a complete device (AZO/ZnO/CdS/CIGS/Mo/glass). Further efforts are underway in improving the efficiency from both the processes while scaling up is also under progress.

Ternary transition metal oxide based solar selective absorber coatings for medium and high temperature solar thermal application (TRC-A6)

Spectrally selective receiver tube is the critical component in Concentrated Solar thermal (CST) technology. To increase the overall efficiency of the solar thermal system, we need high thermal stable spectral selective coating on receiver tube which can be operated at ≤500 °C without any functional degradation. In this regard, solar thermal group at the centre developed a solar selective absorber (SSA) by using wet chemical method which comprises of three crystalline phases such as $Cu(Mn_{0.748}Ni_{0.262})_2O_4$ (Spinel), CuO and $MnNiO_3$ exhibited optical properties of solar absorptance α=0.97, thermal

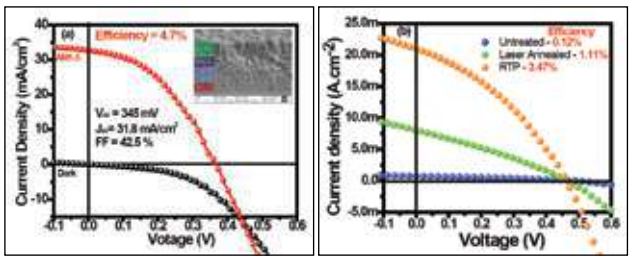

Fig. 9 (a) 4.7 % efficient nanoink printed CIGS solar cell and b) CIGS solar cells from nanocrystal inks with different treatments

emittance ε=0.16 with the aid of SiO_2 based antireflective (AR) layer. Further up scaled to prototype level on 1-meter SS304 tube , which makes it potential candidate for concentrated solar power generation because of its economical and manufacturing feasibility. For up scaling of absorber coating, about 5 L of absorber coating sol and SiO_2 AR layer sol of each were prepared and coated on 1-meter SS304 tube using 1-meter capable motor driven dip coater followed by annealing at 500 °C for 1 h duration. Developed selective absorber coating on SS 304 shows uniform solar selectivity i.e., α=0.97, ε=0.16 throughout the receiver tube which can be used in medium and high temperature CST applications.

Moisture tolerant quasi-2D perovskite for highly stable and efficient perovskite solar cells

Perovskite solar cells (PSC) are one of the most promising 3rd generation solar cells. Despite the significant improvement in their photovoltaic performance; device stability is the major concern. The conventional perovskites (CP) (i.e., $MAPbI_3$, $FAPbI_3$ etc.) are unstable towards moisture. To address this issue, layered quasi-2-dimensional (quasi-2D) perovskite absorber layers have been explored. The newly developed perovskite films were stable for 30 days (no color change), but the conventional perovskite started degrading from 10th day due to the moisture exposure. Contact angle measurement showed the newly developed quasi 2-D perovskite is 106° and CP film is 79° (inset Fig.11a). PSCs made with the CP and newly developed quasi-2D perovskite and its corresponding photovoltaic performances were measured (Fig.11b). As seen in the inset Fig.11b the degradation of newly developed perovskite is very minimal for 30 days; whereas CP PSCs started decreasing with time (within 10 days). Our newly developed quasi-2D perovksite is a promising material for highly efficient and moisture stable PSCs.

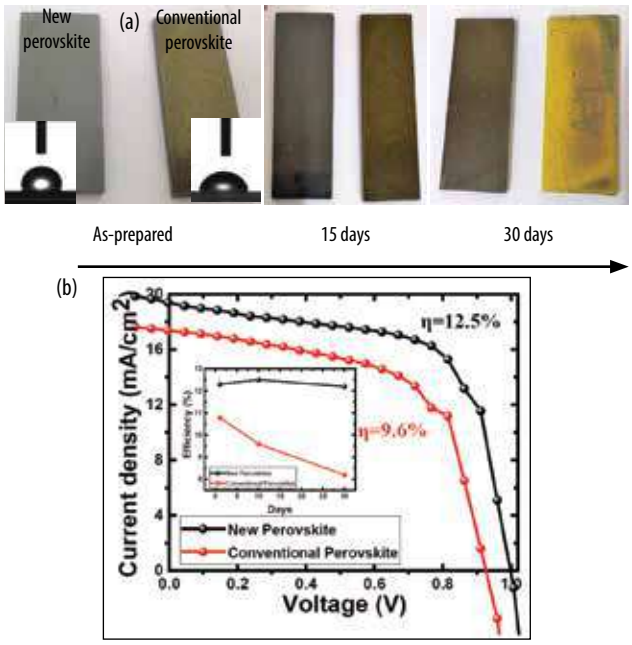

Fig. 11 (a) Photographic images of newly developed and conventional perovskite (inset, contact angle measurement of conventional and newly developed perovskite), (b) Current-voltage analysis of PSCs (inset showing indoor stability).

CIGS Thin-film Solar Cells by sputtering route using CIGS pilot-line R&D facility

Due to reduced material consumption and energy input, thin-film solar cell technologies are considered attractive paralleled to crystalline silicon based PV technologies. In terms of cost per watt and photo conversion efficiency, $Cu(In,Ga)Se_2$ (CIGS) solar cell is considered to be the most promising thin film PV technology. CIGS thin film by two step selenization process, sputtering of bilayer CIG precursor followed by atmospheric pressure selenization process, maximum photo conversion efficiency of 8.2% on lab scale device of about 0.5 sq cm is achieved on solar cell device configuration, Ag/AZO/ZnO/CdS/CIGS/Mo/Glass (Figure 12(a)). The process is scaled up and validated to demonstrate a proof of concept by fabricating monolithically integrated CIGS thin film solar mini module using P1, P2 and P3 scribing for serial interconnection of cells (figure 12 (c)), exhibiting 5 % photo conversion efficiency on 50 mm x 50 mm glass substrate (figure 12 (b)). The power output from the mini module is sufficient to run 2V DC motor with propeller, demonstrated. Further improvement in device performance of lab scale and module level is underway.

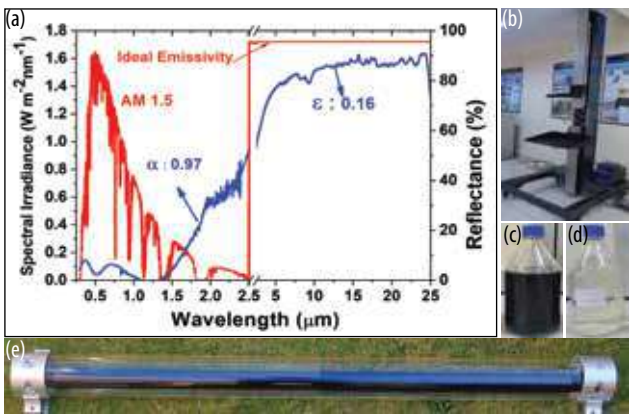

Fig. 10 (a) Reflectance spectra of SSA coating (b) 1-meter capable motor driven dip coater (c) absorber coating sol (d) AR coating sol (e) prototype of receiver tube for medium and high temperature CST application

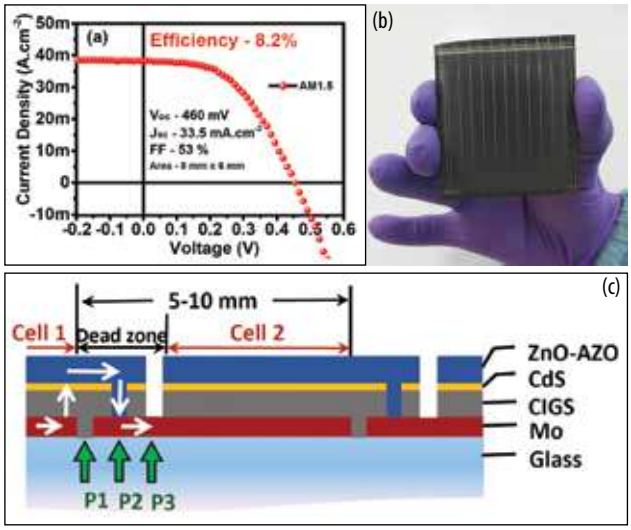

Fig. 12 Development of CIGS thin film solar cells and monolithically integrated modules (a) IV curve under solar simulated light, (b) 50 x 50 mm monolithically integrated module (Efficiency 5%) (c) Schematic representing of monolithically integration and serial interconnection of cells by scribing.

Flexible CIGS thin film solar cells

Flexible CIGS solar cells are prepared on metal foils utilizing both vacuum and non-vacuum based methods. 150 μm thick SS foil is used as substrate in fabrication of cells with vacuum based sputtering and selenization method. A ~200 nm thick dip coated ZrO_2 barrier layer is applied on SS foil to improve the stability of Mo back contact layer. CuGa-In precursor is sputtered in a multilayer form, followed by vacuum selenization to improve structural properties of CIGS absorber. Small area cells showed an efficiency of 3.8%. For utilizing the more economical non-vacuum approach, Cu/In precursor layers are deposited on 50 μm thick Mo foils using pulse electrodeposition method. After selenization, compact device quality CIS absorber of thickness ~500 nm is obtained. These cells exhibited a power conversion efficiency of 3.7%. Efforts are underway to improve the efficiency further for both vacuum and non-vacuum approaches.

Broad band antireflective coating for CSP and PV applications

Broad-band anti-reflective coatings (BARCs) have attracted substantial research interest due to their high transmittance in a broad wavelength range (300–1500 nm) for diverse potential applications spanning photovoltaic systems, solar thermal collectors, optical and architectural glasses, windscreens, high power lasers, windows and video display panels. Due to their high refractive indices, optical elements like PV cover glass and CSP cover glass tubes suffer a reflection loss of about 8-9% in the visible spectrum of the solar radiation. Such reflection losses are undesirable and detrimental to the overall optical efficiency. Hence, broad-band anti-reflective coatings minimize the Fresnel reflections over a wide broad band range to obtain high power conversion efficiencies for photovoltaic modules, receiver tubes and devices which require minimal reflections. The primary objective of this project work is to focus on developing antireflective films with high optical performance in a broad solar wavelength range (300 – 1500 nm), high weather and thermal stabilities for concentrated solar thermal power (CSP) and photovoltaic (PV) applications. In this background, a novel type of broad band antireflective coating was successfully developed on borosilicate glass substrate using novel synthesized MgF_2 nanoparticles or commercial SiO_2 nanoparticles. The developed antireflective coatings exhibit an excellent optical performance (>96% average transmittance from 300 to 1500nm) along with high thermal and weather stabilities. Prototype level AR coated mini module (5 x 5 cm) was developed and compared with uncoated mini module tested under std. test conditions (1000 w/m², AM1.5G) and 14 % increment in device performance compared that of bare coated module. 1% improvement was observed in outdoor performance for AR coated compared to that of bare glass as shown in Figure 13 below.

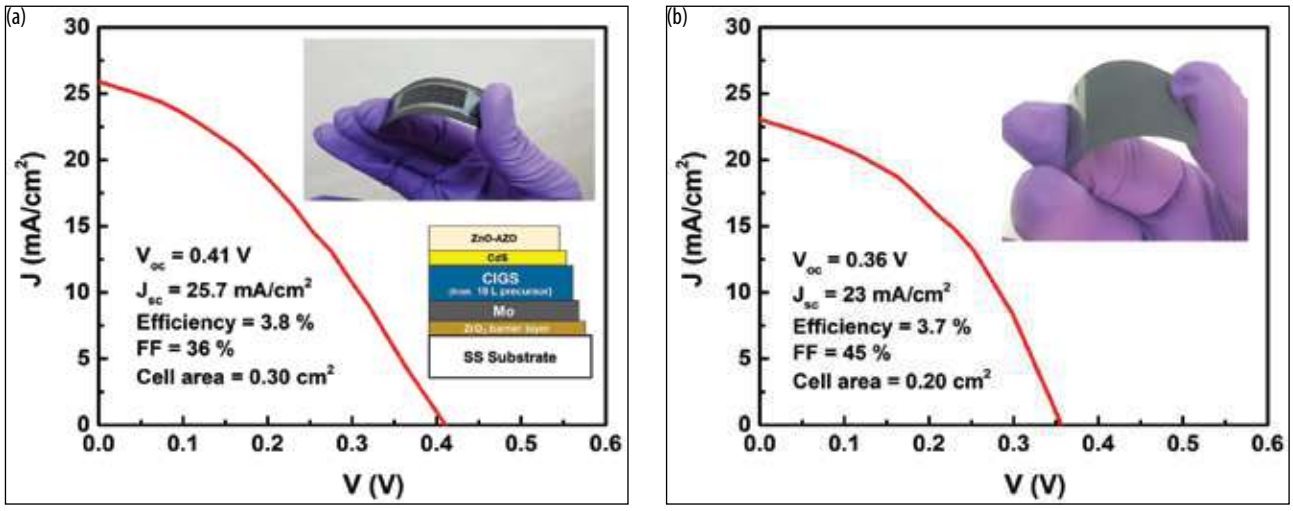

Fig. 13 (a) J-V characteristics of CIGS device made on SS foil by sputtering route (actual device and its structure shown in inset (b) J-V characteristics of pulse electrodeposited CIS solar cells on Mo foil (actual device shown in inset)

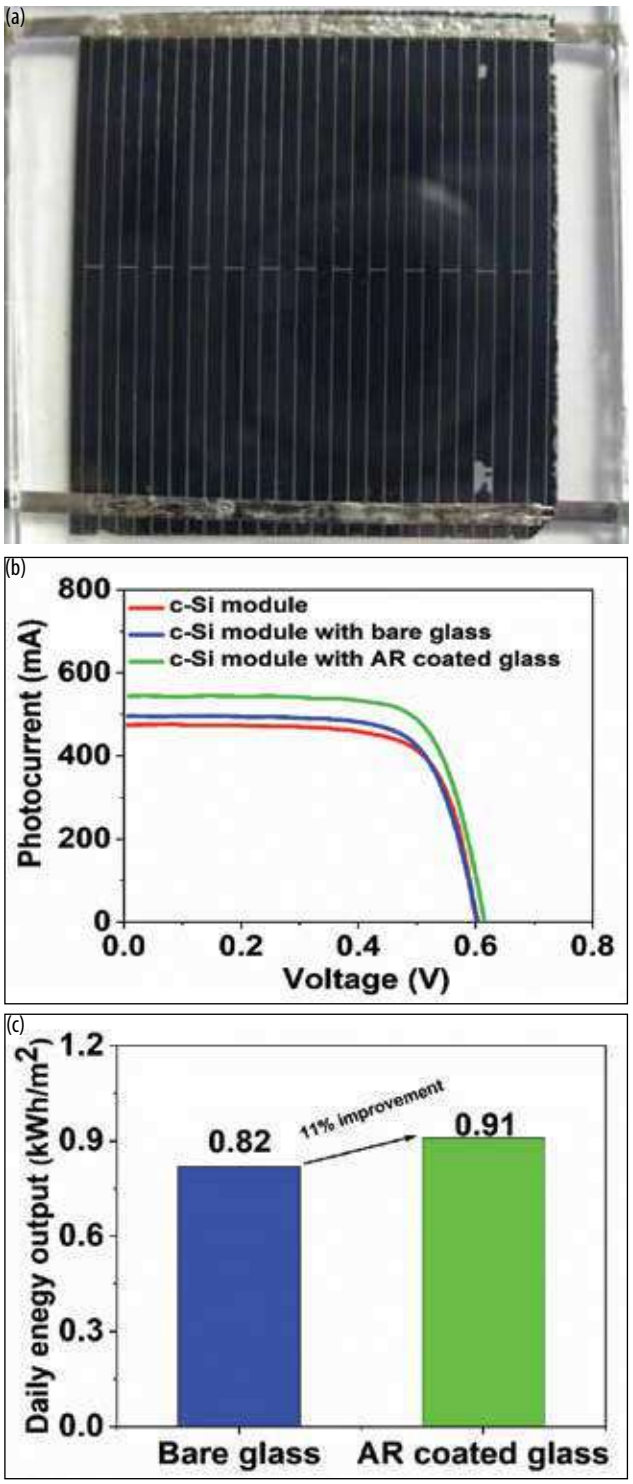

Fig. 14 Digital image of (a) AR coated mini module (b) I-V characteristics for of c-Si cell, mini module with bare PV cover glass, mini module with AR coated PV cover glass (c) outdoor performance of AR coated glass compared to bare glass

Smart carbon based heat transfer fluid for efficient heat transfer applications

Nano Heat Transfer Fluids (nHTFs) is one of the new and potential inventions of nanoscience and nanotechnology. The enhancement of thermal behavior of nHTFs can be provided enormous benefits for heat transport phenomena which are of primary importance to several sectors including industrial heat transportation, solar power generation, microelectronics manufacturing,

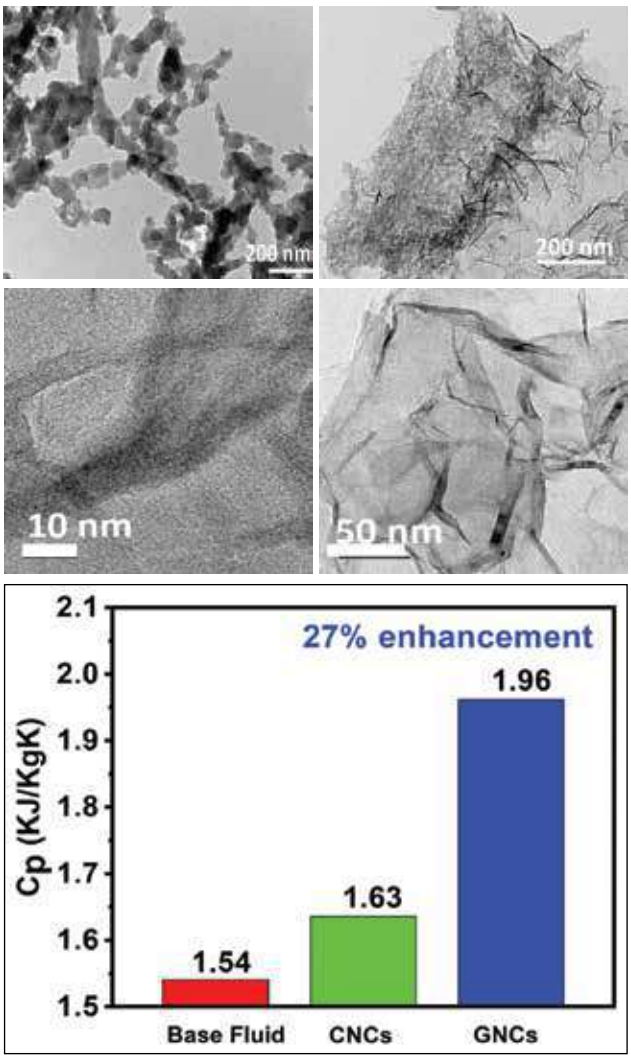

Fig. 15 Surface morphology of Carbon Nanoclusters (CNCs) and Graphene Nanocomposites (GNCs) & Comparison of specific heat capacity of CNCs and GNCs based heat transfer fluids

chemical and metallurgical sectors, thermal therapy for cancer treatment and heating-cooling processes in radiators, electrical transformers, refrigerators etc. nHTFs are fluids which contain suspensions of condensed nano-sized particles in the base fluids. In recent years, nHTFs have shown a great potential research interest because nHTFs show significant enhancement in their thermo-physical properties at low to moderate concentrations of nanoparticles added into the base HTFs. The thermo-physical properties like thermal conductivity (λ), thermal diffusivity (α), heat capacity (Cp), and convective heat transfer coefficients (h) of HTFs can be enhanced by addition of nanoparticles into the base fluids. Thus, it has demonstrated great potential in many emerging fields. In view of the potential importance of nHTFs for heat transfer application, novel smart carbon (Carbon Nano Clusters (CNCs) and Graphene Nanocomposites (GNCs) based nHTFs were developed by combination of hydrothermal and chemical activation process with 27% enhancement in specific heat capacity and high thermal stability.

Centre for Nanomaterials

The major research activities being carried out at Centre for Nanomaterials are: (i) development and 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) Two dimensional transitional metal sulphides as additives to the lubricants and grease and as catalysts in oil refineries and petrochemical industries, (v) Development of tungsten based jet wanes, (vii) Development of powders for additive manufacturing, (viii) Development of filters for fluoride removal, (viii) Solar hydrogen generation materials. New R&D activities like (i) Powders for additive manufacturing, (ii) Solid electrolyte for Li-ion batteries and (iii) Bio-degradable alloys for implant applications are initiated.

The Technology transfer for the production of Silica Aerogel flexible sheets for the thermal insulation application was completed. Development and supply (10 kg) of carbon coated LFP with high C rate to NSTL was completed. Filed trials are being carried out at NSTL. Technology transfers viz. (i) Anode (LTO) and (ii) cathode (LFP) materials for Li-ion batteries are initiated. Received an order from DRDL for the development and supply of 32 no. of 100 mm dia. W plates for jet wane application.

The overall performance of Centre for Nanomaterials during this year is very good and this is due to the concerted efforts of dedicated scientists, technical staff and students.

Li-ion battery materials

Flexible activated carbon electrode

Supercapacitor materials

W-jet wane

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Development of cathode (carbon coated $LiFePO_4$-C-LFP) and anode (lithium titanate-LTO) for lithium-ion battery Application

Realizing the potential of lithium iron phosphate ($LiFePO_4$) as a cathode and lithium Titanate (LTO) as an anode in Lithium-ion batteries for EV application, Centre for nanomaterials focussed on the large scale synthesis of lithium iron phosphate (cathode) and lithium titanate (anode) by a simple and cost-effective methods. The indigenous production of $LiFePO_4$ in Kg level carried out by one step solid state process using high energy milling. The use of an appropriate carbon source resulted in carbon coating upon heating at 700°C in inert atmosphere. The resulting carbon coated $LiFePO_4$ electro-chemical performance in terms of specific capacity, rate capability and cyclic stability was found to be on par with commercial grade $LiFePO_4$ electrode materials. The single step proccess would expected to reduce the synthesis cost as it eliminates a post treatment step for carbon coating.

On the other hand, large scale synthesis of LTO was carried out by high energy milling process. The synthesis conditions such as amount of precursors loading, milling time and calination temperature were optimized. Bench mark studies revealed that the specific capacity of LTO synthesized by high energy Zoz milling (Zoz) process is higher than commercial LTO at high current rates. The use of Lithium carbonate (Li_2CO_3) obtained from various sources, the main lithium containing precursor used in the synthesis process, has been evaluated. The LTO synthesized from various Lithium carbonate precursors delivered similar electrochemical performance. Further, when it was tested as anode in combination with indigenously developed solid state synthesized LiFePO4 as cathode, the LFP//LTO full cell delivered a capacity retention of 82 % after 1000 charge-discharge cycles at 10C rate. The high rate capability of LFP//LTO battery chemistry is an ideal solution for Indian climate changes

Furthermore, the use of high capacity cathodes can enhance the energy density of the LIBs for EV application. In this direction, Ni-rich high capacity $LiNiMnCoO_2$ (Ni ranges from 0.5-0.8 mol%) was synthesized by ball-milling using NiMnCo-hydroxide precursors and lithium carbonate. The synthesis parameters such as

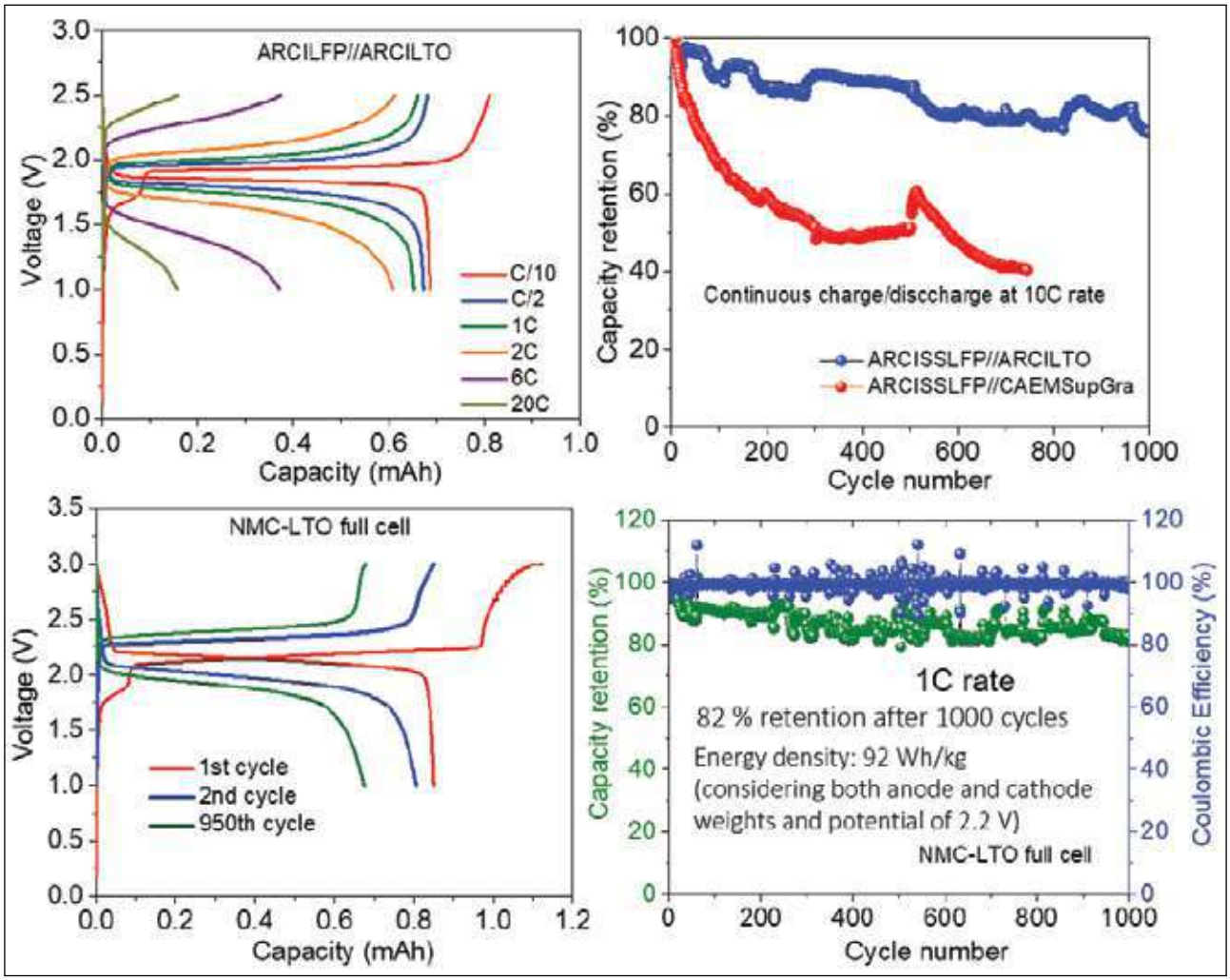

Fig. 1 (a) charge-discharge profiles and (b) capacity retention vs. cycle number plot of LFP//LTO full cell fabricated using indigenously developed materials, (c) charge-discharge profiles and (d) capacity retention vs. cycle number plot of NMC//LTO full cell fabricated using indigenously developed materials

calcining atmosphere, temperature and time were optimized to get better electrochemical performance vs. Li. $LiNiMnCoO_2$ with 0.5 mol % of Ni, 0.3 mol % of Mn and 0.2 mol % of Co in Kg level batches has been synthesized using high energy milling unit. The full cell consisting of indigenously developed Ni-rich NMC and LTO materials exhibited 85% capacity retention after 1000 charge-discharge cycles at 1C rate.

Development of Porous Carbon Materials for Supercapacitor Application

(i) Heteroatom doped petroleum coke derived porous carbon by cost-effective approach for supercapacitor electrodes with improved electrochemical properties

Considering the high carbon content, broad distribution and low prices, combined with economic and environmental benefits, the petroleum coke became the promising carbon source for the preparation of activated carbon. The advantage of using petroleum coke is its high carbon content (90-95%), which yields 60-65% of final carbon after chemical activation. As part of collaboration project with HPCL petroleum coke having high carbon content was successfully converted into high surface area activated carbon with high yield (60-65%) for supercapacitor application. In order to further increase the electrochemical performance, attempt has made to synthesize nitrogen & sulfur doped porous graphene sheets from petroleum coke in which thiourea used as source for sulfur and nitrogen doping. The N & S doping on petcoke derived carbon delivers specific capacitance of 159 F/g at the current density of 1A/g whereas petcoke derived carbon without doping and commercial Supercapacitor grade (YP-50) carbon delivers only 128 and 98 F g-1 respectively.

(ii) Facile and single step process for the preparation of Activated carbon fibres (ACF) as high performance supercapacitor electrodes derived from industrial waste cotton by CO_2 activation

Turning industrial waste cotton into useful energy storage device shows great scientific and industrial importance due to the sustainability, abundance, low-cost and environmental friendliness. The present work delineates the large scale fabrication and

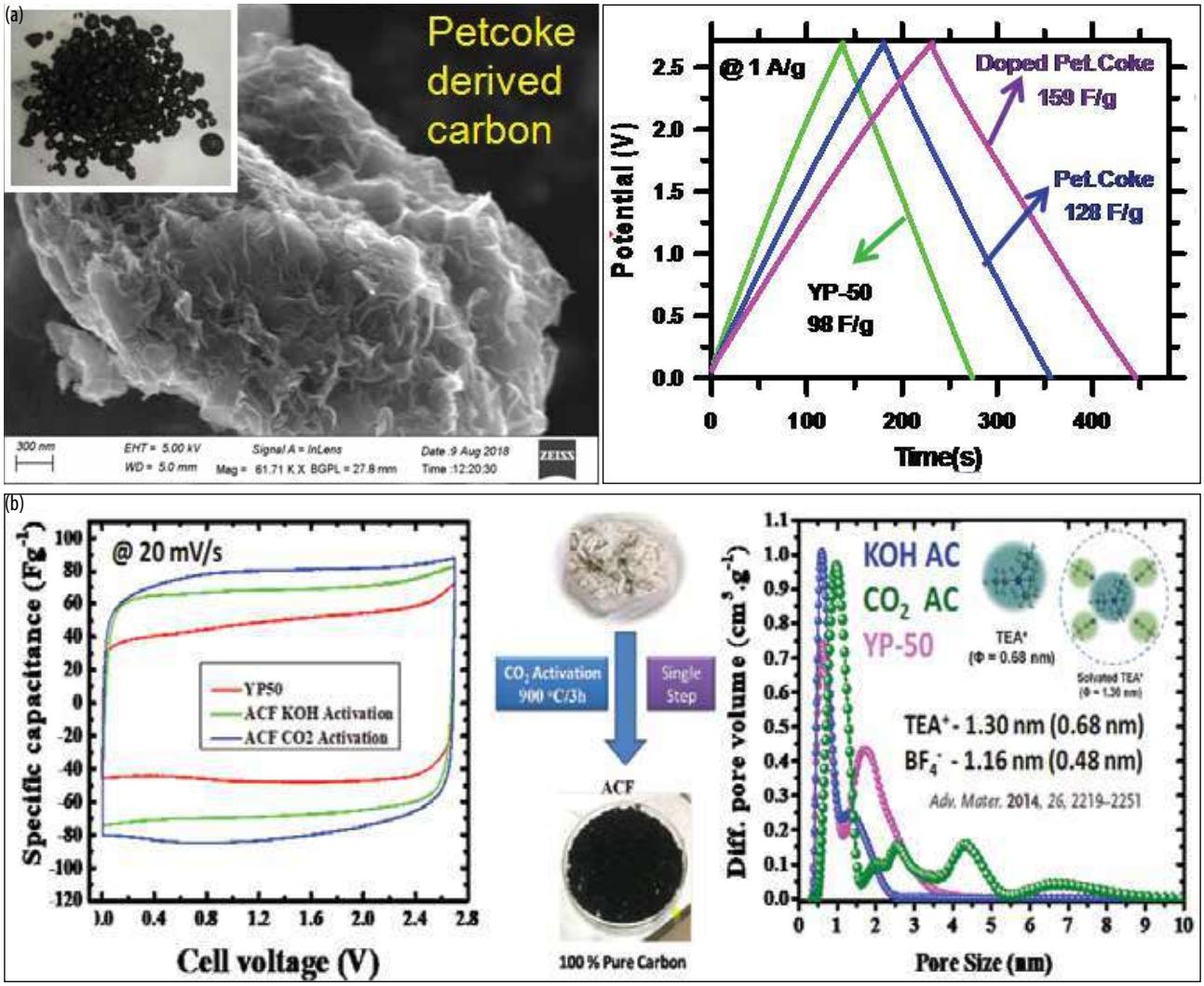

Fig. 2 Electrochemical performance of (a) petcoke derived carbon and (b) indigenous activated carbon fibres compared with commercial carbon YP-50F

electrochemical performances of activated porous carbon fibres used as high performance supercapacitor electrodes with commercial level mass loading (10 mg/cm^2, 140 ± 10 μm thickness,). The electrodes in organic electrolyte TEABF4 at 2.7 V exhibited excellent gravimetric and volumetric capacitances of 125 F/g and 101 F/cm^3 at 1 A/g and it delivers maximum gravimetric and volumetric energy densities of 32 Wh/kg and 20 Wh/L, respectively. For comparison, the similar electrochemical performance has been conducted by using commercial Kuraray YP-50F supercapacitor grade carbon as electrode. From the results, it was observed that the gravimetric and volumetric capacitances of commercial Kuraray YP-50 exhibit around 91 F/g and 60 F/cm^3 at 1 A/g current density in 2.7 V. Besides, YP-50 delivers maximum gravimetric and volumetric energy densities of 22 Wh/kg and 16 Wh/L, respectively. The obtained results clearly demonstrated that activated carbon fibres showed higher gravimetric capacitance and energy density as compared with commercial YP-50F.

Oxide Dispersion Strengthened (ODS) Alloys

Oxide dispersion strengthened (ODS) alloys are being developed around the world for various high temperature applications such as components in steam as well as gas turbines and nuclear reactors because of improved high temperature strength and resistance to creep and irradiation induced void swelling. The improved properties of these ODS alloys are due to the presence of uniformly distributed very fine (2-5 nm) Y-Ti-O complex oxide particles with high number density (2 x 1023/m^3). ARCI has embarked upon major programs to produce variety of ODS steels (9, 14, 18 Cr, as well as austenitic steels and iron aluminides) for components of nuclear reactor, steam as well as gas turbines. The salient features of the developmental work are given below.

(i) Development of Oxide dispersed strengthened Iron Aluminides

Iron aluminides (Fe_3Al) are potential candidates for high temperature structural application due to its light weight and attractive properties such as high strength, resistance to oxidation, sulfidation and corrosion and low cost of production. However, poor ductility, inadequate creep resistance and low fracture toughness limits their commercial applications. Attempts are being made at ARCI to improve these properties. Oxide dispersed strengthened iron aluminides (ODS Fe_3Al) offers an excellent opportunity to improve both ductility and creep resistance due to fine grained microstructure, nano-sized oxide dispersoids (Y-Al-O) and stability of the microstructure at high temperatures.

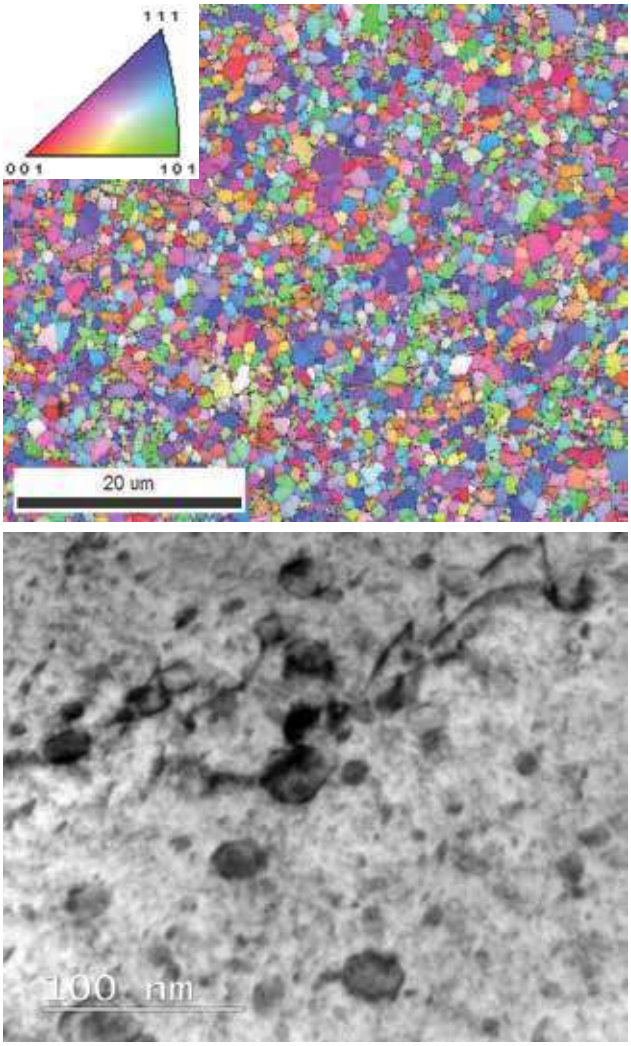

Fig.3 (a) EBSD map and (b) TEM bright field with nano-sized dispersoids in ODS Fe_3Al

Inert gas atomized pre-alloy powder (produced at ARCI) and nano yttria (Y_2O_3) were milled in Zoz CM08 mill for 4 h and consolidated the powder into rods by hot extrusion. The extruded rods were heat treated at 950°C for 1 h and air cooled. The heat treated samples were evaluated for both microstructure and tensile properties. The EBSD grain orientation map (Figure. 1(a)) reveals that the microstructure structure contains equi-axed grains, which are randomly oriented and re-crystallized with an average grain size of 660 nm. The TEM Bright field images (Figure.3(b)) show the presence of fine and uniformaly dispersoid particles and few of them are very fine particles. XRD Pattern in the

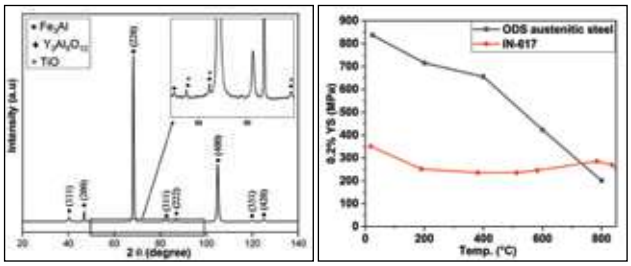

Fig. 4 (a) XRD pattern of heat treated ODS-Fe3Al and (b) variation of yield strengths of ODS Fe3Al and IN617 alloy with temperature

Figure.4(a) confirm the super lattice reflections which indicate the presence of D03 structure of Fe_3Al phase and also the $Y_3Al_5O_{12}$ complex oxide phase and this might be the phase of the particles shown in the TEM image. ODS-Fe_3Al exhibits 8% elongation with a yield strength of 1255 MPa at room temperature and 30% elongation with a yield strength of 211 MPa at 800°C. As the intended application of this alloy is for gas as well as steam turbine blades at operating temperature 650-700°C, the tensile properties of ODS-Fe_3Al is compared with the currently used material (IN617) and is shown in Figure 4(b). It is clear that the yield strength of ODS Fe_3Al at 700°C is higher than that of IN617.

(ii) Development of ODS austenitic steel for gas turbine blades

ODS austenitic steel (AODS) is considered as a promising substitute for of Ni-based super alloys operating in the temperature range of 650-750°C because of strength, oxidation and corrosion resistance at elevated temperatures. ODS austenitic steel of nominal composition Fe-18Cr-22Ni-1.6W-0.23Ti-0.35Y_2O_3 was produced by mechanical milling followed by hot extrusion. The extruded rods were solution annealed at 1150°C. Transmission electron microscopy (TEM) was performed to observe microstructure and for analysis of size and chemistry of dispersoids. Indentation hardness and high temperature tensile properties were measured in the solution annealed condition.

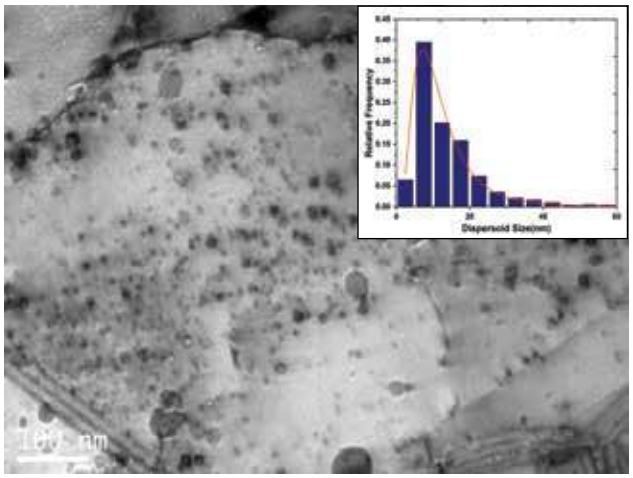

Fig. 5 Bright field TEM image showing dispersoids with size distribution (inset)

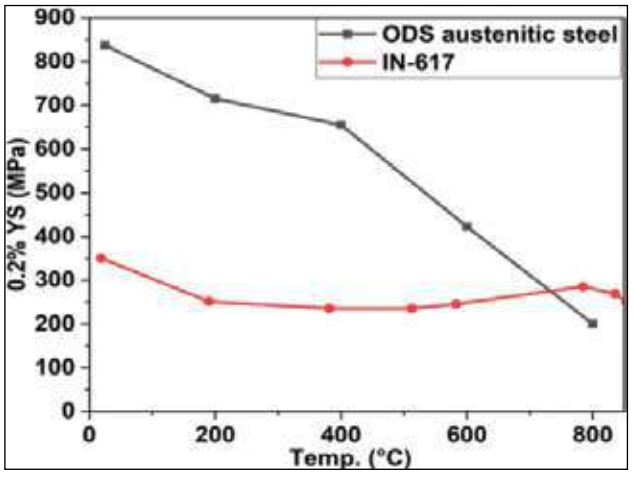

Fig. 6 Yield strength of AODS steel and IN-617 alloy from 25-800°C

The bright field TEM image showing very finer and coarser dispersoids is shown in Fig. 5. It can be observed that dispersoids present within the grain are pinning the dislocations. The size distribution of dispersoids is presented in the inset of Fig. 5 in the form of a histogram fitted with log-normal curve. It can be seen that the majority number of disperosids (80%) are below 20 nm with 45% even below 10 nm. The average size of dispersoids is 14.7 nm. There are some dispersoids whose size is greater than 50 nm also, but their number is negligible. The ones whose size is less than 40 nm were analyzed by EDS to be Y-Ti-O complexes while those whose size is above 50 nm were Y-Si-O complex oxides. Since the diffusion activity is faster at the grain boundaries, the particles pinning the grain boundary are observed to be a little coarsened.

The AODS steel exhibited a hardness of 310 HVN. The yield strength of ODS austenitic steel from room temperature to 800°C in comparison with IN-617 alloy is presented in Fig.6. It can be observed from the figure, yield strength of AODS steel ranged from 837 MPa at 25°C to 201 MPa at 800°C which is consistently superior to that of IN-617 across all temperatures up to around 700°C. The fine dispersoids present in the austenitic steel matrix led to the improved mechanical properties with a combination of good yield strength and elongation. The elongation is more or less in the range of 25-30 % across all temperatures. The reduction in area at low temperature regime of 25-400°C is much higher at 54-63% in comparison with 20% and 27% at 600 and 800°C respectively. It indicates the dominance of ductile fracture during low temperatures and mixed ductile-brittle fracture at high temperatures. Efforts are on to manufacture gas turbine blades.

Bulk synthesis of various grades of 2D-WS_2 and their thermal stability

Two-dimensional (2D) nanostructured tungsten disulphide (WS_2) is a versatile multi-functional material with a wide range of potential applications viz. solid lubricant for aerospace, automotive and manufacturing sectors, mold-release agent, electronic material, catalyst for hydrogen evolution reaction (HER) apart from being an electrode material for Li-ion batteries, supercapacitors, etc. In recent years, it has shown promising performance even in the area of biomedical sciences. However, key to any commercial exploitation of these materials in all these applications requires a viable route for production of various grades of 2D-WS_2

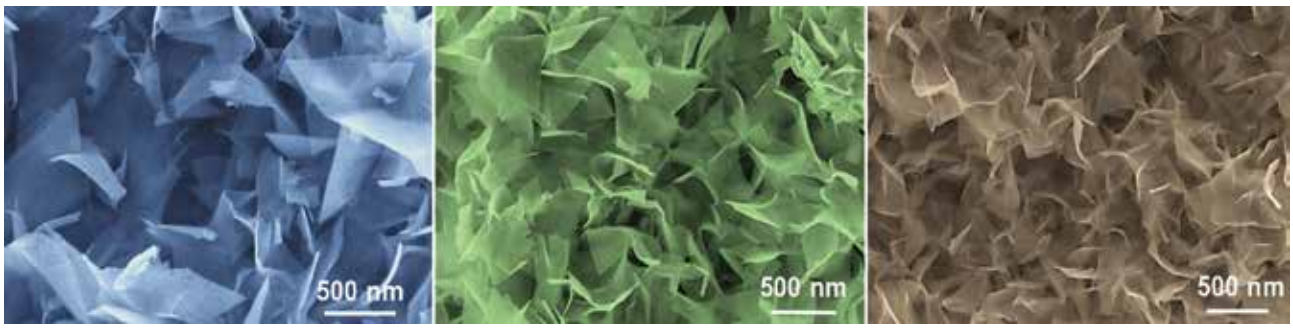

Fig. 7 Various grades of 2D-WS_2 synthesized using scaled-up reactor setup at ARCI (a) MWP (b) HEBM (c) WCS grade

nanosheet powders in bulk quantity and reproducible quality.

In view of the large-scale production requirement to develop any commercial application and as a part of a project sponsored by Hindustan Petroleum Corporation Limited (HPCL), a reactor has been designed with a production capability of about 2 kg per day of 2D-WS_2nanosheet powders. This reactor is a scaled-up version of the lab-scale reactor (50 g per day production capacity) originally designed by ARCI to demonstrate the feasibility of synthesizing 2D nanostructured WS_2. The large available volume of the scaled-up reactor design offers provision to maintain widely varying reaction control parameters and thereby allows to generate different grades of nanostructured WS_2 including inorganic fullerene like WS_2 to inorganic graphene like or 2D-WS_2. It was possible to induce substantial variation in the size of the 2D-WS_2 powders, both in terms of lateral size as well as thickness. It was also established that the mode of processing or synthesis of nanostructured WO_3 precursor has a significant influence on the size of the 2D-WS_2 nanosheets.

Figure 7 and Table 1 shows various grades of 2D-WS_2 successfully synthesized in bulk quantities making use of different grades of nanostructured WO_3 precursors obtained from different processing or synthesis routes viz. microwave plasma processing (MWP), high energy ball milling (HEBM) and wet chemical synthesis (WCS). The MWP and HEBM involved reduction of commercially available coarse grade WO_3 powder to nanostructured WO_3 precursor powder while WCS involved synthesis of nanostructured WO_3 precursors from tungstic acid. The grade of the product could be easily varied in the new scaled-up reactor with the change in the various control parameters. This imparts considerable advantage to the process as different grades of the 2D-WS_2 powders have different thermal stability as well as bandgap, which are suitable for various types of applications. Table 2 shows relative oxidation resistance of different grades of 2D-WS_2 at elevated temperature as ascertained from differential scanning calorimentry.

Table 1: Average thickness and lateral size of various grades of 2D-WS_2 synthesized by scaled-up reactor

Grade	Average thickness (in mm)	Average Lateral size (from DLS)* in nm
MWP	12	1000
BM	10	850
WCS	15	200
* Using Zeta sizer using Coleman's method		

Table 2: Temperature of onset and complete oxidation for various grades of 2D-WS_2 in air

Sample Grade	T_{start} (°C)	T_{finish} (°C)
WCS	320	460
BM	335	460
MWP	370	610

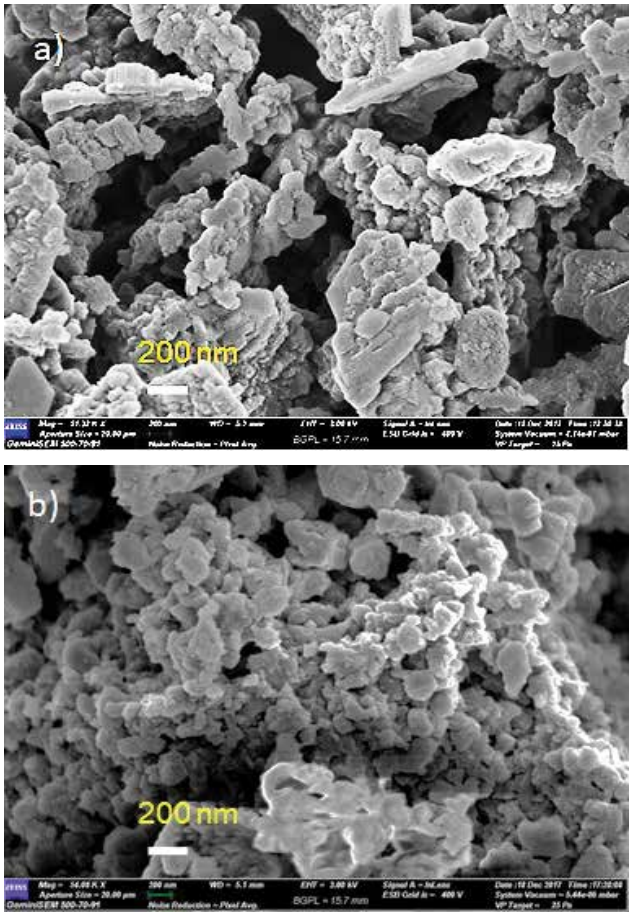

Fig. 8 SEM image of (a) as received powder and (b) cryo milled powder

Development of nano boron by cryo milling

Slurry fuels, which consist of hydrocarbon fuel and high-energy metallic elements, are considered as potential candidates to increase the energy density of conventional hydrocarbon fuels for air breathing propulsion applications. Some of the widely investigated fuel additives are magnesium, aluminum, iron and boron etc. Nano sized additives in fuel provides large surface to volume ratio which facilitates more contact area for rapid oxidation and hence it has unique features to overcome the problems of ignition delay, burning time. Among various nano additives, nano boron is one, which makes it better choice as potential fuel additive in liquid fuels due to its higher volumetric heat production. Attempts are being made to develop nano boron at ARCI, Hyderabad by cryo milling.

Cryo milling is a novel process for converting micron-sized powder to nano powders as the material undergoes ductile to brittle transition at low temperatures. In cryo mill, boron powder is milled at -180°C making it brittle and accelerating the fracture process, thereby producing the nano sized powders in bulk quantity. It is possible to produce 1 kg/day of nano boron powder with an average particle size of 250 nm using the present facilities. Following figures show the SEM images of raw material (micron sized boron) used and nano boron powder produced by cryo milling. The nano boron powders were supplied to GTRE for evaluation.

Large volume Electroless film deposition facility for transition metal phosphide film deposition-energy, tribology, corrosion resistant application

Deposition of multifunctional thin film of metal-phosphide is key to different applications ranging from energy generation/storage, corrosion resistance, and tribological applications. Ni-P is one of the well-known electrocatalyst material that show competitive electrochemical properties desirable for electrocatalytic water splitting. It has a tremendous potential to replace the conventional platinum and its alloy, those are used in fabrication of electrode for electrocatalytic hydrogen generator. In view of high cost of platinum, it is a hindrance to convert the electro catalytic-water splitting hydrogen as a commercial technology. Nanomaterials have ability to tune in the material properties by virtue of the size and surface control. Thus material nano-structuring is an important criterion to achieve best desirable properties for any potential material systems. A scalable and economic method of film deposition is always desirable in commercialization of any material technology.

ARCI has developed a scale-up facility that is capable of deposition various metal and metal-alloys including transition metal phosphides like Ni-P, that can be utilized in various applications say for large number HER (Hydrogen Evolution Reaction) electrode. It has applications in tribology and corrosion resistant films.

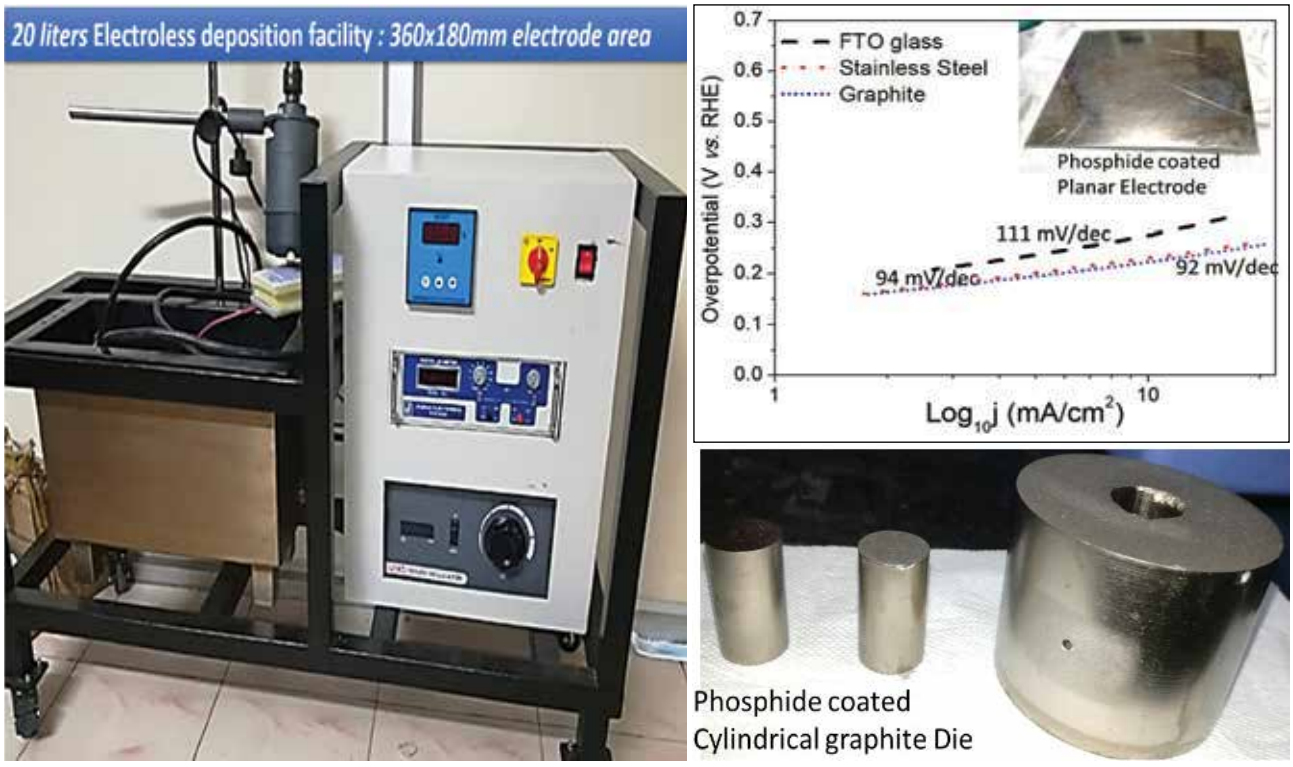

Fig.9 Photograph of large bath electroless deposition facility used for phosphide coating on planar steel and actual cylindrical graphite die. Their electrochemical investigation shows low Tafel value desirable for hydrogen evolving catalysts.

Centre for Engineered Coatings

Building on the decades of experience and proven performance in providing advanced surface engineering solutions, the Centre for Engineered Coatings has further established itself as a frontrunner in the area, by delivering multiple technologies, products, technical solutions in addition to carrying out basic and sponsored R&D to support technology and application development.

The major technology development/transfer achievements during the past year include, transfer and implementation of Micro Arc Oxidation (MAO) systems at NIT-Tiruchirappalli and establishment of a pilot plant in collaboration with M/s. Hyderabad electroplating for eventual transfer of Pulsed electrodeposition (PED) technology. Several critical technical solutions were also provided, including development of Cathodic Arc Physical Vapour Deposition coatings for minting dies resulting in substantial improvement in die life and wear resistant coatings for helicopter compressor blades. Furthermore, a high speed nanoindentation mapping and data deconvolution tool, NanoBlitz 3D+ for surface mechanical property measurements, jointly developed with M/s. Nanomechanics Inc, USA was globally launched on the sidelines of TMS 2019 conference in San Antonio, TX, USA.

Continuing the CEC's rich tradition of providing advanced surface engineering solutions to the industry, a joint demonstration centre for aerospace applications has been established in collaboration with M/s Sai Surface and Coatings Technologies, who were the receivers of multiple coating technologies from ARCI in the past. This center aims to create an ecosystem for providing holistic solutions to aerospace industry starting from identifying the critical issues and performing basic R&D to solve these, to finally deploying the coatings on actual aero-components.

For sustained performance in the short and long-term, several new initiatives are underway and are at various levels of being realized, including the establishment of National Centre for Development of Advanced Materials and Manufacturing Processes for Clean Coal Technologies for Power Applications (NCDAM-CCT), Major highlights of the researchand development outcome of the centre are elaborated as follows.

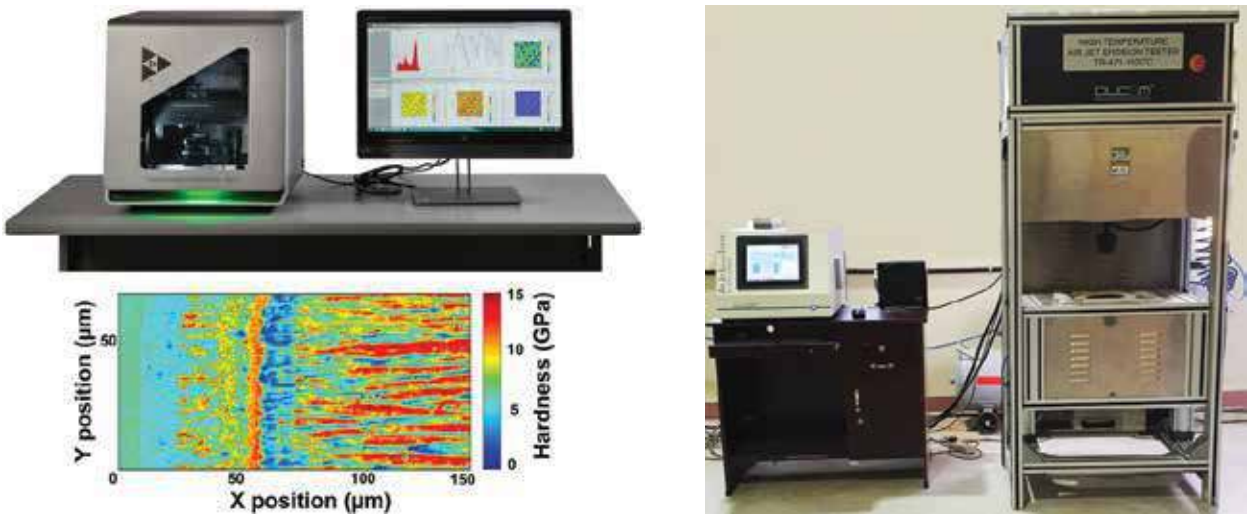

Fig. (a) Advanced nanomechanical characterization facility along with a high speed hardness map across various layers of an EBPVD TBC and (b) High temperature erosion facility for coating erosive wear performance evaluation up to 1100°C

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Transfer and implementation of MAO technological systems at NIT-Tiruchirappalli and critical application development

A 30 kVA MAO system, suitable for research and development demands of NIT-Tiruchirappalli (NIT-), was exclusively designed, tested, supplied and commissioned at Materials and Metallurgical Engineering Department. The integrated systemssupplied to NIT-T includes the power controller, reaction chamber, heat exchanger and the peripheral systems. Post the installation and commissioning, the faculty and scholars were thoroughly trained at their premises on the operation, maintenance and troubleshooting aspects. In addition, to further support and to stimulate the utilization of the MAO technology, an additional round of training including how to conceptualize, monitor and realize the MAO coatings on real-life components was also imparted at ARCI. Towards promoting further MAO technology transfers, new industrial applications demanding challenging solutions including providing electrically insulating coatings in internal areas of Al alloy housing and critical components needing simultaneous wear, corrosion and fatigue protection were demonstrated. For further intensifying application in aerospace sector, corrosion-fatigue performance evaluation studies were initiated.

Fig. 1 30 kVA custom-built MAO control system installed and commissioned at Materials and Metallurgical Engineering Department, NIT-Tiruchirappalli

Development of wear resistant coatings by CA-PVD to improve life of minting dies

Cathodic Arc Physical Vapor Deposition (CA-PVD) is a thin film deposition process in which, a source material is evaporated in an inert or reactive gas environment to form corresponding metal or nitrides/carbides. Arc deposition is usually a high-energy process due to which most of the evaporated material contains ionized species. In any deposition process, the presence of ionized atoms can be highly helpful in controlling the surface energy of the growing film by applying a suitable bias voltage. The ability to control the surface energy of the growing films facilitates tailoring the microstructure and film properties like adhesion strength, etc. The state-of-the-art cylindrical cathode CA-PVD facility at CEC is being extensively used to provide technical sotulution such as erosion resistant coatings for compressor blades, wear resistant coatings for dies, solar selective coatings for solar thermal applications and biocompatible coatings for stents.

In minting process, the dies are subjected to high cyclic loads at a pre-defined frequency. Hence, any coating developed for such applications requires very high resistance to impact wear and also maintain good flowability between the interacting materials (i.e. die and coining material). Among the several candidate materials for wear resistant coatings, TiCrN with considerably high toughness makes a strong case and hence was studied in detail to address the wear resistance issues in minting dies. Systematic deposition process parameter optimization studies were carried out that showed that a low substrate temperature (250 - 280°C) with high deposition rate at -50 V DC bias, yields superior mechanical properties. The real-time performance studies of actual dies coated with TiCrN was subsequently carried out and a significant life improvement of (~2.5 times) was observed as shown in Fig. 2. Furthermore, in order to improve the flowability, a very thin layer of DLC film was deposited on top of the TiCrN coating. This improved the flowability and quality of the coins produced considerably.

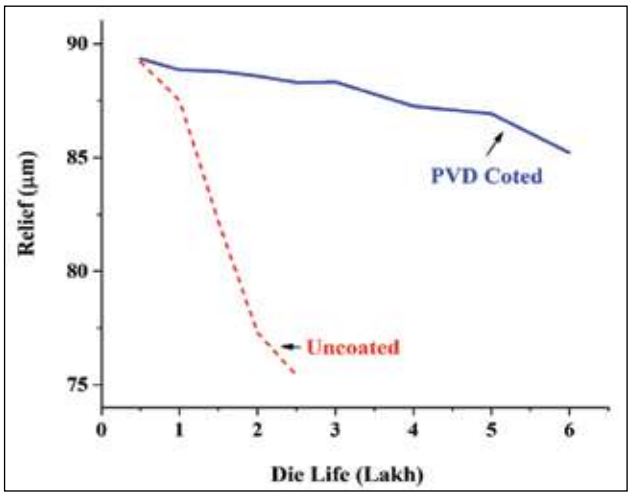


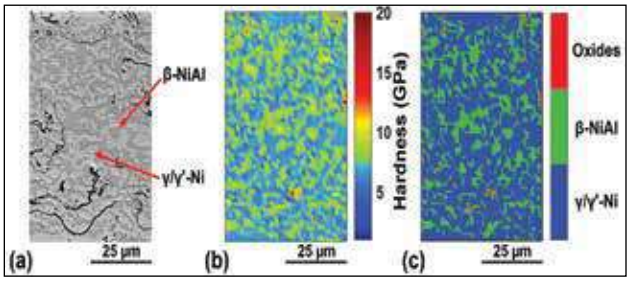
Fig. 2 Comparison of the performance of uncoated and CA-PVD TiCrN/DLC coated Rs. 2 coin die, showing significant improvement in die life with coating

High speed nanoindentation and data deconvolution tool

High speed nanoindentation mapping technique - NanoBlitz 3D, originally developed by M/s. Nanomechanics Inc. USA, is an advanced nanomechanical characterization tool for measurement of local mechanical properties of multi-phase /multi-component materials. Recently, Nanomechanics Inc., has partnered with ARCI to develop the technique further

and to obtain quantitative information of mechanical properties of individual phases from the mapping data. This collaborative effort has resulted in the development of a novel product, NanoBlitz 3D+, which was globally launched during TMS 2019, at San Antonio, TX, USA. In this work, the capability of this state-of-the-art product for studying a complex, heterogeneous material system such as Thermal Barrier Coatings (TBC) which comprises of multiple coating layers, multiple phases and various microstructural features (splat boundaries, porosity, interface) is presented. In addition, the novel methodology to deconvolute the mapping data to obtain the properties of individual phases is also demonstrated. Fig. 3a shows the microstructure of a bond coat region of the TBC subjected to 5 thermal cycles. The bond coat has two phases: β-NiAl and γ/γ'-Ni matrix. The corresponding property map (in this case hardness map) obtained from 3750 indents with 1μm spacing is shown in Fig. 3b. Excellent correlation exists between the microstructure and the hardness map with the beta phase showing higher hardness compared to the gamma matrix. Small regions of oxides with very high hardness can also be observed.

In addition to generating property maps, the properties of the individual phases can be algorithmically extracted from which the phase maps of mechanical properties can be generated as shown in Fig. 3c. The distinguishing feature of this technique unlike standard deconvolution methods like Gaussian deconvolution, is the retention of the spatial information as shown in Fig. 3c. Furthermore, the mean and standard deviation of all the constituent phases can be easily determined. Given the applicability of this technique for a complex material system such as TBC, this technique has the potential to provide critical quantitative insights on local mechanical properties that can serve as an important link for materials development using an integrated computational materials engineering (ICME) approach.



Fig, 3 (a) SEM micrograph and (b) hardness map of NiCoCrAlY bond coat subjected to 5 thermal cycles. (c) Reconstructed mechanical phase map based on deconvolution showing different phases/features

Development of refractory metal-based coatings using cold spray for high temperature wear application

Cold spray technology involves deposition of coatings by high velocity particle impact onto a substrate. Unlike the other thermal spray variants, the thermal energy input in cold spray is very minimal making it the primary choice for depositing coatings for applications that require retention of properties of feedstock such as electrical conductivity that is sensitive to oxidation during deposition. In this regard, refractory metal coatings by cold spray has attracted widespread attention for a variety of applications that require a combination of conductivity and wear resistance. Electromagnetic rail gun with capabilities of launching projectiles of few km/sec velocity is a specific application wherein refractory metal coatings are used. ARCI has successfully developed coatings with several combinations such as Cu-W, Cu-Mo and Cu-Ta in pursuit of developing coatings with high electrical conductivity and superior wear(seizure) resistance. Cu-W and Cu-Mo coatings have shown superior wear resistance in comparison to Cu-Ta. After preliminary R&D trials, coatings on 4 m long rails were successfully deposited for the end user (Fig. 4). Further investigations to deposit coatings with Cu coated W & Mo powder instead of blended powders is underway.

Development of thermal barrier coating (TBC) using EBPVD on CMS-4 (single crystal blade) test coupon for gas turbine applications

The coating formation mechanism in EBPVD process involves accelerating the thermal electrons in an electron gun under high voltages leading to vaporization of ingot material and eventual condensation on the substrate. Compared to other vapour-based methods, EBPVD

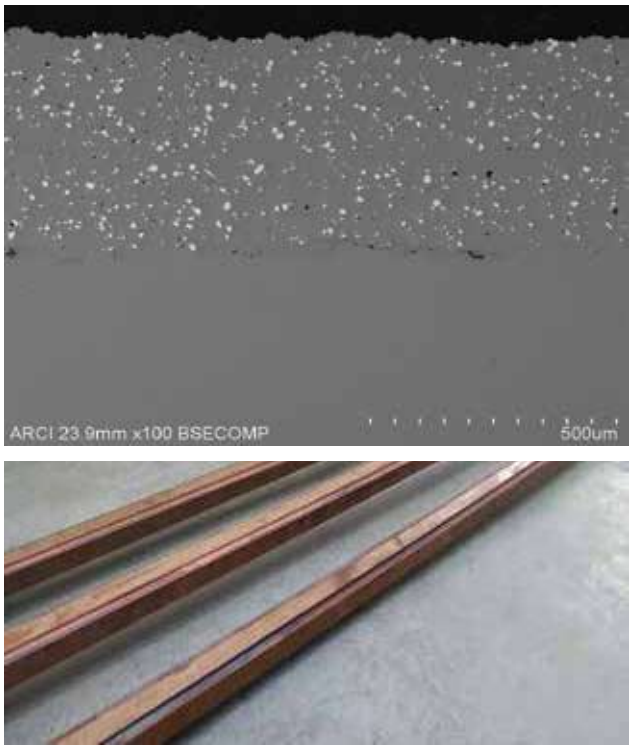


Fig. 4 (a) Cross-section of cold sprayed Cu-W coating and (b) Cu-W and Cu-Mo coatings on 4 m long rails

has many distinct characteristic advantages namely (a) higher deposition rate, (b) strong substrate-coating adhesion, (c) smoother surface finish and (d) columnar structure with controlled porosity. Towards capitalizing such advantages that are vitally useful for developing TBCs, focussed R&D studies were conducted on single crystal blade (CMS-4) test coupon.

Initially, the process parameters were optimized to deposit NiCoCrAlY bond coat of 40-60 µm thickness on CMSX-4 substrate followed by 160-180µm thick columnar YSZ coatings through EBPVD. By careful selection of process parameters and by process optimization, uniformity in the coating thickness and good bonding between bond coat and top coat even on the curved sections was ensured across multiple batches of coating. A customized multiple sample holder was designed and used for this purpose. Microstructural analysis of the coatings (Fig. 5) shows good columnar growth, uniformity in thickness of bond coat and top coat that are the critical requirements of TBCs. The high temperature oxidation resistance and the thermal shock performance are being assessed through thermal cycling tests at elevated temperatures. The successful development of such TBCs on this substrate is expected to pave the way for its deployment on gas turbine components.

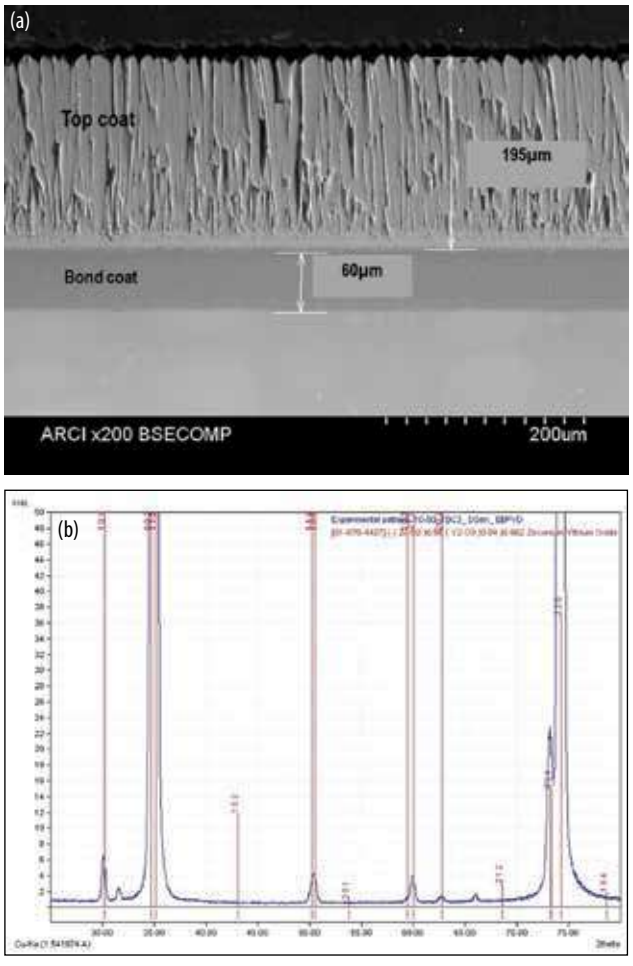


Fig. 5 (a) Cross-sectional micrograph of TBC coating on CMS-4 test coupon and (b) XRD pattern of the top coat

Development of advanced detonation spray system

Detonation spray coating is a well-established thermal spray technique for depositing a wide range of coatings for superior tribological performance. Productivity of traditional DSC system is not on par with the competing continuous coating alternatives due to limited operational frequencies (~ 3 Hz) and moving mechanical parts. Towards this end, a computer-controlled advanced DSC system shown in Fig. 6, which can operate at double the usual frequency (6 Hz) and provide precise gas flow control using solenoid and mass flow controllers has been developed.

In addition, many moving mechanical parts used in the traditional DSC system have been eliminated in the advanced detonation spray system. The new PLC based controller also enables operation at higher powder feed rates and improves the overall ease of use resulting in higher productivity and higher deposition efficiencies. Process parameter optimization studies were carried out to deposit cermet and ceramic coatings using the advanced system at higher frequencies. Dense coatings with good interface bonding were obtained. Deposition efficiency of more than 30% was obtained for carbide coatings and more than 40% for ceramic coatings. The high deposition efficiency at 6 Hz was achieved by precisely controlling the powder feed during coating deposition. Identical or improved wear resistance was observed for coatings deposited at 6Hz in comparison to 3Hz. Furthermore, the performance of coatings deposited using computer controlled detonation spray system is very similar to the coatings deposited by traditional detonation spray system.

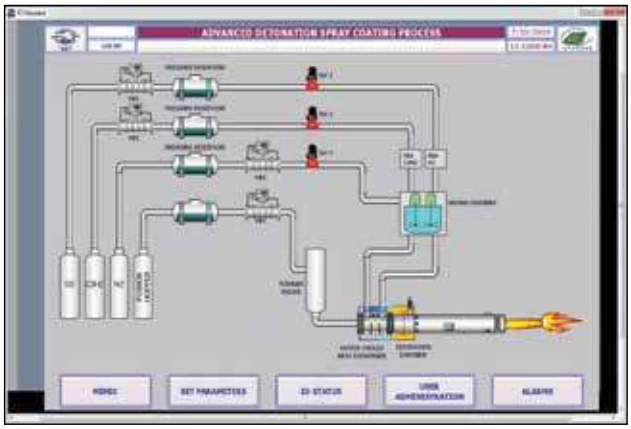


Fig. 6 Process control panel - ADSC Mimic

Compositionally modulated coatings using Pulsed Electrodeposition Technique

Conventionally, coatings are developed to meet the specific requirement of an application such as resistance to corrosion, wear, erosion, high temperature etc. However, a single coating may not be capable of cater to

the multiple requirements of a given service environment, wherein several degradation mechanisms synergistically act. This forms the basis for the need for multi-functional coatings. The pulsed electrodeposition facility at CEC is an ideal choice for depositing multi-layered coatings, wherein it is possible to achieve fine modulations in the layer thickness and composition in a very economical way when compared to other sophisticated techniques such as PVD and CVD. In addition, electrodeposition being a low temperature process, has a clear advantage in deposition of multilayers with layer thickness in the nano-regime where the high temperature processes fail due to the inter-diffusion between the adjacent layers. In this regard, compositionally modulated Ni-W multilayer coatings with each layer having different W-content as shown in Fig.7, have been developed. This process does not have a limitation in terms of the number of layers, thickness of individual layer or the composition of individual layer deposited. These coatings demonstrate excellent hardness, wear and corrosion resistance when compared to their monolithic counterparts.

Development of lanthanum cerate based thermal barrier coatings (TBC) with enhanced resistance to ingestion by volcanic ash particles

Yttria stabilized zirconia (YSZ) is widely used as a TBC top coat to protect various gas turbine components. However, for increased service temperature and there by higher operational efficiency and resistance to infiltration of glassy deposits composed of calcium-magnesium-alumino-silicate (CMAS), fluorite based $La_2Ce_2O_7$ (LC) ceramics are considered along with doped rare earth oxides. Spray grade LC and $Gd_2O_3/Y_2O_3/Yb_2O_3$ doped LC powders were synthesized through solid state reaction which were crushed and sieved to subsequently deposit coatings using atmospheric plasma spray (APS). Cross-sectional microstructural images of coatings show typical lamellar structure with considerable amount of porosity (between ~15-20 %).

Thermochemical interaction studies of LC, doped LC and YSZ coatings with volcanic ash (VA) were carried out for 1, 8 and 24 h at 1150°C and 1250°C on free-standing films. VA reacts to form dense layer of $Ca_2(La_xCe_{1-x})_8(SiO_4)_6O_{6-4x}$ apatite phase which prevent further infiltration. Examination of arrested layer revealed globular and rod-shaped crystal features corresponding to $Ca_2(La_xCe_{1-x})_8(SiO_4)_6O_{6-4x}$, anorthite $CaAl_2Si_2O_8$ and spinel $MgAl_2O_4$. For doped LC, the layer is composed of $Ca_2(La_xCe_{1-x})_8(SiO_4)_6O_{6-4x}$, $Ca_2RE_8(SiO_4)_6O_2$ along with $CaAl_2Si_2O_8$ and spinel. Destabilization of t'-ZrO_2 in YSZ coatings due to Zr/Y migration into VA resulted in deeper infiltration depth of 430µm at 1150°C itself and complete infiltration at 1250°C within 8 hours. Comparative performance of LCs can be seen in Fig 8, which shows that Y-rich compounds exhibit higher resistance to VA infiltration, followed by Yb-LC and Gd-LC.

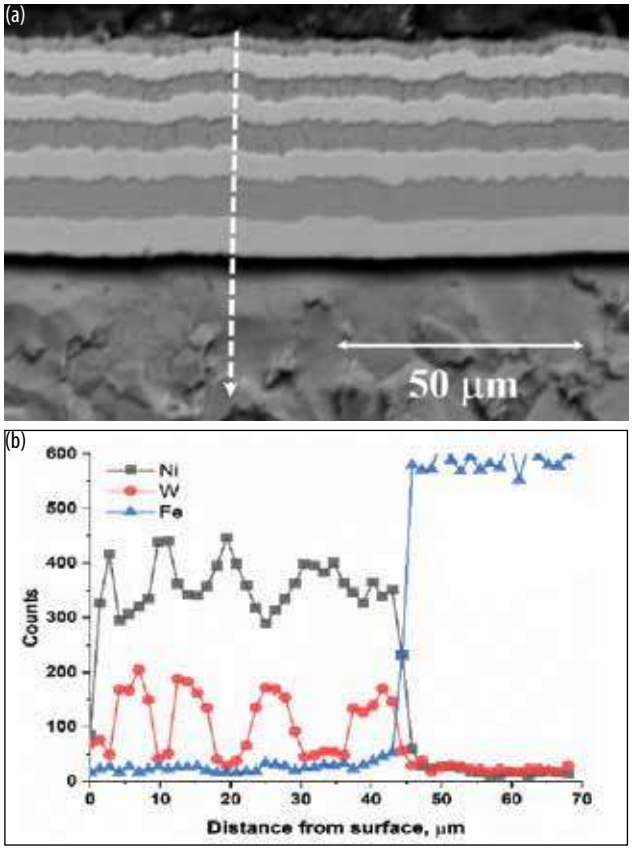


Fig. 7 (a) Cross-section of a Ni-W multilayer coating and (b) composition of individual layer

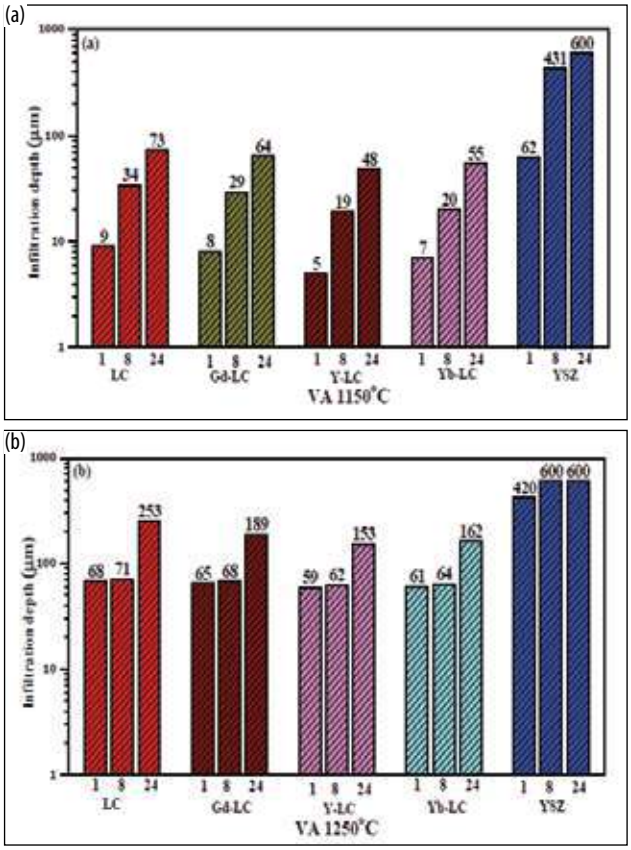


Fig. 8 Comparison of VA infiltration depth of different coatings (a) 1150°C and (b) 1250°C

Centre for Ceramic Processing

Centre for Ceramic Processing with its objective to develop novel ceramic materials and innovative processing techniques continue to extend the boundaries of the existing technologies through up-gradation of properties, in-addition to venturing into a few new areas during the past one year. Complex shaping of advanced ceramics though advanced processing being the core strength of the center 3D extrusion printing capability using variety of ceramics such as alumina (Al_2O_3), spinel ($MgAl_2O_4$) and cordierite ($Mg_2Al_4Si_5O_{18}$) has been recently established using an indigenous facility. In order to address the environmental challenges caused by the used sanitary napkin the center has been providing the technical support for ARCI- CSIR-NEERI- Sowbal Aerothemics developed environmentally friendly sanitary napkin incinerator leading to the installations at several places across the country.

Apart from fulfilling the commitments of sponsored programmes on transparent ceramics including limited production and supply, the centre has geared up to take up a consortium programme in the new area of the development of low expanding glass ceramics. In addition to the strategic sector initiatives are also underway to set up a pilot scale facility for 5 kW SOFC in collaboration with CSIR-CGCRI, Kolkata. Centre has executed several job orders such as supply of porous magnesia discs and protypes of Sodium beta alumina one end closed tubes demonstrating the technologies developed for various users.

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Aqueous Sol-Gel Synthesis of Submicron Aluminum Oxynitride Powder

luminum oxynitride (ALON) powders were synthesized through a cost effective, facile aqueous sol-gel processing procedure. 30 – 35 mol% of Aluminum Nitride (AlN) powder and aqueous boehmite sol were mixed to obtain molecular stoichiometry of AlON. In this process, the AlN deteriorated into its hydrated compounds in the aqueous sol due to its intrinsic hydrolysis tendency and hindered AlON formation. Hydrolysis of AlN in the aqueous sol-gel medium was circumvented by subjecting AlN to a surface modification process. The homogeneously dispersed Al_2O_3 sol and AlN mixture was further gelled dried, and heat treated at temperatures between 1600°C and 1850°C for the formation of AlON powder. AlON phase formation was confirmed through XRD investigations, and its physical and microstructural properties were also evaluated through FESEM and TEM analyses. Through this process, AlON powder with an average particle size of 490nm was successfully synthesized. This process is suitable for producing AlON powder in bulk quantities, and it can be used readily for further processes such as shaping and sintering to produce various optical AlON products such as such as bullet proof armors and IR windows and domes etc. Fig1. a & b depict the morphology and the formation of the desired phase by SEM and powder XRD results respectively.

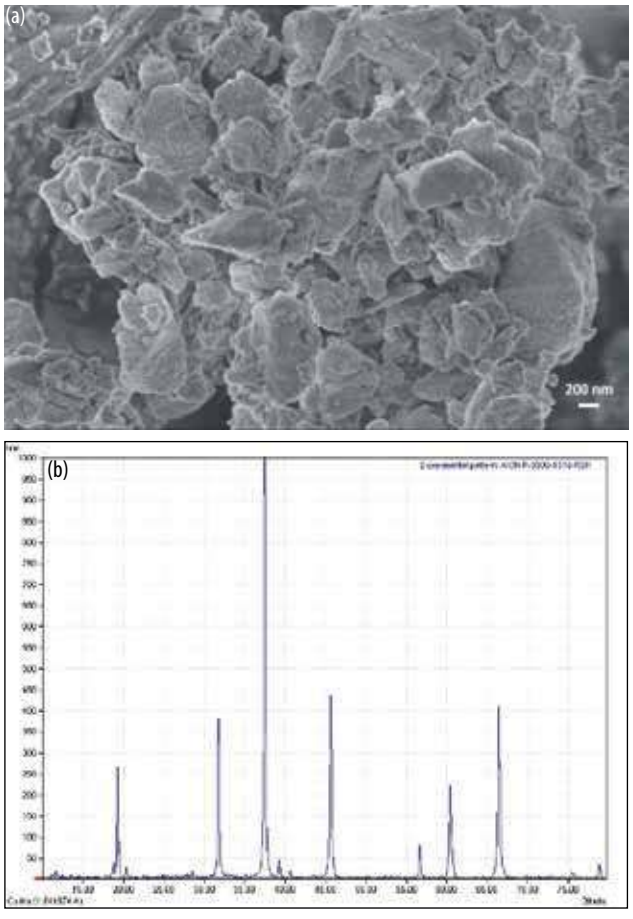


Fig. 1 (a) Morphology of sub-micron AlON powder synthesized through aqueous sol-gel route (b) AlON phase formation as seen through XRD

Porous 8YSZ with low thermal conductivity for improved service life of metal tubes

Zirconia (ZrO_2) has one of the lowest thermal conductivities in a ceramic, is widely used as thermal insulator at elevated temperatures. One such application of yttria-stabilized zirconia (8YSZ) is thermal insulation, which is used to carry the heat and to protect the outer sleeve from high temperatures, thereby improving the service life of the outer sleeves. In the present study, 8YSZ is used to develop 50% porous sleeves with sufficient mechanical strength and thermal conductivity less than 1 W/m-K. The average particle size of the powder is 270 nm with highly stable cubic structure. A technical scheme has been adapted, which starts with the study of critical binder volume concentration with respect to powder, paste rheology and solid loading and concentration of the pore former material. The raw mix of 8YSZ powder, binder and optimized concentration of graphite pore-former was dry milled for 6 hr to achieve the homogeneity and made into dough with water as an aqueous media using kneader and finally aged for 24 hr. The resultant dough is extruded into sleeves using indigenously designed and fabricated die. The extruded and dried sleeves were sintered with optimized sintering schedule to achieve the porosity of 50% in the final product, which can be observed through the SEM scan shown in Figure 2 (a). The flexural strength of 70 MPa by three point bend test method and thermal conductivity of 0.7 W/m-K due to scattering of phonons by oxygen vacancies and by the hopping of oxygen vacancies in 8YSZ by laser flash technique method were achieved in 50% porous sleeves.

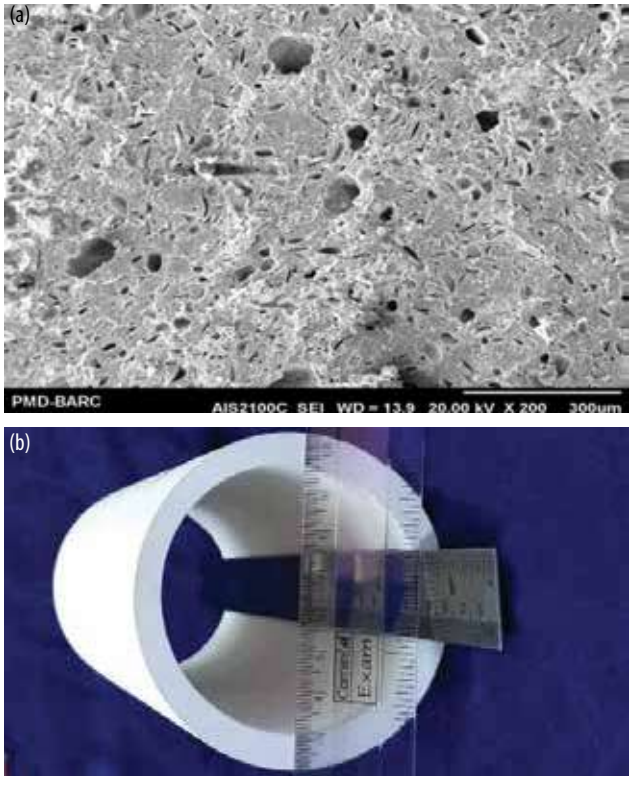


Fig. 2 (a) SEM image & (b) Sintered 8YSZ tube of dimensions Dia 80 x L 225 mm with 50% porosity

The extruded tube of 225 mm length with 80 mm dia., is shown in the Figure 2(b).

3D Printing of Alumina Ceramics

3D printing of ceramics is now gaining interest due to the unlimited flexibility in shaping and also by the virtue of the complex shaping capability with micro-features. For 3D printing of ceramics, homogenization of powder formulation and processing of the powder to the printable consistent paste with a shear thinning behavior is very critical. As the 3D printing proceeds based on the virtual design which will tailor nozzle path for printing, the paste should consistently flow under pressure and retain its shape after printing. In the current study, commercially available α-alumina powder (Rohini Industries, Pune, India) with average particle size of 331 nm was made into a printable paste using methylcellulose (binder) and poly ethylene glycol (plasticizer) in water medium. The paste has shown a shear thinning behavior with viscosity of 4 Pa.s at 100 s^{-1} shear rate with a shear rate exponent of 0.74. The paste was printed using a ram type 3D printer with 1 mm nozzle and printing speed of 6 mm/min. Printing speed beyond 6 mm/min results in overflow of the paste, hence, component layer deform beyond tolerance and a rate below 6 mm/min extends printing time and accordingly loss of moisture and inhomogeneities in layers. Samples were dried and were pressureless sintered (PLS) at 1650°C for 1 hr. Additionally, a few 3D printed green specimens were vacuum encapsulated and hot isostatically pressed (HIPed) at 1350°C and 1650 bar and further compared with PLS samples. PLS samples have shown a density of 3.86 g/cc against the HIPed samples exhibiting density of 3.94 g/cc even at 1350°C. PLS sintered samples are shown in Fig. 3(a). Deformed CAN after HIPing and HIPed sample are shown as Fig. 3(b). X-ray radiography of the HIPed sample (Fig. 3(b)) have exhibited removal of defects under the simultaneous application of temperature and pressure. Further, HIPed and PLS samples have shown Vickers hardness of 18 GPa and 15 GPa respectively.

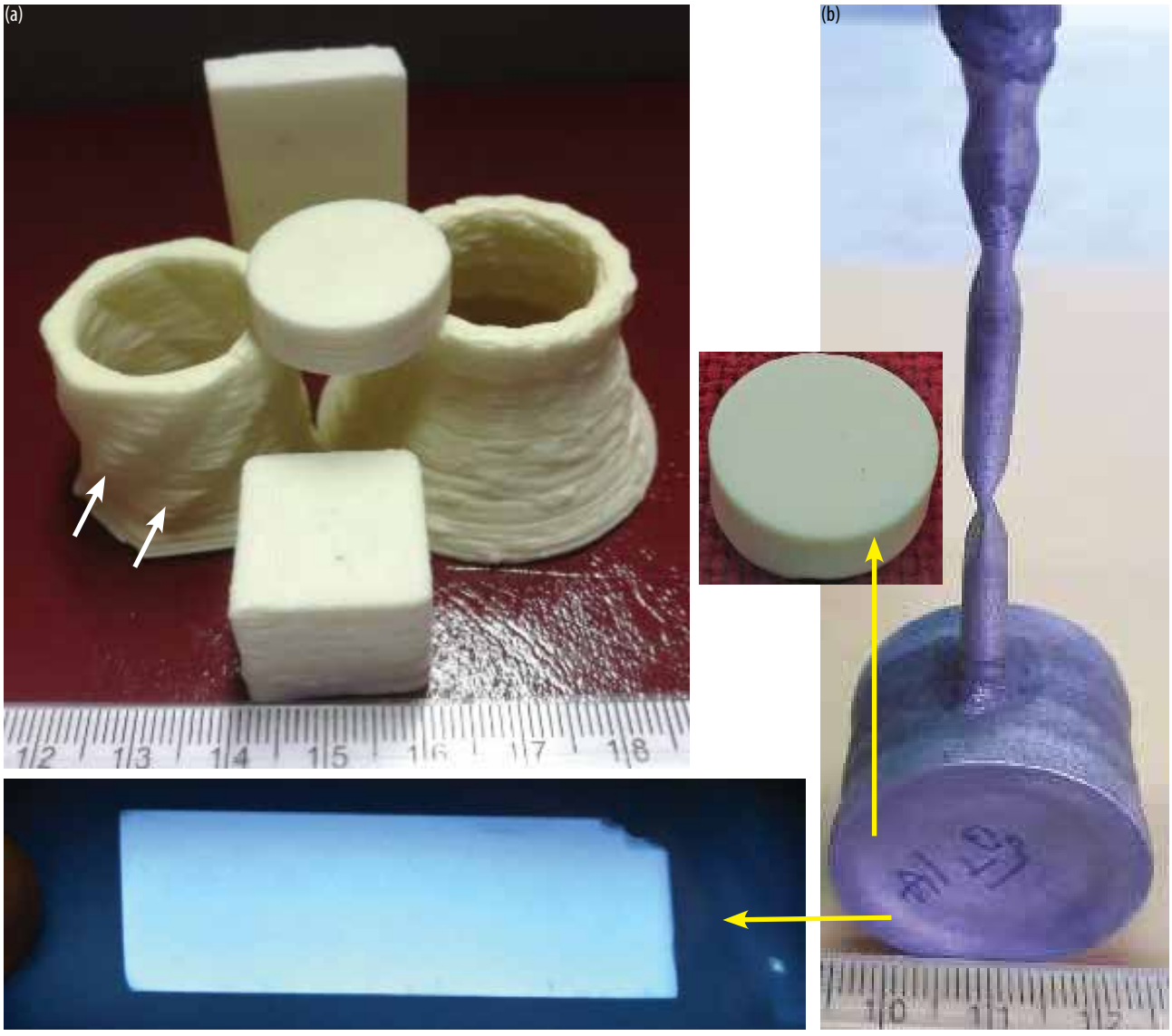


Fig. 3 (a) 3D printed PLS sintered samples, (b) Deformed CAN, HIPed sample along with X-ray radiography

Centre for Laser Processing of Materials

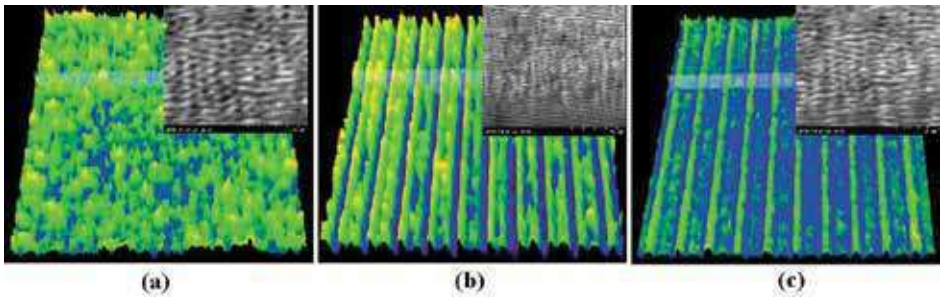
Laser, a high intensity, precise, flexible and clean heat source is used as a manufacturing tool in several industrial sectors. With the advent of more robust, energy efficient, cheaper and low footprint lasers such as fiber lasers, laser based manufacturing is increasing rapidly. The Centre for Laser Processing of Materials (CLPM) at ARCI, established about 20 years ago has been carrying out R&D on several processes for application in industry. The centre has been conducting R&D in the areas of additive manufacturing, micro-processing, surface engineering, repair & refurbishment, materials joining and drilling with the help of an array of laser processing systems available at the centre.

Several applications were attempted using laser based additive manufacturing during the last year, such as (a) Nozzle guided vane (NGV), (b) Core pin for Pressure die casting (PDC) with conformal cooling channel and (c) Metallic Bipolar Plate for PEM fuel cell.

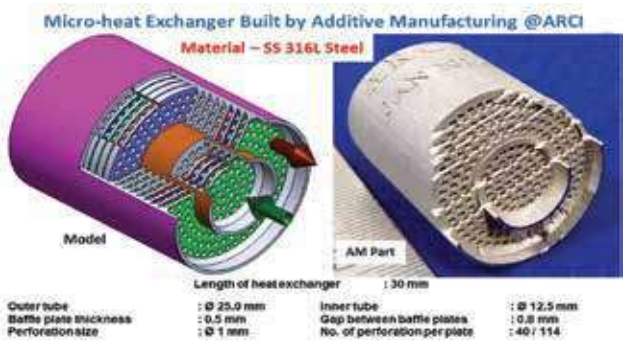
Major projects in the area of laser surface texturing of automotive components and multifunctional surfaces using ultrafast laser have been pursued. In the area of laser hardening, substantial effort has been put on development of novel and innovative methods of hardening bearing components for increased capacity and performance. Laser clad deposition technology was demonstrated for repair of aerospace components. Feasibility of dissimilar material joining of Titanium and Aluminium Alloys has been pursued.

One of the major initiative of the centre is participating in the "National Centre for Development of Advanced Materials and Manufacturing Processes for Clean Coal Technologies for Power Applications" project; which includes: Laser Clad protective Coatings for various components exposed to hostile environments namely, fire-side corrosion, steam-side oxidation, ash particulate erosion, combined erosion-corrosion, laser based welding techniques for joining pipes and tubes with sections, weld overlays, joining of dissimilar materials, with high speeds and better weldment creep and fatigue resistance, and laser assisted machining of AUSC components.

Highlights of the same are presented in the following sections.



Surface topography of laser modified surfaces and inset SEM of laser induced periodic surface structure (LIPSS)



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Additive Manufacturing

a) Nozzle guided vane

In an attempt to demonstrate the capability of additive manufacturing (AM) applications in aerospace industry, Nozzle Guided Vane (NGV) a vital part of aeroengine, is chosen. NGV with patterns of holes, is being manufactured by investment casting followed by machining and laser drilling, which involves high lead time and cost. Manufacturing NGV along with holes by AM from metal powder, has eliminated different manufacturing process involved and there by reduced the lead time. The 3D model of NGV is shown in Figure 1a, with patterns of 300 holes of 1 mm diameter and oriented in different angle. The AM build orientation was chosen to achieve minimum support structure with design modification of internal stiffeners with self-supporting design using Inconel 718 alloy powder in 72 h. The NGV built (shown in Figure 1) by AM showed very good as built surface quality (Ra= 6 µm), minimum distortion and allowed dimensions' tolerances. AM built Inconel 718 alloy properties and post heat treatment procedure are optimized and established in preliminary studies.

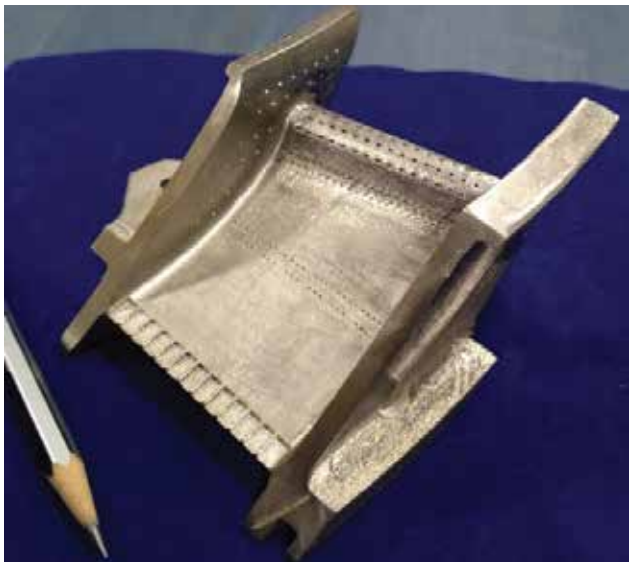


Fig. 1 Photograph showing NGV built by additive manufacturing

b) Core pin for Pressure die casting (PDC) with conformal cooling channel

PDC tools with efficient cooling channel has been challenge to manufacture by conventional processes. Efficient cooling channel design in terms of conformal channels can be realized using metal additive manufacturing process. In this regard, core pin of 200 mm length and varying diameter across the length as shown in Figure 2(a) has been selected to build by additive manufacturing using AISI H13 tool steel material. Corepin design has been modified with conformal cooling channel (Shown in Figure 2(a)) of diameter 2.5 mm without overhang features to eliminate internal support structures. AISI H13 tool steel alloy powder suitable for AM process was procured from third party source and optimized AM process parameter to achieve defect free dense part. AISI H13 being hardenable alloy with carbide precipitates is sensitive to rapid solidification of AM process and post heat treatment. Hence, optimization of post heat treatment has been carried out to achieve the desired microstructure and required hardness and toughness in AM manufactured part. Four core pins were manufactured (Figure 2(b)) AM facility at ARCI using AISI H13 tool steel alloy powder and post processes in terms of surface finish, heat treatment and final machining and delivered for part validation in actual PDC process at industry.

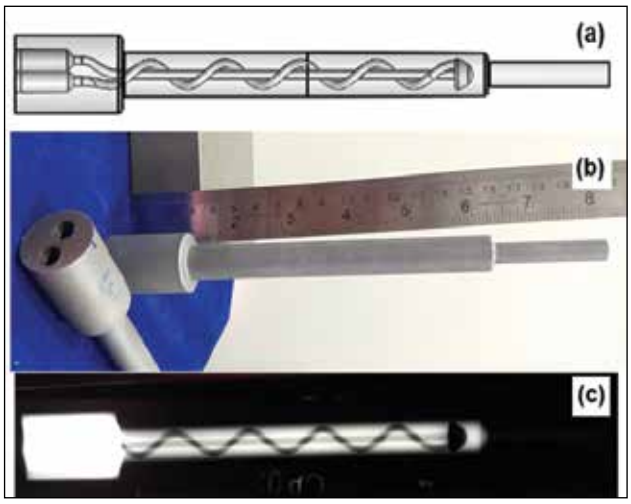


Fig. 2 PDC core with conformal cooling channel showing (a) 3D model (b) Core pin built by AM and (c) X-ray radiography

c) Metallic Bipolar Plate for PEM fuel cells

Metallic bipolar plate (MBP) was identified as one of the potential components for metal additive manufacturing technology, considering the challenges in manufacturing non-magnetic austenitic stainless steel by machining to achieve the intricate flow patterns in thin section. To exploit the maximum benefit of additive manufacturing, design of MBP was modified for part integration in collaboration with CFCT, so as to accommodate the flow channel (400 µm) pattern of oxygen, hydrogen and water in single plate of thickness 2 mm. This design eliminates the number of manufacturing process involved to achieve required pattern combination. The modified design of MBP was manufactured by metal additive manufacturing using SLM 280HL machine at ARCI. Part orientation and support structure have been optimized for build time and distortion. Twelve MBPs were built by additive manufacturing with as-built surface roughness of 8 - 9 µm Ra, which is latter improved to 4 - 5 µm Ra by shot blasting process and delivered to CFCT - ARCI for validation (Figure 3(d)) in real time application.

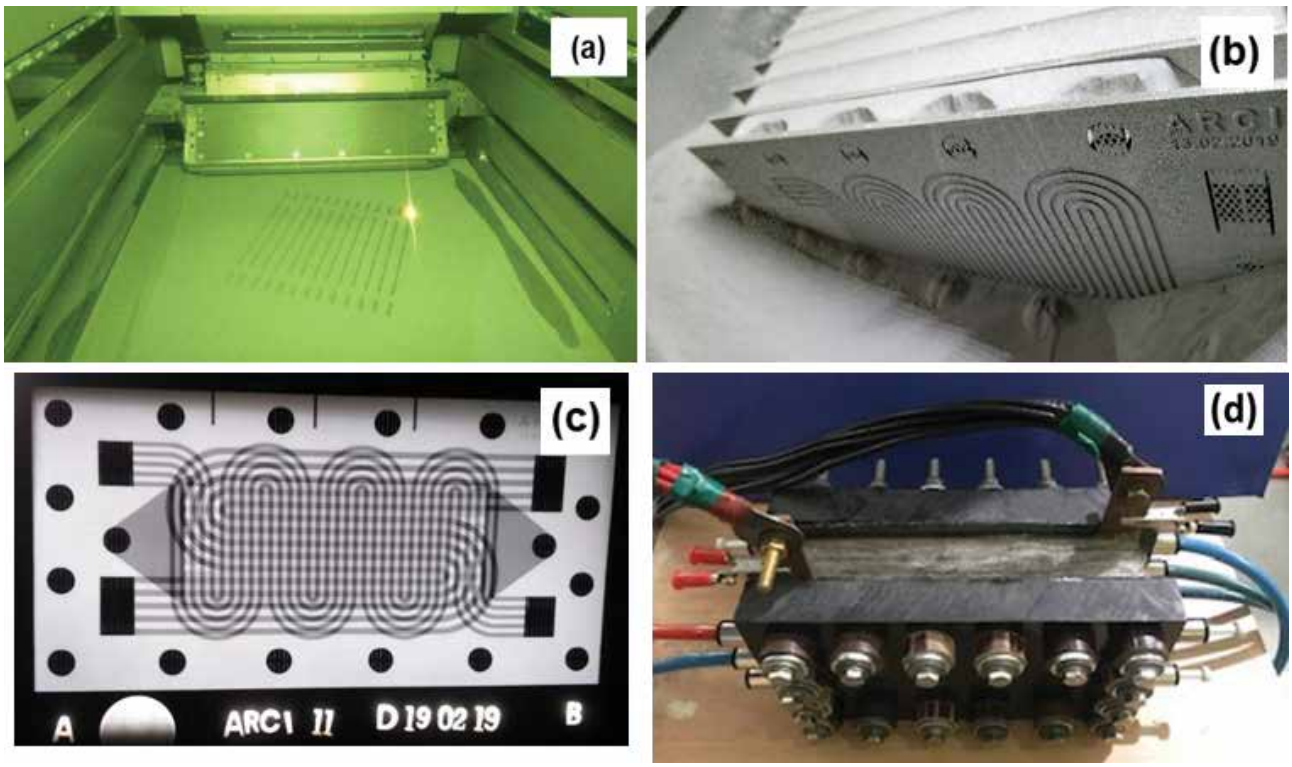


Fig. 3 Photographs showing (a) Process of additive manufacturing (AM) of MBP, (b) AM built plates, (c) X-ray radiography image of MBP and (d) stack of fuel cell with AM built MBP

Tribological behavior of surface textured gray cast iron by ultrafast laser

Laser surface texturing process involves the creation of microfeatures e.g., tiny dimples, usually distributed in a certain pattern, covering only a fraction of the surface of the material that is being treated. This process offers several advantages for tribological applications, including improved load capacity, wear resistance, lubrication lifetime, and reduced friction coefficient. In the present study, surface modification of Gray Cast Iron, using femtosecond Laser irradiation, is adopted in order to establish an optimal geometric pattern with dimple features and dimensions, to improve wear and friction behavior. The surface texturing of Gray cast iron was done with the help of 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 wear tests under starved lubrication condition were performed using ball-on-disk tribometer. The textured surfaces cause a significant reduction in friction coefficient (by 72%) and wear (by 19%) over the un-textured surfaces. Further, an analysis of wear tracks using SEM and EDAX show a significant improvement in wear resistance. The wear track of textured surface exhibited a significant reduction of wear debris and was found to be smoother than the un-textured surface. Among various patterns tried, the

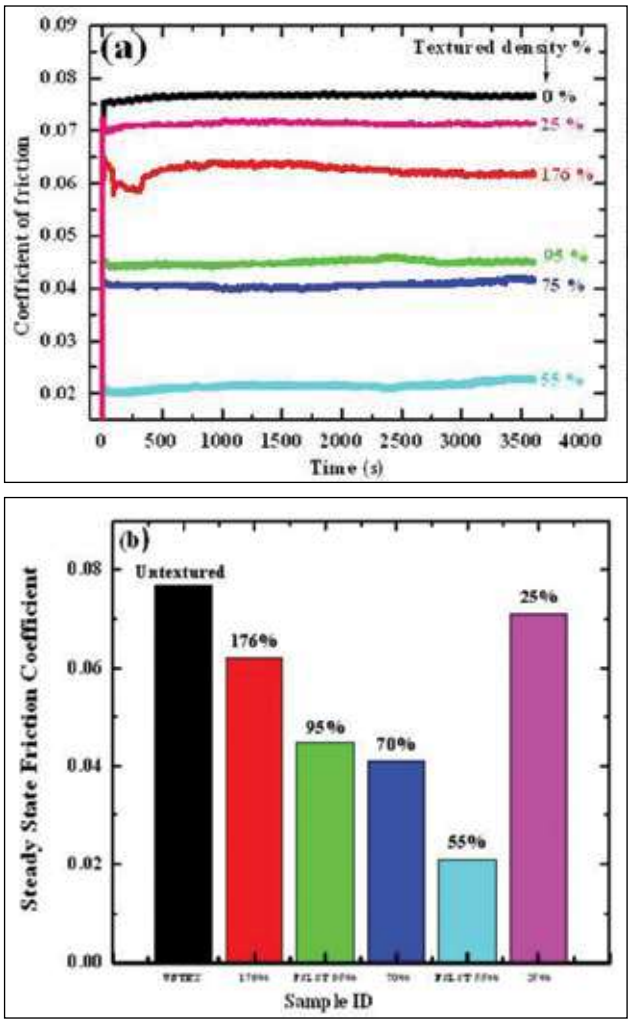


Fig. 4 Ball-on-disk test: (a) coefficient of friction vs time and (b) steady-state friction coefficient for untextured and textured samples

pattern with 55 % texture density gave the best results (see Fig). The approach could be adopted to reduce friction losses in internal combustion engine.

Fabrication of superhydrophobic surfaces on stainless steel by femtosecond laser micro-processing

Ultrafast laser processing has emerged as an important tool for micro and nano-scale fabrications. It is also used to create self-organized microstructures with nanoscale features on surfaces. Fabrication of superhydrophobic surfaces induced by femtosecond laser have many applications that include anti-corrosion, self-cleaning, and drag reduction. Hydrophobic surfaces on stainless steel AISI 304 surfaces were created by producing a hierarchical nano/micro structures with ultrafast laser ablation. Periodic nano/micro structures with different topographies were fabricated using femtosecond laser with pulse duration of 100 fs and wavelength of 800 nm. Ablation was performed in open air with no subsequent treatment. In this study, a three-level Box-Behnken design of response surface method was used to investigate and optimize the process parameters. The structures were examined using scanning electron microscope and opto-digital 3D microscope. The wetting of surfaces was measured in terms of contact angle of a water droplet using digitized goniometer. The contact angle of laser modified surfaces changed from a hydrophilic behavior to a hydrophobic. The effect of pulse energy was found to be significant. Average pulse energy range of 0.035-0.05 mJ at 10000 Hz with scanning speed 10-100 mm/s and line separation of 10-30 µm produced hydrophobic surfaces with an apparent contact angle of 110-1350 (Fig.). A simple way has been demonstrated to tune hydrophobicity using femtosecond laser surface modification in a single step with no subsequent post treatment.

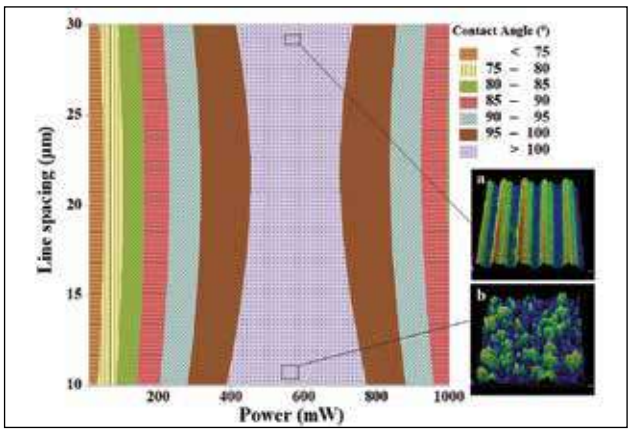


Fig. 5 Contour plot of contact angle versus line spacing and power. Inset shows (a) micro-grooved structure at higher line spacing and (b) pillar structure at lower line spacing

Dissimilar material joining of Titanium and Aluminium Alloys

In several areas of the civil, military transportation and aircraft industry, use of lightened hybrid structures of titanium and aluminum alloys is growing significantly for example in fuselage areas, seat tracks of aircraft body. Currently, joining of dissimilar materials is achieved by riveting, clinching & fastening processes. However, thermal fusion joining of dissimilar combination remains a difficult because of mismatch in thermo-physical properties, limited mutual solubility and formation of intermetallic phases in aluminium-titanium (Al-Ti) system. However, formation of brittle intermetallic phases can be minimized with low heat input processes like energy reduced arc techniques (CMT Weld Brazing, Cold Arc), laser weld Brazing etc. Heat input in these processes is precisely controlled such that only the aluminium base material and filler material melts and wets the unmelted titanium sheet to form a braze like joint. This open new joining possibility with high productivity. Experiment were undertaken

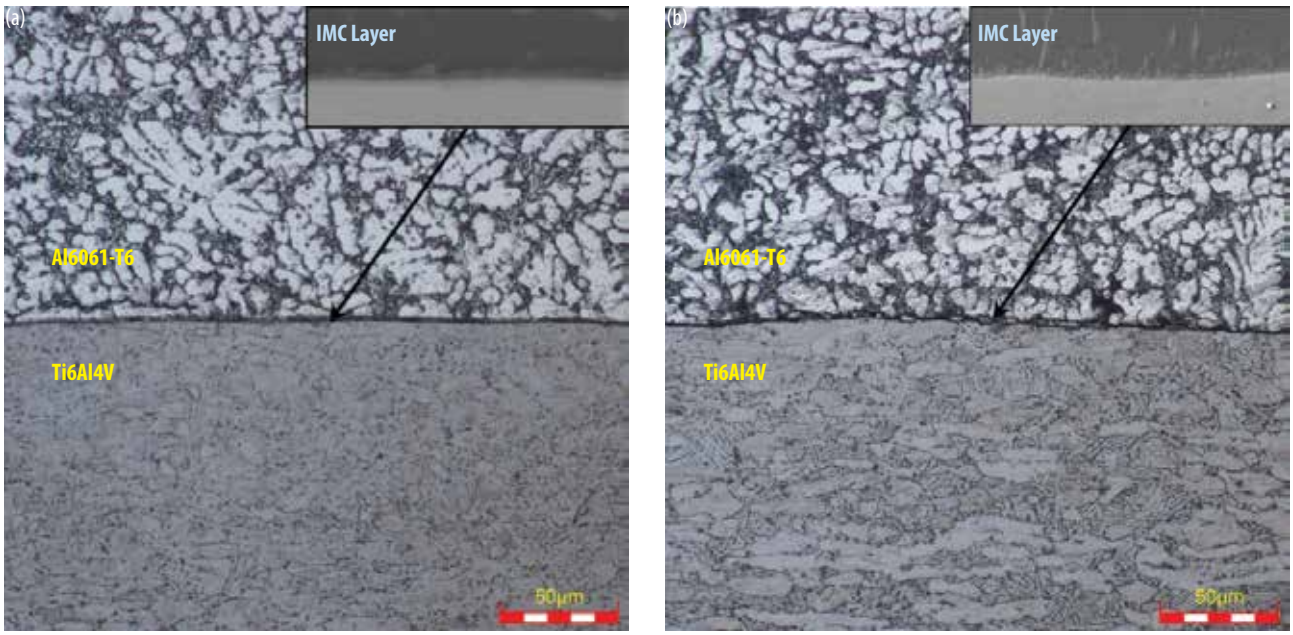


Fig. 6 (a) CMT weld brazed microstructure (b) Laser weld brazed microstructure

to join aluminium AA6061 T6 (2 mm thick) to titanium Ti6Al4V sheets (4 mm thick). 1.2mm diameter filler wire of aluminium AA 4047 (Al12%Si) were used.

Robotic integrated Cold Metal Transfer and diode laser brazing processes were investigated. Cross-sectional microstructures are shown in figure. In both the processes, the intermetallic layer thickness is limited to much below 10 µm, which is known to be an upper limit to have a good joint. Morphology of IMC layer appears to be different for the two processes. IMC layer is smooth in case of CMT weld brazed specimens, while in case of laser weld brazed specimens, some needles nucleated in the Aluminium side. EDX analysis of the IMC layers indicated presence of different intermetallic phases i.e., AlTi in case of CMT weld brazed specimen & Al_3Ti in case of laser brazed specimen. Further investigations into process development, detailed characterization of the seam morphology and evaluation of mechanical properties is under progress.

Laser surface hardening of automotive steels used in dumpers

A unique laser surface hardening treatment that enable to enhance life of steels has been developed by employing a robot-integrated fiber-coupled diode laser system. The feasibility study involved laser hardening on the surface of various low-carbon micro-alloyed steel sheets (thickness ranging from 5.0 mm – 8.0 mm) with different chemistries (Type-I (0.05%C+0.55%Mn); Type-II (0.13%C+1.6%Mn); Type-III (0.06%C+1.6%Mn). These steels commonly used in furnace-baked condition with strength varying between 500 – 800 MPa, 20 – 25% Elongation and 130-240 HV hardness. Improvement in surface hardness on these steels can help facilitate in enhancing abrasive and erosive wear resistance required for life improvement. A first attempt to surface harden these steels using diode laser with appropriate setup, modulated laser power control with process optimization showed improvement in hardness by 30% and 65% in Type-I and Type-II steels, whereas, Type-III steel did not yield any tangible improvement. The process developed for Type-I/Type-II steels is unique since so far no such hardening developments were reported on such low-carbon non-hardenable steels. Microstructures of laser-treated and untreated depicted in figure clearly illustrate hardness improvement achieved in these steels as evident from grain refinement and transformation of pearlite into bainite/martensite (top right corner inset shows micrograph of substrate steel). Nano-indentation analysis of these microstructures also showed 2.8-3.2GPa and 3.6-4.2GPa nano-hardness in bainite/martensite regions of Type-I and Type-II laser-treated steels as compared to untreated counterparts whose nano-hardness in pearlitic regions was 2.0 – 3.0GPa. Tribological performance of these laser treated surfaces were assessed

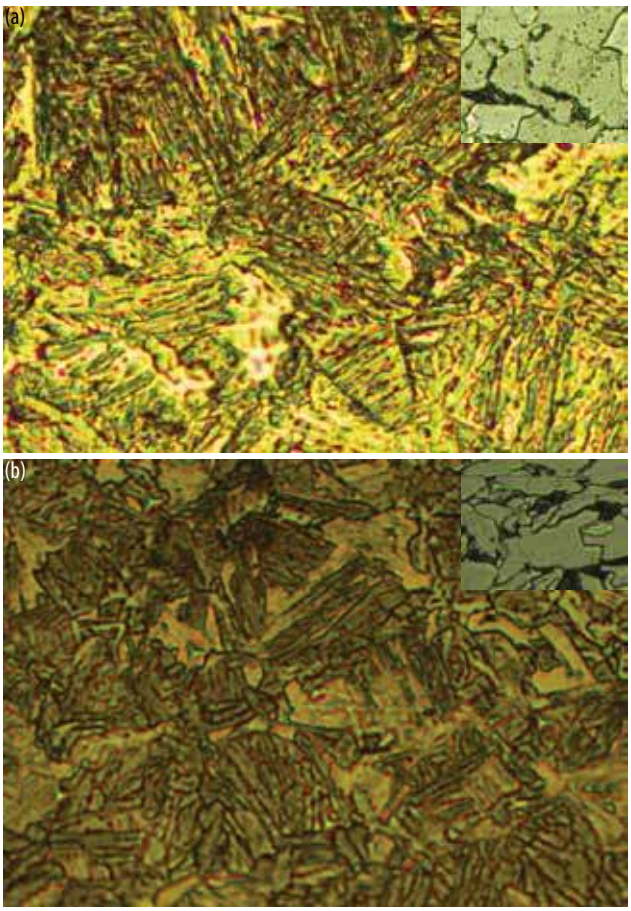


Fig. 7 Microstructures of laser-treated steels: (a) Type-I; (b) Type-II
(Inset shows microstructure of substrate)

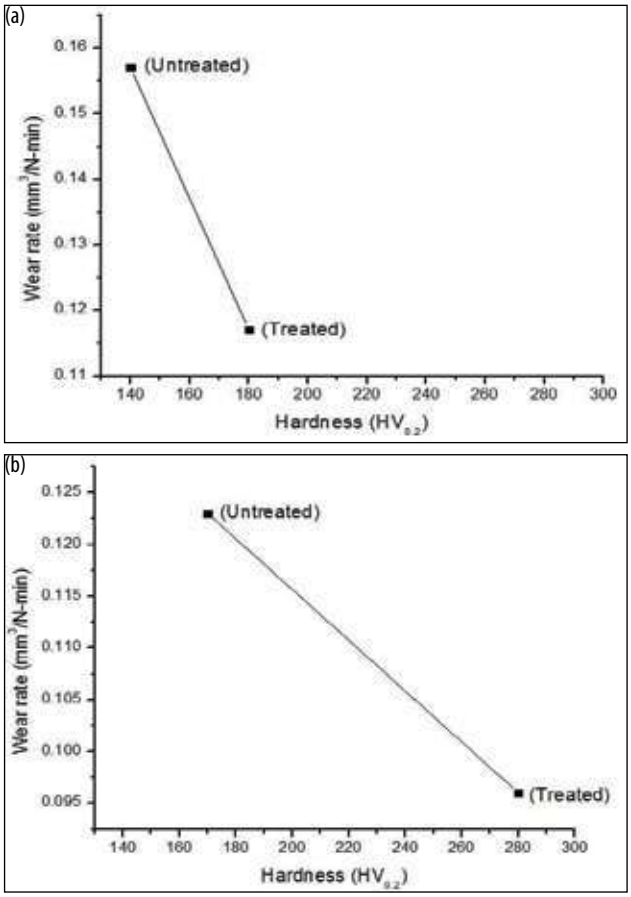


Fig. 8 Comparative abrasive wear performance of laser-treated and untreated steels
(a) Type I; (b) Type-II

and compared with untreated substrate counterparts by subjecting to laboratory scale abrasive wear testing as per ASTM-G65 standards. It is clear from the depicted figure that abrasive wear rate reduced by 30-35% in laser-treated steels as compared to untreated substrates owing to microstructural improvement observed in terms of hard bainite/martensite transformations from soft pearlite observed in untreated counterparts.

Novel method of laser surface hardening technology on a bearing racer for improvement in surface hardness with control in distortion and deformation

A novel laser surface hardening treatment on a conventionally hardened bearing racer (outer) with controlled heat input provide one such best solutions to enhance the life of the bearings with vast reduction in post-process machining requirements and costs. The novelty of the technology lies in enhancing the surface hardness by 25-35% (compared to that of conventionally hardened counterpart) with retention of core strength and negligible distortion (measured in terms of roughness and roundness) on 3-mm thick taper-roller bearing racer. Figure illustrates improvised fixture designed and fabricated to fix on a rotary table connected to 6+2 axis robotic workstation of the integrated diode laser system. As laser processing has to be done on the inside diameter of the outer racer, fixture has been designed such that complete external body of the outer racer will be in contact with fluid. The section thickness of the top-cover and the hollow depth of bottom cover (parts made of steel and coated with copper) were optimized to 5-mm and 30-mm that enabled sufficient encapsulation of fluid into the fixture for adequate heat sink effect to retain core properties. Improved laser pulsing conditions with specific design of fixturing setup exhibited vast advantages over other conventional continuous-mode processing methodologies. Radial measurements performed on the inner side (treated side) of the outer racer utilizing CMM and depicted in Figure indicated 40-45 μ m in as-received racer as against 615-620 μm in Continuous-Wave processed one without fluid contact. The pulsed-wave (PW) processing methodology under optimized conditions under fluid (UF) contact showed minimal distortion with roundness being observed in the range of 60-70 μm only. This could be attributed to the factors such as controlled heating rate, higher cooling rate and thermal diffusion associated with the processing condition and setup. Apparently, maximum cooling rate in PW-UF condition induced lesser deviations in the profiles with maximum hardness in treated layer with roundness almost equivalent to the as-received condition. The technology developed for laser treatment of bearing racers is ready for actual testing and use in industry.

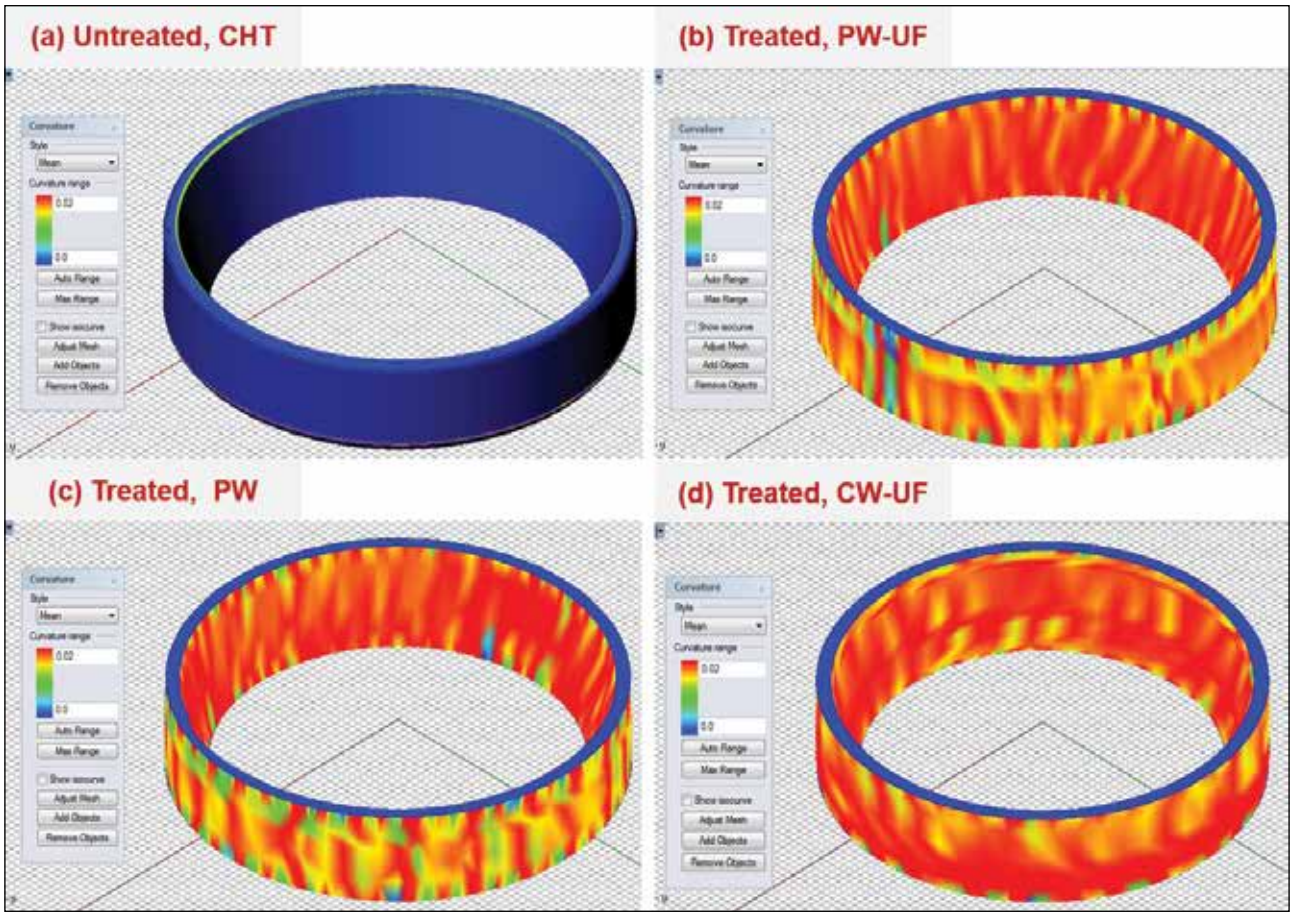
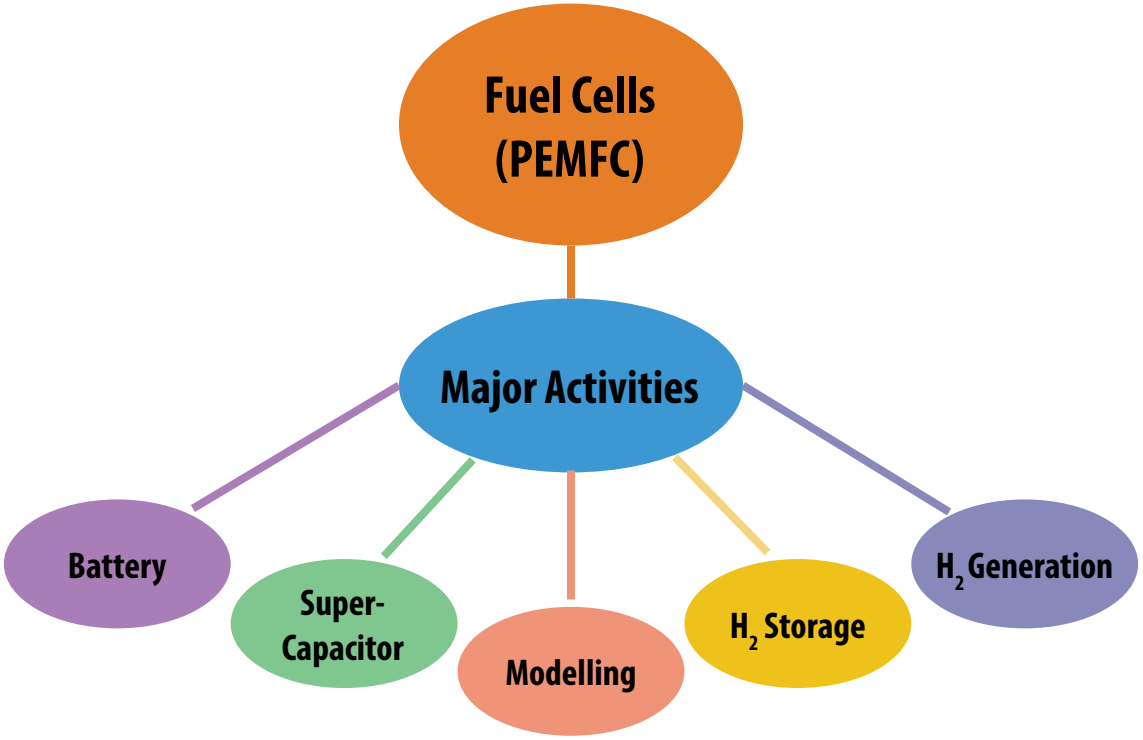


Fig. 9 Radial measurements performed on the inner side (treated side) of the outer racer utilizing CMM are depicted

Centre for Fuel Cell Technology

The centre is playing a crucial role in the development of PEMFC systems for stationary applications. CFCT has been engaged in demonstarting fuel cell systems at various locations where hydrogen is available, and also simultaneously developed water based electrolysers with 2.5 Nm^3 capacity for decentralised power generation. CFCT is well equipped with state-of-the-art infrastructural facilities and highly qualified and trained manpower is its strength. CFCT has been engaged in the following activities as depicted in the following diagram.

In addition to fuel cell technology demonstration, CFCT is also engaged in all R & D activities related to fuel cells viz., durable electrocatalysts, modeling, electrolysers for hydrogen generation, metallic bipolar plates for transport application of fuel cells, energy storage using Zn based batteries, hydrogen storage using Alane, and supercapacitors using carbon derived from agricultural wastes. All these projects are funded by National funding agencies like Department of Science and Technology, DRDO, GAIL India, MNRE etc. A few additional equipments are in palce at CFCT and notable ones are optical profilometer, contact angle measurement unit, SVET spectrometer, cross hatch adhesion tester etc. It works in harmony and complete confidence with its members, customers and the government to offer its finest product.



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Development of air-cooled proton exchange membrane fuel cell stack

Air-cooled polymer electrolyte membrane fuel cells have emerged as a potential power source for stationary & portable applications because of its simplicity, ease of operation, elimination of subsystems like liquid coolant, heat exchanger, compressor, and air humidifier. Thus, the complexity of the system, parasitic power loss and overall cost of the system are all reduced. The flow field configuration plays a significant role in the development of an efficient air-cooled stack, as they have a dual role of supplying reactant as well as cooling the system. A new flow field optimization which replaces the existing ARCI's air cathode design has been carried out. A 'Land and Pillar' flow field has been preferred to use as cathode design for the newly developing air-cooled stack. The channel depth and width of flow channels play a crucial role for the uniform flow of gases, which are optimized through ANSYS-CFD. The flow design optimization was accomplished through a detailed parametric study of varying the inlet air velocity, flow design modification and inlet port variation (Fig. 1). In a Similar way, the flow profile for the anode side (H_2) was also studied and optimized.

The finalised flow designs obtained from CFD results are machined on graphite plates. A two-cell short stack was assembled with acrylic endplates, using two DC fans for supplying air flow to the stack as displayed in Fig. 1. The evaluation of stack was carried out at varying cell temperature and at different humidification temperatures.

Catalyst coated membranes for use in PEMFC system

Centre for fuel cell technology has been actively engaged in developing totally integrated systems both for transport as well as stationary applications. The developed systems have aslo been sought for demonstration at a few governmental organizations having provision for hydrogen supply. In order to roll out a fool proof integrated fuel cell system computational simulation, materials research and engineering development are required, all of which has been addressed in-depth at CFCT. CFCT has an ambitious project of developing the highly efficient catalyst coated membrane (CCM). In this regard CFCT had recently procured an Ultrasonic-Spry Coating Machine. A 95% transfer efficiency of the catalyst to the membrane has been achieved with this instrument. The distribution of the catalyst and the thickness of the catalyst layer were highly uniform at ± 0.05 µm as shown in Figure 2. The process developed is scalable from small area 1 sqcm to 800 sqcm and also a programmable version for multiple ccms, amenable for manufacturing. The in-house developed catalyst coated membrane (CCM) was tested for its performance and was found to achieve 800 mA/cm^2 at 0.6 V. 1kW PEMFC stack assembled with in-house prepared CCM as shown in Fig. 3(a). The cell voltages of in-house prepared CCMs are in bar with the commercial CCMs with the CFCT testing protocols (Fig. 3(b). Further testing is in progress.

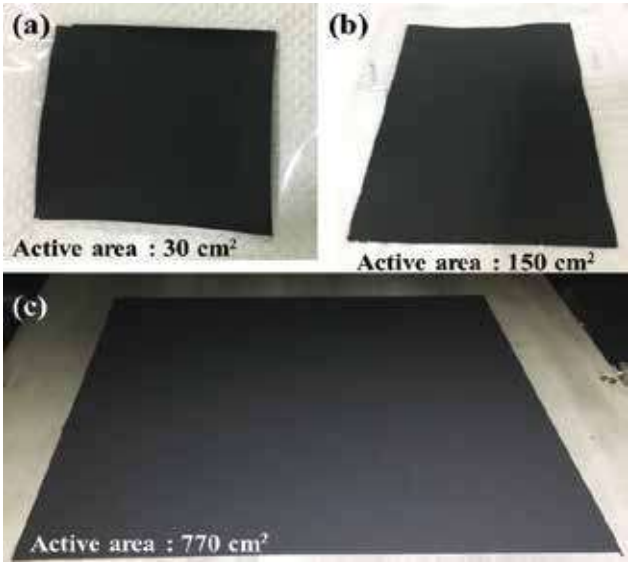

Fig. 2 (a-c) Photographs of various CCM with different active area

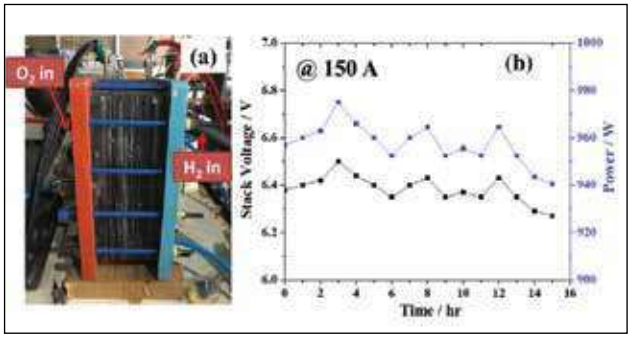

Fig. 3 (a) 1kW PEMFC stack assembled with in-house prepared CCM (b) Comparison of cell voltages of in-house prepared CCMs with the commercial CCMs

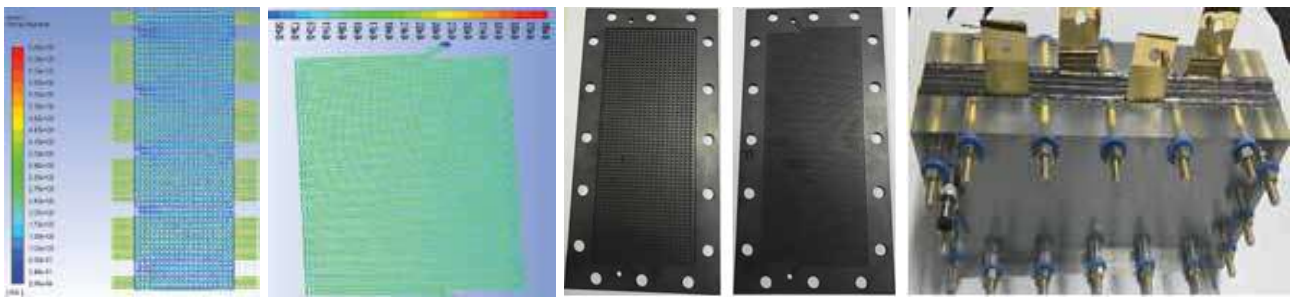

Fig. 1 Optimized flow profile for both cathode and anode side, machined graphite plates & 2-cell assembled stack

Cost reductiuon has also been addressed by identifying alternative membrane viz., FUMATECH, which exhibited comparable performance to the Nafion membrane. The cost factor was estimated to be 1/3rd of the Nafion membrane. Apart from catalyst and membrane, tuning of Gas diffusion layer was also carried out by benchmarking with a high peroforming commercial GDL. Concerted effort in this direction showed the cruical role of managing the thickness GDL. Optimization of CCM and GDL enabled CFCT to fabricate an all in-house stack.

Development of modular type electrolyser stack for hydrogen generation (2.5Nm³/h) through electrochemical methanol reformer (ECMR)

The objective of upscaling the ECMR process to produce hydrogen of 2.5 Nm^3/hr capacity the GEN-2 stack with improved performance was fabricated in modular type. The present approach of integrating the modular type Electrolyser stack will facilitate the uniform reactant distribution and collection of produced gases. The present design eliminates the stagnant zones, which may occur during the operation. In line with the modular type Electrolyser stack development, the required major BoP components (power supply, reactant feed system, reactant concentration monitoring system) has also been developed. The above developed modular type electrolyser stack was tested and the targeted amount of about 2.5 Nm^3/hr of hydrogen was achieved. Further the testing was carried out for longer duration Currently, efforts are underway in developing BoP components, efficient control & monitoring system and to integrate with the developed ECMR stack of 2.5 Nm^3/hr with the help of Indian industry partner to demonstrate an integrated system of PEM based ECMR for hydrogen generation.

Zinc-air battery module with non-precious based catalyst (20 Wh)

The low cost high performance zinc-air flow battery consists of four cells with each cell electrode area of 100 cm^2 was assembled. Air electrode for battery was prepared by synthesised transition metal-based catalyst prepared with ionomers as template. The assembled zinc-air flow cell could be discharged with the current density of 8 mA cm^{-2} at 1V discharge potential per cell. A maximum of 20 Wh capacity was achieved by assembled flow cell.

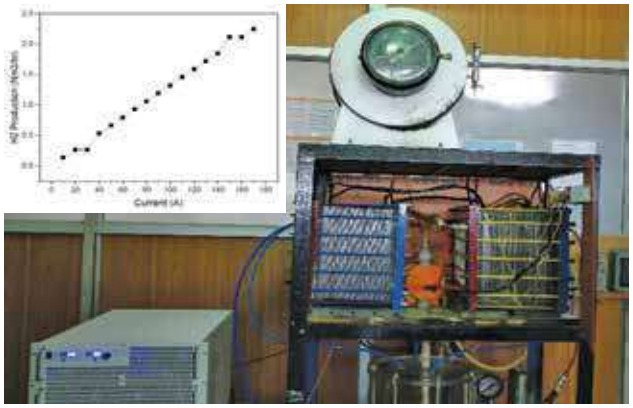

Fig. 4 Operational view of modular type ECMR stack for 2.5 Nm^3/hr Hydrogen production with performance characteristics

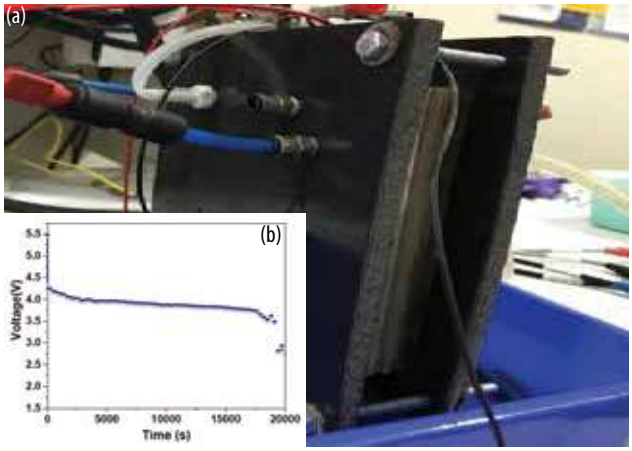

Fig. 5 (a) Assembled stack (b) discharge curve for four cell flow battery.

Development of 15 Whr alkaline Nickel-Zinc Secondary Battery

In CFCT, attempts are being continued for the development of rechargeable alkaline Nickel-Zinc for energy storage application. The performance improved electrode area was scaled up from 35 sq.cm to 150 sq.cm and developed electrode was tested in higher volume cell. The stable cell performance was found to be around to be 1600 mAh over 100 cycles and tested upto 200 cycles with the capacity fade of about 30%. Further, the attempt has been made to develop multi cell assembly with the above improved electrode to develop about 15 Whr battery. Five cells of electrode area of 150 cm^2 and the corresponding battery casing with acrylic materials was fabricated and its cyclability was tested upto 20 cycles and further testing is in progress. The above battery was tested and demonstrated with LED display board as load.

Design and Development of Metallic Flow Field Plates for PEM Fuel Cell

Flow field plates, through which the reactants pass through and product water is facilitated out, is a key

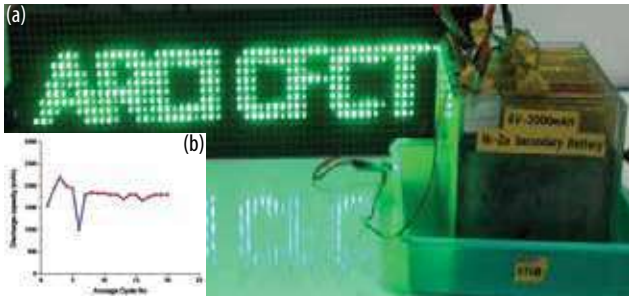

Fig. 6 (a) 5 cells were fabricated and tested with LED display board as load & (b) cyclability tested upto 20 cycles

component in the fuel cell. Metallic plates, predominantly Stainless Steel, serves as an alternative and thin sheet of it can replace thicker, conventional graphitic flow field plates. An 8 cells assembly with 30 sq. cm electrodes were established and was tested for its performance evaluation as given in Figure 7 (a-b).

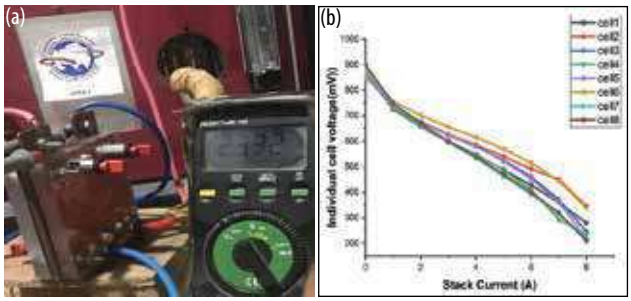

Fig. 7 Eight cells assembly with 30 Sq.cm electrodes (b) performance evaluation

Though complex flow field designs can be incorporated and occupies less volume than graphite, it suffers in the aspect of corrosion. Various surface treatments are imparted to enhance corrosion in the PEMFC environment. Though stainless-steel possess good corrosion characteristics in open atmosphere, the case is different in fuel cell operative conditions. The insulating nature of the oxide layer on the stainless steel increases the contact resistance and the presence of oxidative, reducing and acidic environments while operating the fuel cell, decreases the longevity as well as performance of the stainless-steel flow field plates. Corrosion resistant, conducting coatings need to be imparted on the surface of the flow field plates to counter the above aspects. In this regard, coatings of metallic and polymeric in nature were applied on the SS316L plates by various techniques. Based on the optimization, metallic nitrides such as Chromium Nitride (CrN) and Titanium Nitride (TiN) were deposited over the SS316L plates using Cathodic Arc – Physical Vapor Deposition technique.

The electro chemical performance and the corrosion current density were ascertained from the Potentiodynamic and Potentiostatic studies carried out on the coated specimens and they fall well within the Department of Energy (DoE), U.S standards. Based on the durability studies conducted, it is decided to utilize Chromium Nitride coating by Cathodic Arc Physical Vapour Deposition method for large area plates due to its high corrosion resistance in comparison with the revised DoE standards.

Other techniques to form the flow field plates, apart from stamping, like Additive Manufacturing was adopted. The plates were made in the Centre for Laser Processing of Materials (CLPM) of ARCI Hyderabad division. As additive manufacturing technique allows vast freedom in designing a new coolant plate integrated bipolar plate design was arrived. The novelty of the design lies in creating coolant channals in between H_2 flow field side and O_2 flow field side of the bipolar plate, leading to an integration of both the reactant plates and the coolant plates in a single plate. The major advantages expected from these integrated plates were (i) efficient cooling during peak power operation (ii) a leak-proof system; as the water plate is not a separate entity and does not require any welding or other joints and (iii) reduction in volume. In this context, a new bipolar plate with the integrated water channels was designed using computer aided designing and was fabricated using (selective laser melting) additive manufacturing technique with commercially procured 316L SS powder.

These additive manufactured plates were assembled (Fig. 9 (a-b) and stack performance (Fig. 9 c) reveals the possibility of utilizing additive manufacturing technique as a method to form the flow field designs while generating the component from scratch.

Electrochemical synthesis of gram level α-Aluminium hydride for advanced propellant ingredients

In CFCT attempt has been continued to synthesis alane by electrochemical method under ambient pressure and temperature through DRDO funded project Among the metal hydrides, aluminium Hydride, AlH_3, commonly

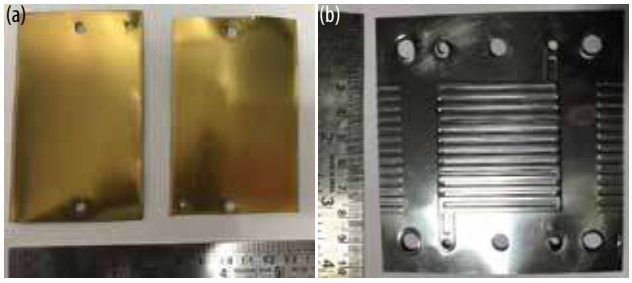

Fig. 8 (a) Titanium Nitride, and (b) Chromium Nitride, on SS316L plates by cathodic arc physical vapor deposition (CAPVD)

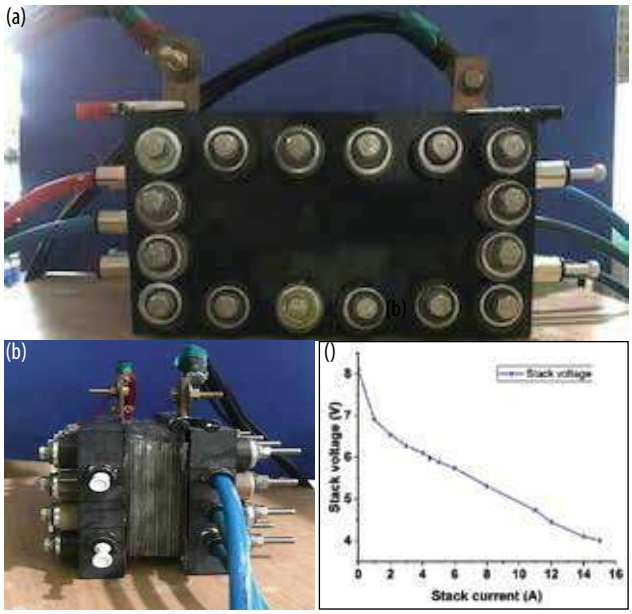

Fig. 9 Eleven-cell stack assembly of SS316L flow field plates made by Additive manufacturing (a) Front view (b) side view (c) 11-cell stack performance

known as alane is the most interesting fuels for propulsion, because of its ability to substantially increase the performance of a given system. Previously, the preliminary experiments were carried out using aluminium anode and platinum cathode in an electrochemically stable, aprotic, polar solvent such as tetra hydro furan (THF). Currently, the preparation of desired Alane polymorphs also depends on the other reaction conditions such as time, temperature, concentration and impurities in the electrolyte, which are all optimised to obtain reproducible results. The obtained product was characterised and electrochemical experiments were scaled up to synthesis alane in a batch type process about 1.0 gm /batch. Accordingly, about 5.0 grams of aluminium hydride/THF adduct was prepared and regeneration of spent electrolyte for reuse purpose is currently underway.

Engineering of Gas diffusion layer for better water management in PEMFC

Proper thermal and water management strategies are two aspects that requires optmization to overcome major bottlenecks in achieving a rugged perfromance. Recently, we have attempted to reduce water flooding by engineering the GDL with alternate hydrophilic and hydrophobic paths for easy water removal. Fig. 11(a) represents the GDL surface with multiple hydrophilic and hydrophobic tracks.The novel concept of engineering the GDL allows the water generated at the GDL/ Catalyst layer interface to get absorbed at the hydrophilic tracks and sufficient reactant gas supply for the electrochemical reaction is provided through the hydrophobic tracks. Optimization of hydrophobic region towards catalyst layer region or towards the flow field region was done in order to validate the water prodctuion and removal ratio from the fuel cell performance at various operating current densities [Fig. 11(b)]. Further modification and analysis are in process for better results to reduce the water flooding.

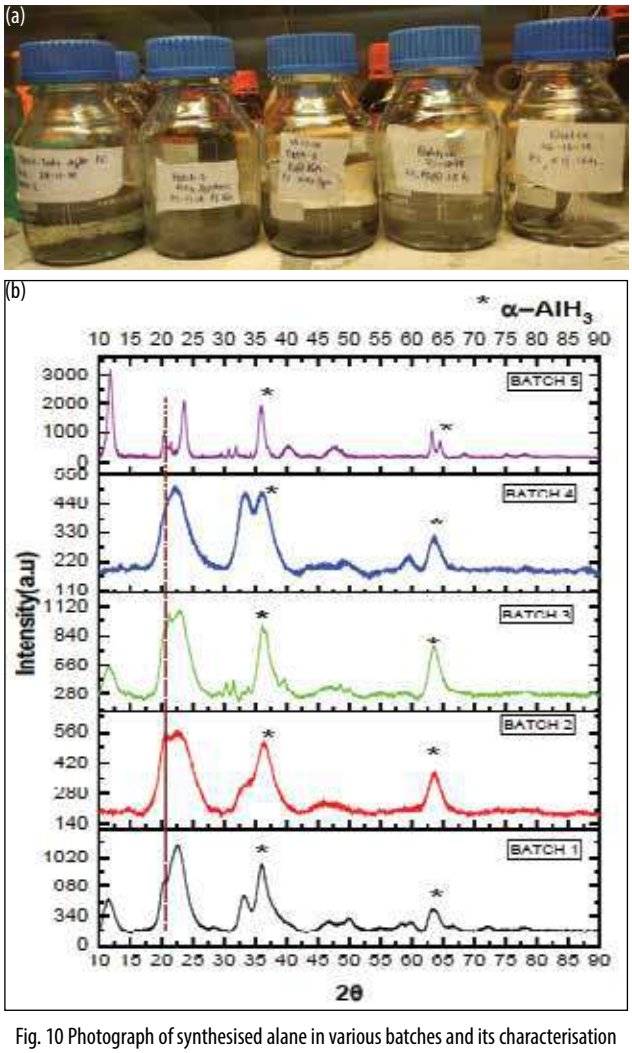

Fig. 10 Photograph of synthesised alane in various batches and its characterisation

Low loaded Pt electrocatalyst for Oxygen reduction reaction

Reduction of Pt content in the catalyst is the major bottle neck in the commercialization of Fuel cells (FC). CFCT is involved in a project aiming to reduce the Pt in the catalyst layer. Intermetallics is one of the solutions for this effects. 3wt% Pt loaded on CoNi nanosheets and 6wt% PtNi loaded over functionalised acetylene black for such a purpose. The results were highly promising with enhanced ORR activity as shown in Figure 12.

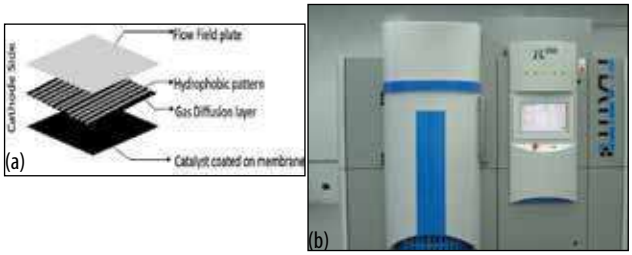

Fig. 11 (a) Hydrophobic pattern on GDL (b) Comparision of patterned MEA

Durable electrocatalyst supports for PEMFC cathodes

The conventional carbon supported platinum electrocatalyst has a challenging durability issue in the

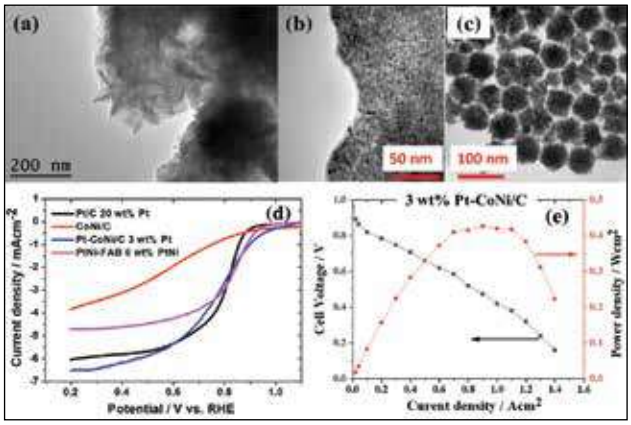

Fig. 12 TEM images of (a) CoNi nanosheets (b) Pt-CoNi and (c) PtNi dendrites (d) ORR polarization curves of various catalysts at 1600 rpm with the scan rate of 10 mV/sec in 0.1 M $HClO_4$ solution (e) PEMFC single cell performance of 3 wt% Pt-CoNi/C

transport application of PEMFC. Especially, the carbon corrosion is accelerated at high potentials >1.2 V generated during the start-up and shut down a fuel cell. The durability of PEMFC hindered due to corrosion of carbon support is mitigated by using modified supports and alternative supports. At CFCT, we chemically modify the commercial carbon supports to improve its corrosion resistance. Various carbons like vulcan carbon, acetylene black and ketjan black are modified and studied for its corrosion resistance using various electrochemical techniques like impedance spectroscopy. The acetylene black carbon had showed better corrosion resistance in its original and in its modified form compared other carbon materials. As an alternative new support material, we proved experimentally for the excellent corrosion resistance of Zirconium carbide based materials. Computational studies are being carried out to prove theoretically the durability of this novel support material with the energy level diagrams and d-band centre of materials.

Studies on recycling of valuable components from PEM fuel cell/electrolyser stack

PEM fuel cell/electrolyser Membrane Electrode Assembly (MEA) contains carbon supported Pt catalyst and it is dispersed on special grades of activated carbon and is present in high level (approx upto 60% W/W). Further the Membrane is also expensive and can be reused if proper recovery method is adopted. Globally there are few groups

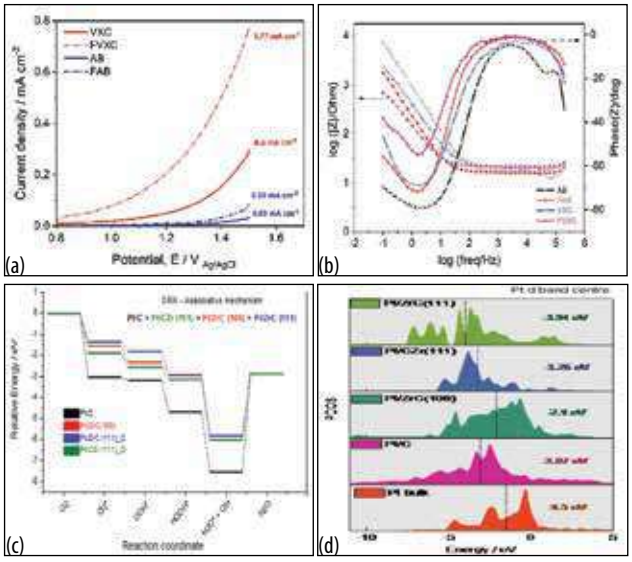

Fig. 13 (a) Linear Sweep voltammogram and (b) Bode plots for the Vulcan carbon and acetylene black and their functionalized forms.
Computational studies on Zirconium carbide based supports showing the (c) Energy level diagram for ORR and (d) d-band centres.

working on the process for precious metal recovery from used MEAs. The recovery of platinum metal and membrane from used MEA (after subjected into several hours of operation) is significant and it has commercial value. Hence attempts are being taken to recover the Pt metal and membrane from electrolyser/fuel cell stack. The preliminary studies are carried out by adopting various steps such as solvent separation, chemical dissolution and reduction and hydrometallurgical method to recover the Pt metal from MEA. As a result, about 75% of Pt was recovered from PEM fuel cell MEA and it's characterised. Further improvement in recovery efficiency and characterisation is in progress.

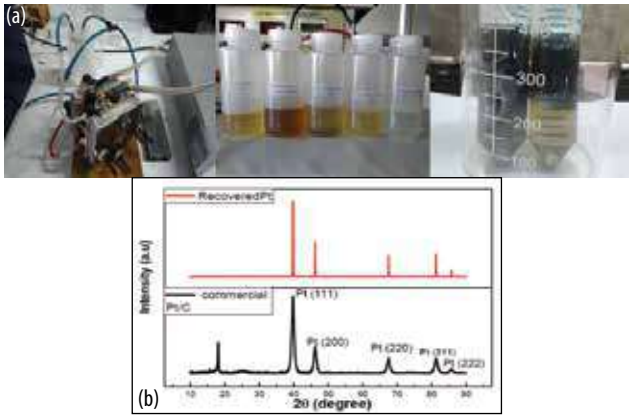

Fig. 14 (a) Photograph of experimental setup/recovered Pt solution/catalyst and (b)its characteristics

High pressure operation of ECMR by modelling as well experimental studies

Attempts have been initiated to develop ECMR stack with self-pressurised hydrogen generation. This approach will eliminate the need of external mechanical compression for hydrogen storage for fuel cell operation The results of preliminary studies are encouraging and could pressurise the hydrogen upto about 2 bar. Further flow field plate design modification through ANSYS fluent software and its evaluation are in progress.

Modelling studies on HT-PEM fuel cells

The modeling studies initiated during the previous year was extended further to predict the performance

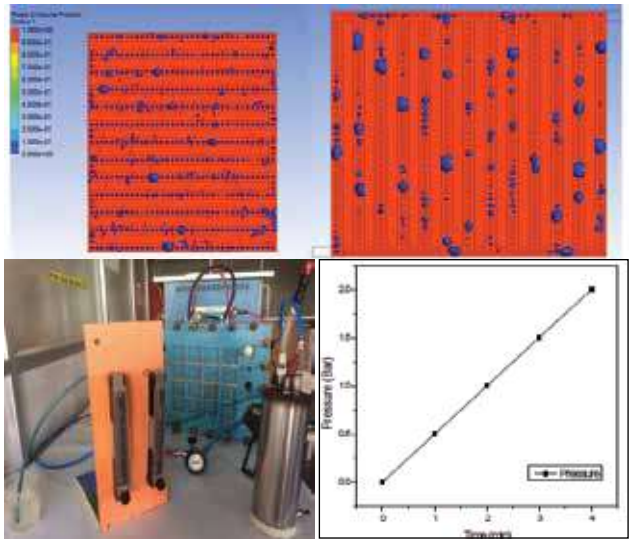

Fig. 15 Operation of ECMR stack under pressurized condition and simulated gas bubble formation under various flow field plate design pattern

of AB-PBI membrane based HTPEM MEAs prepared in house at different temperature. Different kinetic models for hydrogen oxidation reaction (HOR) and oxygen reduction reaction (ORR) reactions were derived considering different rate limiting steps in the underlying electrochemical charge transfer reactions and the predicted results are shown in Figure 16.

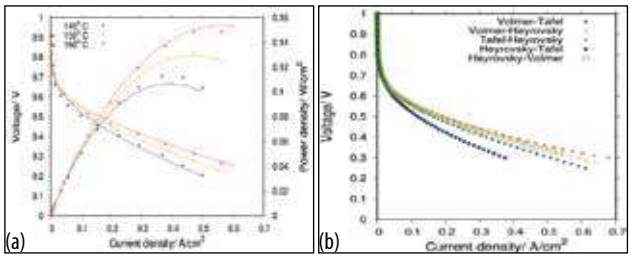

Fig. 16 (a) Experimental (points) and predicted (line) performance of in-house prepared HTPEM MEAs (b) comparison of performance using different HOR kinetic models

Non noble electrocatalysts for proton exchange membrane fuel cell

Pt free class of non-precious metal catalysts (NPMCs) have gained tremendous attention in hope of alleviating commercial restrictions of PEMFC. Under this context, zeolitic imidazolate frameworks (ZIFs) comprising of tetrahedral metal ions (Zn^{2+}, Co^{2+}) and imidazolate based linkers have emerged as potential precursors for in-situ preparation of NPMCs comprising of metal/nitrogen/carbon (MNC) in the catalytic framework. CFCT is working on the development of Pt free, Co/N/C catalysts derived from Zn and Co based ZIFs aimed at cost reduction of PEMFC. ZIF precursors were prepared through a facile aqueous based route at room temperature. Co/N/C catalysts were derived by direct carbonization of ZIFs under inert atmosphere and evaluated for ORR in acidic medium. Fig. 17 shows ORR polarization plots and Koutechy- Levich (K-L) plots. The Co/N/C catalyst exhibited onset potential of ~ 0.74 V and kinetic current density (ik) of 2.7 mA cm^{-2}. The catalyst followed near 4 electron reduction of oxygen which is desirable for an efficient ORR catalyst. After 500 cycles of durability testing, Co/N/C showed 12 % loss in ik displaying good stability in acidic medium. This work represents a new paradigm of NPMC catalysts for achieving reduced production cost of PEMFC. Studies are in progress on further optimization of the synthesis procedure and improving ORR performance for PEMFC.

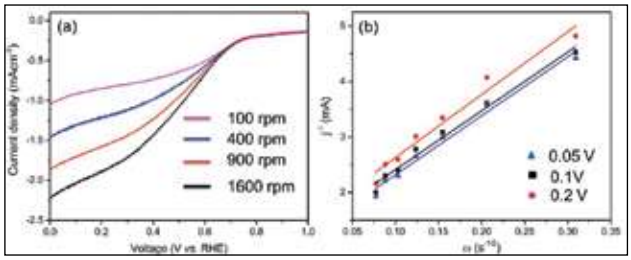

Fig. 17 (a) ORR polarization plots at different RPM in 0.5 M H2S04 at the scan rate of 10 mV s-1 and (b) K-L plots at different potentials for Co/N/C catalyst

Rechargeable alkaline electrochemical cells based on Zinc

Development of efficient, low cost and stable electrocatalysts as the alternative to precious metal-based catalyst for the oxygen reduction is of significance for many important electrochemical devices, such as metal-air batteries and fuel cells. However, metal-based catalysts often suffer from multiple disadvantages, including high cost, low selectivity, poor stability and detrimental environmental effects. An active nitrogen, sulfur and phosphorous doped carbon-based metal-free oxygen reduction reaction electrocatalysts, prepared by scalable, one-step process involving the pyrolysis was developed as an ORR catalyst. The sulfur and phosphorous doping can be further achieved by treating polymers with suitable dopants. Accordingly, the prepared N-doped(C-N), N, S-doped(C-N-S) and N, S, P-doped(C-N-P) carbon-based catalyst shows the onset-potential of 0.91 V, 0.88 V and 0.80 V, respectively in alkaline medium. Significantly, it demonstrated open-circuit potential of 1.48 V when used for constructing air electrode of zinc-air battery. The achieved current density for C-N, C-N-S and C-N-S-P at 1 V was 69 mA cm-2, 52 mA cm^{-2} and 39 mA cm^{-2} respectively. The two electrode rechargeable batteries could be cycled stably for 100 cycles at 10 mA cm^{-2}. The obtained results show comparable performance with state-of the-art platinum-based catalyst.

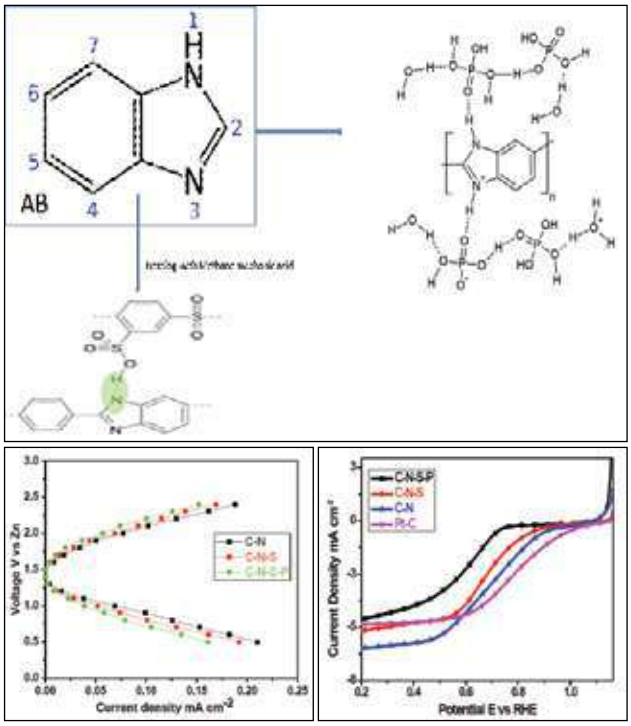

Fig. (a) Scheme of fabrication of metal free catalyst (b) LSV curves of C-N, C-N-S, C-N-S-P and Pt-C catalysts in 02 saturated 0.1 M KOH (c) Polarization curves for C-N, C-N-S and C-N-S-P

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 state-of-the-art forming, heat treatment and machining facilities for the processing of wide range ceramic components. In the recent past, the centre has demonstrated its core competence in executing several sponsored programme for producing large size non-oxide ceramic parts for application in demanding environments. During the period of this report, CNOC has developed SiC-based thrust bearing components for applications at elevated temperature under highly oxidative and corrosive environments. 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 drying and 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. This centre is also working on the development of near-neat shape components adopting various colloidal forming methods, wear and impact resistant parts, silicon nitride based ceramics with favourable dielectric and mechanical properties for the protection of antenna systems in supersonic/hypersonic vehicles.

SiC cold finger for heat sink application

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Development of SiAlON sleeve using cold iso-static pressing

SiAlON is a promising non-oxide ceramic material owing to its moderate density (3.0-3.2 g/cm^3), superior mechanical properties such as high elastic modulus (250-300 GPa), hardness (14 -16 GPa), flexural strength (300-600 MPa), moderate thermal conductivity (≈ 25 W/m/K), high oxidation resistance, high thermomechanical properties like thermal shock resistance, high operation temperature (≈1050°C). Such properties make SiAlON a potential candidate for numerous applications such as crucible for molten metal handling, sleeves on rollers for dip galvanization of non-ferrous metal, and cutting tool etc.

In view of the demand in metallurgical industry, ARCI is developing the SiAlON based components for application as thermal shock and wear resistant sleeve on metallic rollers used during dip galvanization in molten zinc or aluminium bath. However, development of such a complex shape component is challenging. In the present case, ARCI has opted to use in-house developed SiAlON premix powder and flexible rubber bag for cold-isostatic pressing to obtain a green product, followed by pressureless sintering of the component (Fig.1a). Thereafter, the component has been sectioned as per the required dimensions and profile as shown in Fig.1b. The sintered SiAlON exhibit hardness of ≈ 14 GPa, Young's modulus ≈ 250 GPa and flexural strength ≈ 260 MPa.

Development of SiC nozzle for bearing high thrust in jet engine

Silicon Carbide (SiC) is a promising non-oxide ceramic material due to its moderate density (≈ 3.16 g/cm^3), high mechanical properties such as elastic modulus (400-420 GPa), hardness (25-28 GPa), flexural strength (350-500 MPa), high thermal conductivity (≈ 120 W/m/K), low CTE (3.6×10^{-6}/°C), and high temperature tolerance ability (≈ 1200°C). Such properties make SiC a potential candidate for many applications such as thrust nozzle, heat exchanger, solar thermal tube.

In view of the above, ARCI is developing SiC based complex shaped component for using as thrust bearing nozzle in jet engine. Here, a suitable powder formulation comprising of fine SiC powder (submicrometer sized) and sintering additives, has been optimized. The green compact obtained by cold isostatic pressing from such powder has been machined into complex shaped nozzle (Figure 2) as per the required geometry and dimensions with the help of 5-axes CNC machine, followed by densification at ≈ 2150°C under argon environment. With optimized sintering parameters, defect free and dimensionally stable SiC product has been obtained. The dense SiC shows Young's modulus ≈ 410 GPa , hardness ≈ 25 GPa, flexural strength ≈ 500 MPa and fracture toughness ≈ 3 MPa.√m. The SiC nozzle is being tested for thrust bearing purpose in jet engine.

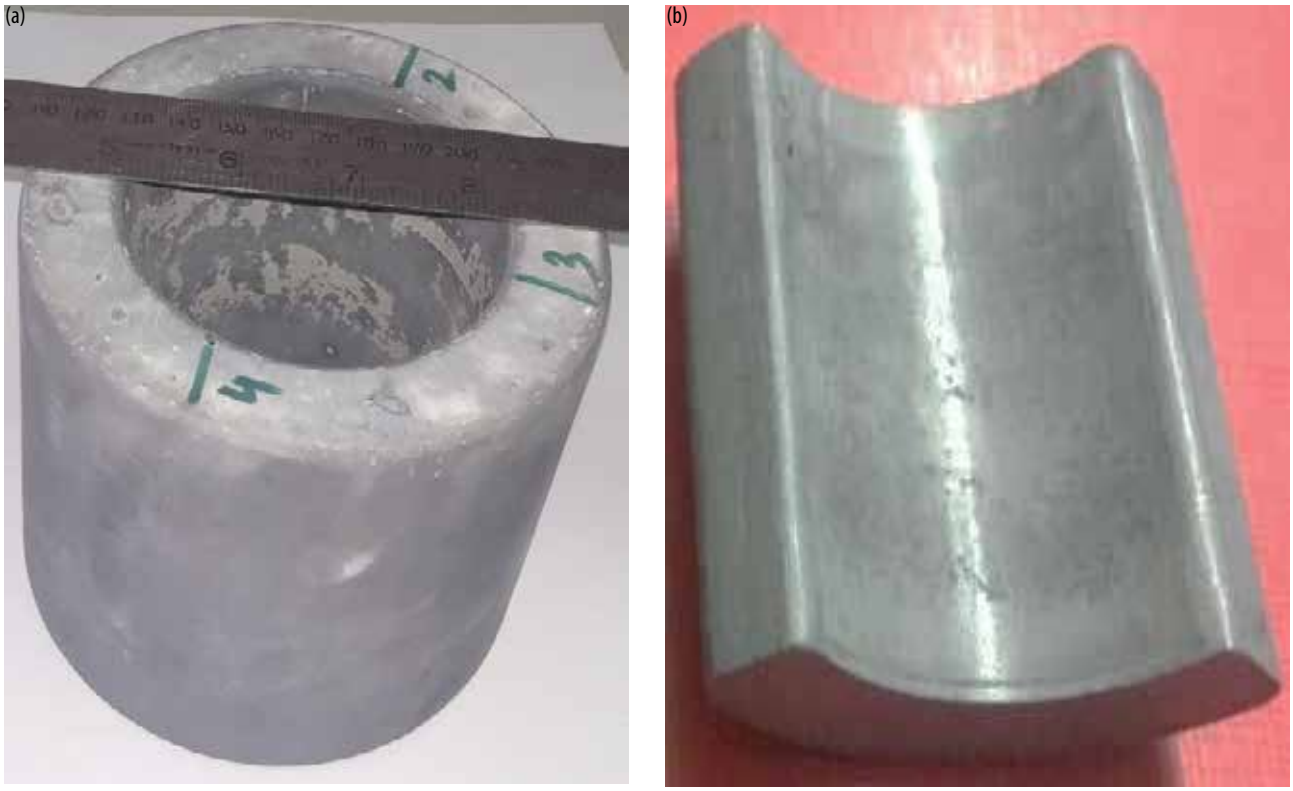


Fig. 1 (a) SiAlON cylinder (Sintered), (b) SiAlON sleeve sectioned from cylinder

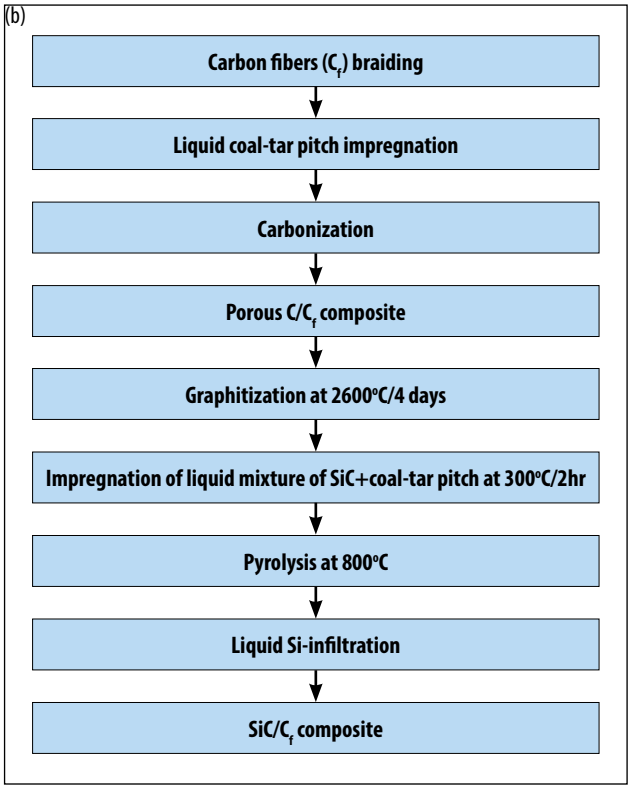
Fig. 2 Complex shape SiC nozzle

SiC-CNF Si Infitrated tube

The fracture behavior and high temperature thermal properties of monolithic SiC can be improved by incorporation of the high strength continuous carbon fibers (Cf) reinforcement. Dense carbon-fiber-reinforced SiC composites (Cf/SiC) with superior thermal and mechanical properties are used in numerous industries like aerospace, high temperature nuclear fission and fusion etc,. The common processes followed for fabrication of Cf/SiC composites are CVI, LSI, PIP, EPD etc.

LSI was adopted in the present study, due to the several advantages like complex and near net shape processing in a short time at low cost with optimized thermo-mechanical properties. Therefore, SiC based composite tubes were processed with in-house produced spray freeze granulated SiC-CNFs (carbon nano fibers) composite powder. Thin (1mm wall thickness) and dense (> 98% theoretical density) SiC-CNFs composite tubes produced by cold iso-staic pressing followed by pressure less sintering were braided with long carbon fibers (Cf) (SYG, dia: 6-8 µm, 7-9k/tow). The cross section of three SiC-CNF composite tubes braided with three different types of Cf at different weave configuration are 8H satin weave high strength carbon fibers (HSC), 8H satin weave spun yarn graphitized fabric (SYG), and quadriaxial braided non-crimp carbon fabric (NCF) is shown in Fig.1(a). Braided composite tubes with the thickness of 8-9 cm were carbonized and infiltrated with liquid silicon (LSI) to fabricate dense SiC/Cf composite on the SiC-CNFs composite tube, shown in Fig.4(b).

(b)



(c)

(a)

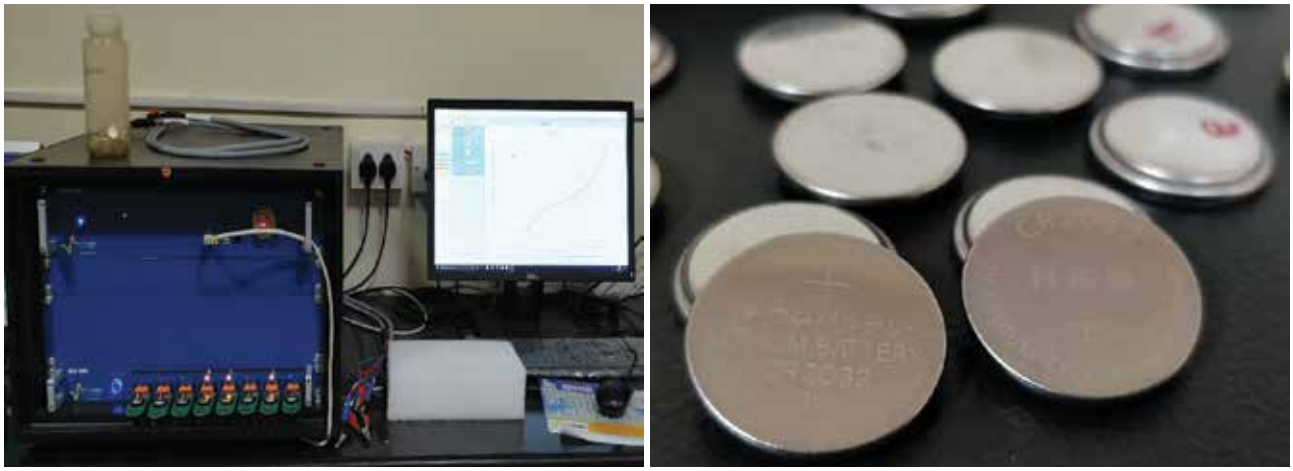
8H satin weave high strength carbon fibers (HSC) | 8H satin weave spun yarn graphitized fabric (SYG) | Quadriaxial braided non-crimp carbon fabric (NCF)

Fig 4 Sintered SiC-CNFs tube with C-fiber braiding: (a) before Si-infiltration (b) Si-infiltration process flow chart, (c) After Si-infiltration

Centre for Carbon Materials

Carbon finds wide range of applications either in the bulk or nano form. One can consider carbon as wonder material due to its applicability in various engineering and technological sectors. For last few decades nanocarbon technology is of prime research interest as it offers unique set of thermal, mechanical physical and electronic properties. The interesting characteristics and assured functionalities of nanocarbons motivated the researches to focus on the study of a series of nano carbons, and its characterization. The carbon atoms bonded differently and resulted in the evolution of various nanocarbon materials like bucky balls/fullerene, nanotubes, nanodiamonds, graphenes, graphite nanoplates etc. These unique and fascinating properties of nanocarbon have resulted in many potential applications for high volume as well as for the nich areas. Due to the recent advances in nanocarbon technology, flexible and stretchable electronics have been intensively explored for enabling new applications otherwise unachievable with the conventional silicon technology. The energy sector is one important sector where many research groups are attempting to develop a supercapacitor with high energy density and power density. Carbon nanomaterials based hybrid materials that synergistically integrate electric double layer capacitance of carbon nanostructure with fast and highly reversible pseudocapacitance properties of metal oxides or sulphides will be promising for high energy density supercapacitor development. Transition metal oxides, 2D structured metal sulphides or conductive polymers are essential candidates for achieving such pseudocapacitive behaviour in these hybrids.

High surface area carbon materials with tunable porosity are crucial for the development of electrode materials for supercapacitor applications. Carbon nano materials are highly anisotropic in nature and the properties vary with processing conditions. Optimization of processing parameters and controlling the structure are the decisive factors for such applications, and therefore in the center serious efforts are going on to get the carbon nanomaterials with desired properties. Keeping these emerging applications of carbon nanomaterials in view, centre for carbon materials has initiated the efforts in the electrode development for supercapacitor and battery applications. To achieve the compatible porosity with good pore size distribution, chemical activation of coconut based charcoal has been initiated as collaborative research. Research efforts are going on to develop carbon nanomaterial based hybrid electrode material to achieve high energy density supercapacitors. 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 in present date. The transition from conventional additives to carbon nano-additives will lead to a big leap towards an efficient lubricant also persuaded in the centre. Considerable research is going on at the center on PCM based thermal management technology and large scale synthesis of graphite nanoplates as a filler material in various composites. Center also initiated the work on producing flexible carbon nanotube-mats which offers huge scope in various applications in energy, sensors, composites etc.



Biologic instrument (BCS-805) & Coin cell cases CR2032

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Development of coconut charcoal based activated carbon with tailored properties for high performance super-capacitor application

Activated carbon finds many industrial applications in energy storage (super capacitors, batteries), water purification, energy conversions (fuel cells, solar cells), sensors, environmental protection (regulation of SOx and NOx) etc. Due to its high specific surface area and tunable porosity activated carbon is becoming the most demanding electrode material for commercial super capacitor fabrication. We aim for the cost effective production of activated carbon material with tunable properties for super capacitor application and finally match the properties of commercial YP-50 based super capacitor. Here, we report a scalable synthesis method of activated carbon from coconut char (AC-ARCI) in a batch level of 100 gm, which has a potential to go directly to industrial scale. Coconut char is being treated by potassium hydroxide (KOH) in presence of N_2 gas. It was then annealed in the range of 700 to 900^{0}C in Ar and H_2 atmosphere to remove the traces of metallic potassium. A collective study to optimize the treatment process for better yield was done. And, the yield was found to be around 45 – 50 wt %. The microstructural, elemental and crystal structural characterization was done by scanning electron microscopy (SEM), energy dispersive x-ray spectroscopy (EDX), and x-ray diffraction (XRD). Fig.1 shows the SEM images of commercial YP-50 and AC-ARCI at different magnifications, which indicates a porous structure with grain like morphology.

The comparative XRD patterns are shown in Fig. 2. KOH activated carbon shows poor crystallinty compared to YP50, which indicates higher temperature annealing treatment is required to improve the crystallinity of AC-ARCI.

The elemental analysis was performed using EDX for both the commercial YP-50 and AC-ARCI. The detail analytical

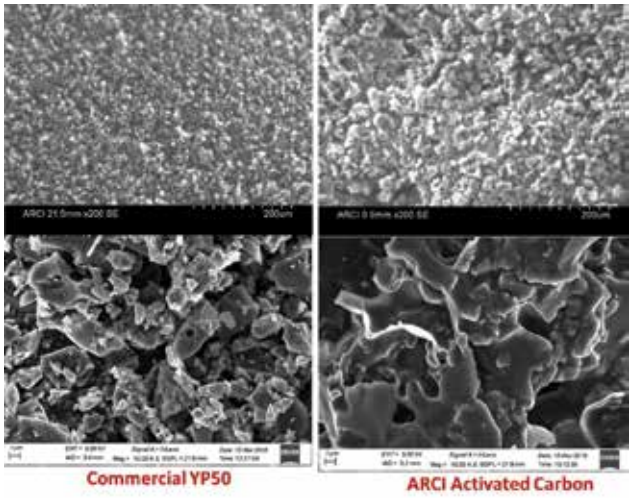

Fig. 1 SEM micrographs of commercial YP50 (a and c) and ARCI activated carbon (b and d)

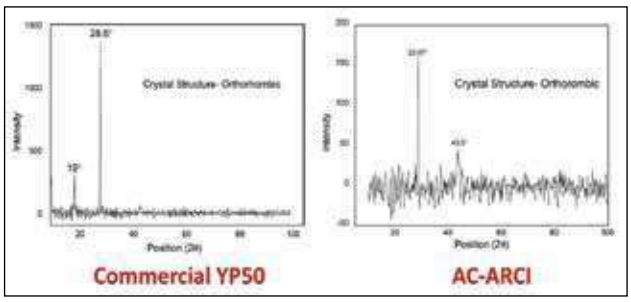

Fig. 2 XRD pattern of (a) commercial YP50 and (b) ARCI activated carbon

parameters as well as the EDX spectra are shown in Fig. 3. The analysis indicates YP-50 contains 99.87% (wt.) carbon with 0.13% (wt.) whereas AC-ARCI contains 1.2% (wt.) impurities. Primarily Si and its associated oxides are present as impurities in the AC-ARCI, the processing experiments are going on to remove these trace amount of impurities from the AC-ARCI.

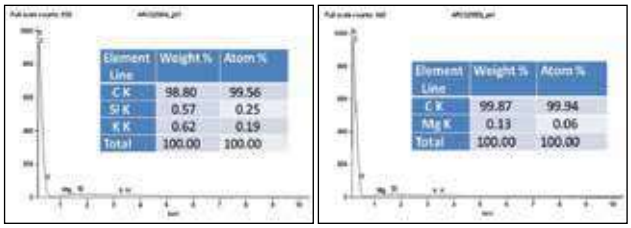

Fig. 3 EDX pattern of (a) ARCI activated carbon and (b) commercial YP50

The average particle size (~ 5.5 µm) has been optimized by optimizing the milling parameters. The BET specific surface area and micro pore volume was found to be 1374 m_2g^{-1} and 0.65 ccg^{-1} respectively which is comparable with that of commercially available activated carbon YP-50. The comparative values of particle size, specific surface area and micro pore volume of coconut charcoal based activated carbon and YP-50 are shown in Table1.

Table -1 (Comparison table of particle size, specific surface area and micro pore volume coconut charcoal based activated carbon and YP-50)

Particle size (mm)	**YP-50**	**ARCI - activated carbon (coconut based)**
D-minimum	*1.7*	*1.1*
D-maximum	*12.2*	*15.2*
D-average	*5.56*	*5.47*
	YP-50 (literature)	**ARCI - activated carbon (coconut based)**
Specific surface area - BET (m^2g^{-1})	*1500*	*1374*
Micro pore volume (ccg-1)	*0.60*	*0.65*

Fig. 4 shows a detail comparative electrochemical study of AC-ARCI and commercial YP-50 to see the performance as super capacitor. We have tested supercapacitor performances fabricated using three different electrode materials like AC-ARCI powder, YP-50 powder and YP-50 coated commercial foil respectively.

Fig. 4a and b show the comparative performance of the supercapacitor devices fabricated using AC-ARCI and YP-50 powder. The coating of the electrode materials onto current collector was done at ARCI facility. It can be clearly seen that the specific capacitance of AC-ARCI is higher compared to that of YP-50. Fig. 4b and d show the charge-discharge and impedance study of AC-ARCI, YP-50 and YP-50 coated commercial foil based supercapacitors. The specific capacitance of AC-ARCI obtained by galvanostatic charge-discharge was found to be 150 F/g at a current density of 0.25A/g with energy and power densities of 20.65 Wh/kg and 254.40 W/kg respectively. These values are close to those obtained by using commercial YP-50. However the ESR value of commercially coated YP-50 was found to be 0.509 Ohm which is much lower than that of AC-ARCI. Further optimization of coating technology of electrode material onto current collector and removal of Si related impurities are in progress. In summary, an efficient and cost-effective technique is developed to prepare activated carbon with high specific surface area and specific capacitance comparable to commercial YP-50.

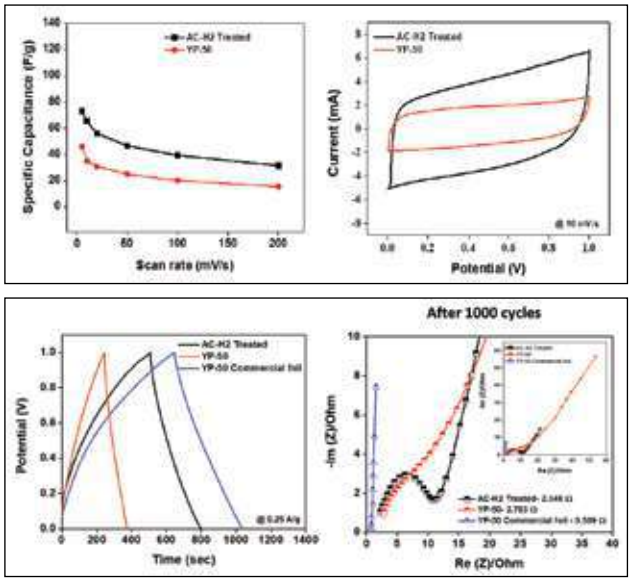

Fig. 4 Comparative electrochemical study of AC-ARCI and YP-50

Activated functionalized carbon nanotube and 2D nanostructured MoS_2 hybrid electrode material for high performance supercapacitor application

Alkali-activated functionalized carbon nanotubes (AFCNT) and 2D nanostructured MoS_2 have been investigated as novel hybrid materials for energy storage applications. The surface morphology, crystallinity and the microstructures of the hybrid materials have been thoroughly analyzed. The nanoflower like 2D MoS_2 were grown on the surface of AFCNT using the controlled one-step hydrothermal technique. The activation of functionalized carbon nanotubes resulted in greater performance due to

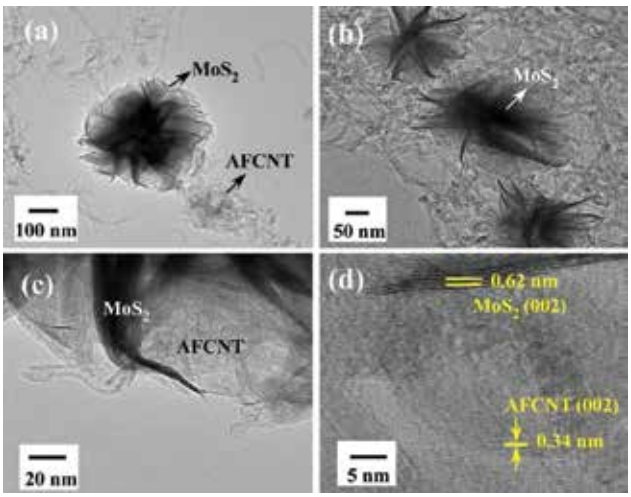

Fig. 5 (a-c) TEM image of AFCNT/MoS_2 hybrid (d) High resolution TEM image of AFCNT/MoS_2 hybrid showing lattice fringes of CNT and MoS_2

the improved surface area. The BET surface area of the activated carbon nanotubes was found to be 594.7 m^2/g, which was almost 30 times that of the as prepared carbon nanotubes. The improved surface area with attached hydroxyl and carboxylic functional groups helped in the greater attachment of MoS_2 nano flowers onto the AFCNT, thus reducing the interfacial resistance and providing an easy path for electron transfer. The electrochemical analysis showed high specific capacitance of 516.72 F/g at 0.5 A/g with corresponding energy density of 71.76 Wh/kg in aqueous 3M KOH electrolyte which is the highest reported value for CNT and MoS_2 hybrid material and it showed an ESR value of 0.652 Ω and a capacitance retention of 88.78% even after 1000 cycles. The enhancement in the specific capacitance and corresponding energy density is believed to be due to larger surface area which was achieved by incorporating nanoflower like MoS_2 and

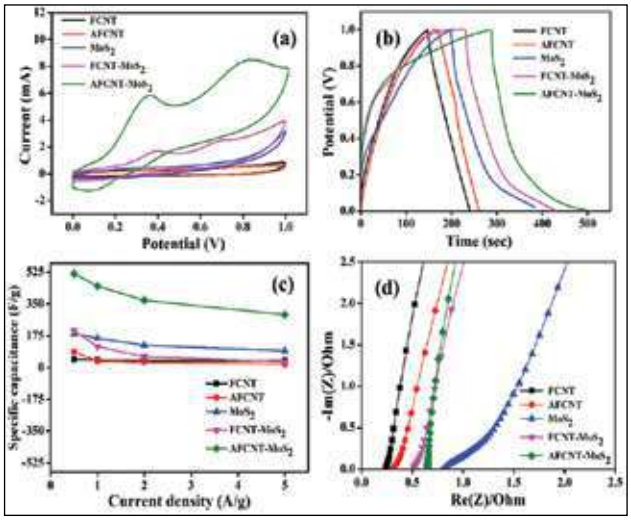

Fig. 6 Electrochemical performances of FCNT, AFCNT, MoS_2, FCNT-MoS_2 and AFCNT-MoS_2 electrodes in a two-electrode system: (a) cyclic voltammetry (CV) curves at scan rate of 5 mV/s (b) Galvanostatic charge/discharge (GCD) curves at current density of 0.5 A/g (c) performance curves of FCNT, AFCNT, MoS2, FCNT-MoS2 and AFCNT-MoS2 at current density of 0.5, 1, 2 and 5 A/g (d) Nyquist plot at low frequency region.

activated functionalized carbon nanotubes. Further, for the demonstration of practical application, a prototype of coin cell supercapacitor using organic electrolyte was fabricated to glow the LED.

Degradation test of the AFCNT-MoS_2 electrode performed with 1000 charge/discharge cycles at 1 A/g, showing the degradation of electrode specific capacitance during the test, with (insets) plots of the first and last 10 charge/discharge cycles (time axes t is referenced to the beginning of each 10-cycle set) (c) Measurement results and comparison of the energy density, power density, and capacitance of the FCNT, AFCNT, MoS_2, FCNT-MoS_2 and AFCNT-MoS_2 electrodes (d) Performance of several other devices in terms of specific capacitance.

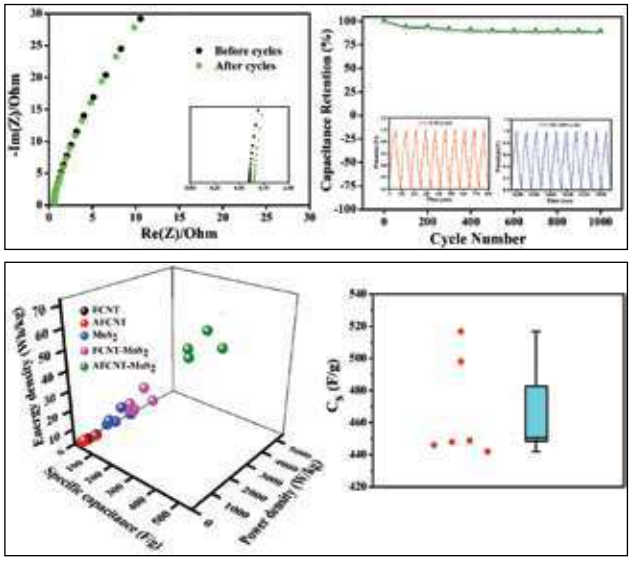

Fig. 6 (a) Nyquist plot of AFCNT-MoS_2, the inset shows the low frequency region (b)

Functionalized carbon nanotube and MnO_2 nanoflower hybrid as an electrode material for high energy density super capacitor application

We report one-step synthesis method of functionalized carbon nanotube and MnO_2 nanoflower hybrid material using hydrothermal technique and its application as a promising electrode material for high energy density supercapacitor. Nanoflower like morphology of MnO_2 acts as an electrolyte reservoir which facilitates greater ion diffusion and faster electron transfer leading to an overall improved electrochemical performance. The morphological investigation reveals the formation of 'nanoflower' like structure of MnO_2 (shell) covering the functionalized carbon nanotube surface (core). Significant improvement in capacitance properties is found in the hybrid material, in which, carbon nanotube acts as a conducting cylindrical path, while the major role of MnO_2 is to store the charge and participate in the pseudocapacitive electrochemical mechanism. A specific capacitance of 533.32 $F.g^{-1}$ is observed at a current density of 0.25 $A.g^{-1}$. Maximum energy density of 74.07 $Wh.kg^{-1}$ and maximum power density of 898.84 W.kg-1 are achieved using functionalized carbon nanotube -MnO_2 hybrid as electrode material. As per our knowledge the above mentioned energy density value is superior to previously reported MnO_2 based hybrid supercapacitors. Our results show promise for the future of supercapacitor development where high energy density can be achieved along with high power density and long cycle life.

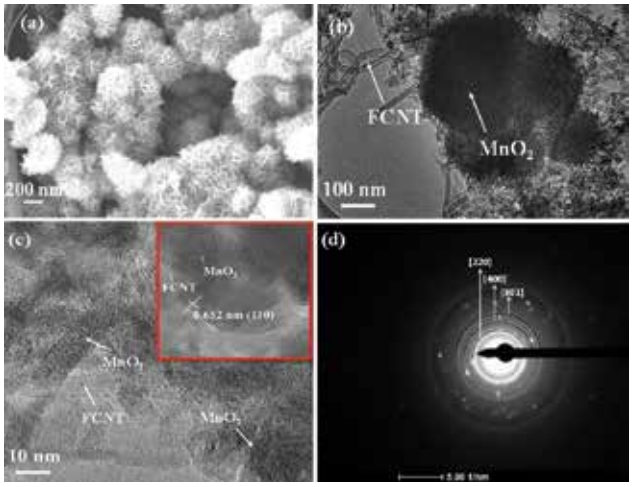

Fig. 7 (a) FESEM of FCNT-MnO_2 (b) TEM analysis of FCNT-MnO_2 (c) HRTEM of FCNT-MnO2 with inset showing the lattice spacing of MnO2 in the hybrid FCNT-MnO2 and (d) SEAD pattern of FCNT-MnO_2.

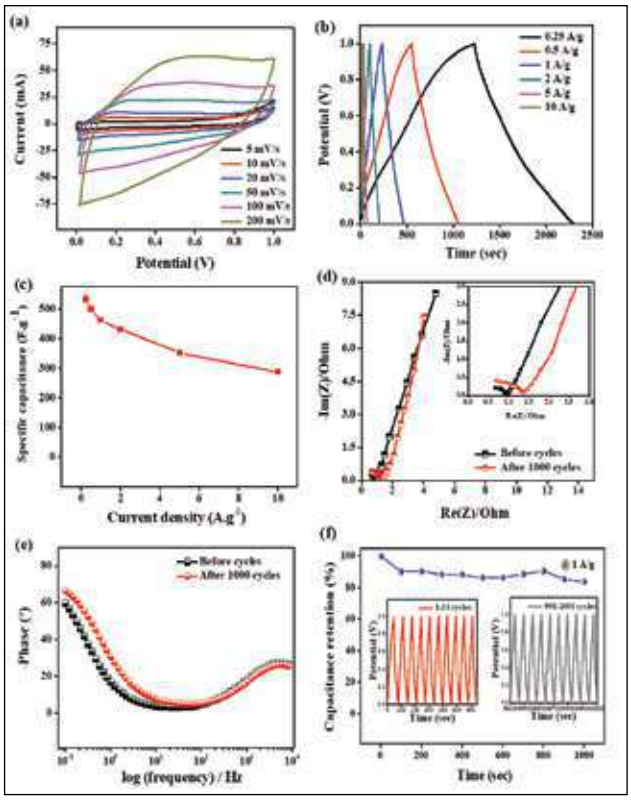

Fig. 2. Electrochemical analysis of FCNT-MnO2 (a) cyclic voltammetry (b) galvanostatic charge-discharge and (c) specific capacitance from the galvanostatic charge-discharge (d) Nyquist plot before and after 1000 cycles, inset showing the Nyquist plot at higher frequencies (e) Bode plot before and after 1000 cycles (f) Capacitance retention plot with a retention of 83.59% at 1 A.g-1 from GCD with insets showing (left) 1-11 cycles and (right) 990-1000 cycles

Centre for Sol-gel Coatings

Centre for Sol-Gel Coatings has been constantly joining hands with various industrial partners for commercialization of the sol-based nanocomposite coatings for diverse applications. The distinct advantages of using sol-gel coatings on any substrate is 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 seriously focusing on the following applications:

1. *Scratch/abrasion resistant coatings on transparent plastics*
2. *Superhydrophobic coatings for antibiofilm formation*
3. *Self-healing, corrosion protection coatings on steel sheets for automotive applications*
4. *Room temperature curable solar control coatings on glass for architectural and automotive applications*

Transparent scratch and abrasion resistant coatings on acrylic sheets for possible application on aircraft canopies and retroreflective road marker lenses has been studied

Antibiofilm forming ability of the superhydrophobic coatings was seen to be promising and feasibility of applying these coatings on surgical instruments is being investigated.

Presently, room temperature curable solar control coatings on glass for architectural and automotive applications are being developed.

Protective coatings on steels that can obviate phosphating are being developed.

Photograph of salt spray chamber test facility to study the accelerated corrosion of sol-gel coated specimens installed at the Centre

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Abrasion resistant protective coatings on retroreflective lenses of road studs

Road studs are used to light a road at night. Retroreflective road marker lenses which are part of the road studs as shown in Fig. 1, undergo severe abrasion, because of vehicular traffic, due to which, their retroreflectivity decreases during service conditions. In order to enhance the life of the road studs, sol-gel based abrasion resistant coating formulation was spray deposited on PMMA lenses and thermal cured at 80°C. The coated samples were tested for scratch resistance, adhesion and haze measurement after abrasion. The coating samples exhibited 5H pencil scratch hardness, and 5B adhesion strength, when tested as per ASTM D 3359. Co-efficient of luminous intensity was measured as per ASTM-D4280-4 for unabraded and abraded samples and depicted in Fig. 2. It can be seen that the that the sol-gel coated lens show higher retroreflectivity values when compared to uncoated and commercially available protective coatings, even after being subjected to abrasion thereby showing superior abrasion resistance. In order to carry out field test trials, 500 nos of retroreflective lens fitted road studs were coated and fixed on road studs. were fixed on concrete road as shown in Fig. 3 and observed from a distance of 10', 20', 30' 40' and 50' from a stationary vehicle and from 50' to 5' from a moving vehicle. The sol-gel coated lenses showed superior retroreflectance when compared to commercial protective coatings.

Fig 1. Photograph of a road stud

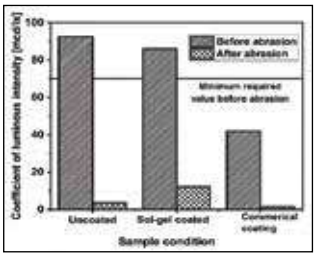


Fig 2. Comparison of coefficient of luminous intensity values for uncoated, sol-gel coated and commercial coated lenses

Fig 3. Field test trials of road studs fitted with sol-gel coated lenses and commercial hard coated lenses (Inset shows the photograph of 500 nos of sol-gel coated retroreflective lenses)

Sol-gel derived fully dielectric solar control coating stack on glass for architectural and automobile applications

Glass is extensively used in architectural and automobile sectors both for aesthetic appeal as well as a protective material from adverse atmospheric conditions, while maintaining transparency for day light illumination. However, it is the largest source of heat penetration and does not render protection from ultraviolet (UV) and near infrared (NIR) radiation, leading to increase in the load of comfort air conditioning. This is a cause for serious concern, more so in tropical countries like India. Blocking the harmful UV radiation as well as NIR radiation without hampering the visible light transmittance is possible by suitable engineering of the glass surface, either by way of solar control films or by depositing solar control coatings. However, solar control films, that are mostly polymer-based, do not have sufficient durability due to their poor scratch resistance and reactivity with UV radiation. Moreover, they are banned for use in automobile windows in India for security reasons. Presently, the statutory requirement for the visible light transmission for windshields and windows in automobiles is ≥70% and ≥ 50% respectively. IR reflective coatings based on metal dielectric stacks have been proposed as an alternate solution. However, these systems need to be protected from environment due to softness and reactivity of the metallic layers to oxygen and humidity. Transparent conducting oxide (TCO) films based on Indium tin oxide have also been investigated as suitable alternates to the polymer-based sun control films and metal-dielectric based IR reflective coatings on glass. Nevertheless, due to their high cost and depleting reserves of indium, the TCO based solar control coatings require a suitable replacement. In view of the above, a cost-effective fully dielectric solar control coating on glass has been developed at ARCI, that comprises multilayered stacks of alternate high refractive index materials (HI) like metal titanates and low refractive index materials (LI) like MgF_2 of specified thickness and refractive index, that yield optimized solar control properties, while maintaining a high visible light transmittance. In the present study, $BaTiO_3$ and $SrTiO_3$ were used as high refractive index materials and MgF_2 was used as the low refractive index material to generate the fully dielectric coating stack. Three-layered stacks $BaTiO_3/MgF_2/BaTiO_3$ and $SrTiO_3/MgF_2/SrTiO_3$ were generated using $BaTiO_3$, $SrTiO_3$ and MgF_2 sols deposited on soda lime glass by employing optimized dip coating parameters. The multilayered coating stack was fired at 450°C employing different heating rates using a conventional muffle furnace (slow heating) and a conveyorized belt furnace (fast heating). The heat treated coatings were characterized for their UV-Vis-NIR transmittance, microstructure, thickness and

refractive indices. All the coating stacks investigated in the present study showed a considerable amount of NIR blocking. It can be seen from Fig. 4 that the coating stack based on $BaTiO_3$ as the high refractive index material in conjunction with MgF_2 exhibited better solar control properties than $SrTiO_3$ as the high refractive index material. Moreover, as seen from Fig. 5, a fast firing of the $BaTiO_3|MgF_2|BaTiO_3$ stack in a conveyorized belt furnace yielded higher NIR blocking (67% visible light transmittance with an NIR transmittance of 55%), whereas slow firing exhibited ~80% visible light transmittance with an NIR transmittance of ~ 75%. During the fast firing of the coating stack, there was >40% reduction in the NIR transmittance of the glass, while maintaining the visible light transmittance at > 65%. Present investigations show that this multilayered solar control coating derived from sol-gel technique on soda lime glass substrates will have immense potential to reduce the load on air conditioning for the automotive and architectural industries.

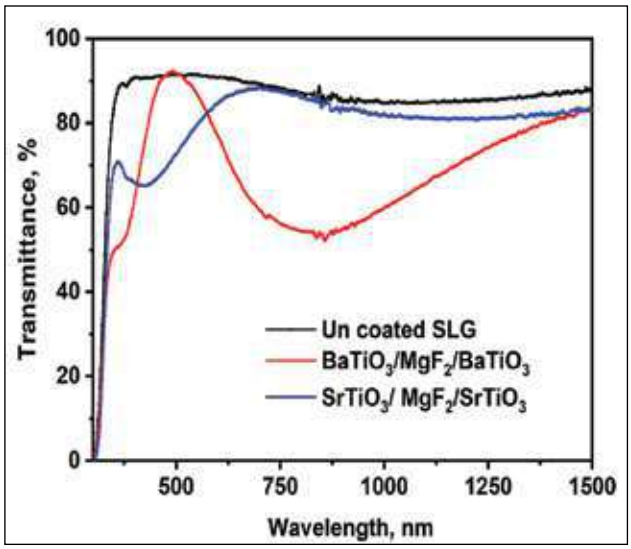


Fig. 4 Transmittance spectra for $BaTiO_3/MgF_2/BaTiO_3$ and $SrTiO_3/MgF_2/SrTiO_3$ coating stacks applied on soda lime glass (SLG) substrates

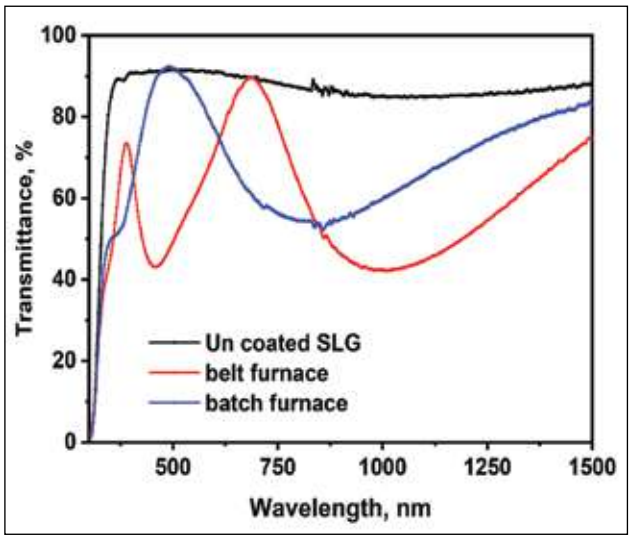


Fig. 5 Transmittance spectra as a function of annealing rates

Development of antibiofilm forming superhydrophobic surfaces on stainless steel 304 for biomedical applications

The microbial adsorption on biomedical devices, surgical equipment, implants etc. are cause for concern, since majority of the bacterial infections occurring in hospitals are due to the infections from surgical equipment and biomedical devices. This increases the use of antibiotics and cost expended towards healthcare. Recently, there has been lot of interest in using super hydrophobic (SHP) coatings as anti-biofilm forming surfaces in biomedical devices and surgical equipment to reduce the use of antibiotics. Accordingly, superhydrophobic surfaces were generated by deposition of sol-gel nanocomposite coatings on SS-304 substrates. Nanocomposite superhydrophobic sols were deposited by dip coating and heat-treated at 130°C. Surface roughness, water contact angles (WCA) and sliding angle measurements were carried out. Water contact angles of ~155±3 degrees, as shown in Fig. 6 and sliding angle <5 degrees were obtained for the coatings. Durability and adhesion of coatings were evaluated using weathering tests and scratch resistance measurements. The antibacterial resistance of uncoated and coated substrates was analyzed. As seen from Table 1, bacterial inhibition of ≥ 93 % was obtained for the superhydrophobic surfaces towards the bacterial species E. coli for an exposure time of 30 min and 4 hours. Superhydrophobic coatings were seen to be promising for use as antibiofilm forming surfaces.

Table 1 Comparison of antibacterial activity for uncoated and superhydrophobic coated substrates

Sample	*Time of exposure (min)*	*Initial E.coli count*	*Final E.coli count*	*Bacterial inhibition (%)*
Uncoated SS 304	*30*	*$1x10^5$*	*80,00*	*91.7 ± 0.2*
SS304|SHP sol	*30*	*$1x10^5$*	*6,367*	*93.7 ±0.3*
SS304| SHP sol	*240*	*$1x10^5$*	*1,233*	*98.8± 0.03*

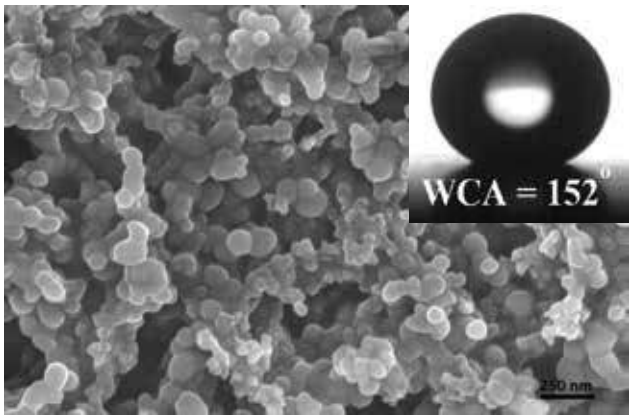


Fig. 6 FESEM image of the surface morphology of superhydrophobic coatings on SS 304

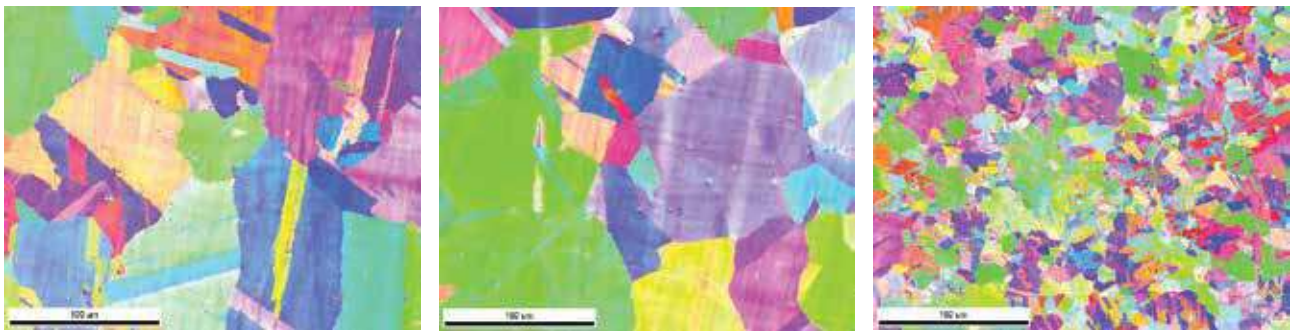
Centre for Materials Characterization and Testing

A material can be characterized using a variety of experimental techniques based on several aspects such as microstructure, structure, chemistry and mechanical behaviour. While the Centre for Materials Characterization and Testing has strived to provide an as complete picture of a material as possible, the existing facilities do favour microstructural characterization using a suite of electron microscopic tools. Chemical (elemental) analysis is being carried out at present using energy dispersive spectroscopy (EDS). As is known, EDS is not really suitable for the determination of trace elements whereas increasingly, several projects and fields of research in ARCI require accurate chemical analysis with high sensitivity. Thus, to strengthen this aspect of chemical characterization, the Centre is procuring an inductively coupled plasma optical absorption spectroscopy (ICP-OES) unit which can be used for detection of most elements even in ultralow concentrations (parts per million).

In order to make the facilities of the Centre accessible to users from outside the Organization, both from academia and industry, the portal 'Facilities for Materials Characterization and Testing' (FMCT) has been implemented on the ARCI webpage. External users can now view the list of available facilities, obtain relevant information from the brief write-ups provided and have their experiments carried out at the Centre. The procedure has been streamlined and the feedback has been positive.

In addition to carrying out characterization of samples from different Centres of ARCI, Team Members are also involved in individual research projects. In the past year, the focus has been on two areas of work, namely additive manufacturing and high entropy alloys.

In the following, highlights of research on the structural stability of CoCrFeMnNi high entropy alloy, additive manufacturing of IN718 superalloy, laser clad Inconel 625 and corrosion behaviour of WC-based coatings are presented.



Crystal orientation maps on Inconel 718 samples fabricated by additive manufacturing

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Structural stability of CoCrFeMnNi high entropy alloy with Ni content

Multi-component or high entropy alloys (HEAs) are a new class of materials and are being explored for possible structural applications. Among the well-studied compositions is the CrMnFeCoNi alloy which possesses superior mechanical properties, especially at cryogenic temperatures. One of the aspects of discussion in the literature is that this alloy becomes unstable if the content of Ni is reduced, or if Ni is removed completely from the composition. Therefore, we have investigated the evolution of the phases in the $(CrMnFeCo)_{100-x}Ni_x$ HEAs with varying Ni content (x=0, 2.5, 5, 10, 15, and 20, at. %). The alloys were synthesized by vacuum arc-melting and the microstructure as well as hardness of the as-cast alloys have been studied. Alloys with low Ni content ($x \leq 2.5\%$) consist of a two-phase microstructure of dendritic and inter-dendritic regions with fcc (matrix) and tetragonal (Sigma) crystal structure, respectively (Fig. 1). When the Ni content is 5 at. %, a two-phase structure with fcc (matrix) and bcc (secondary phase) are observed, with the addition of Mn-rich inclusions that are present in the entire matrix. Alloys with higher Ni content ($x \geq 10$, at. %) exhibit a single phase fcc structure. The secondary phase in the HEA transforms from tetragonal to bcc with increase of Ni from 2.5 to 5 at. % and further increase of Ni suppresses the secondary phases. The hardness of the HE alloys decreases from 320 to 120 Hv with an increase of Ni content (Fig. 2). High hardness in the HE alloys with low Ni content is due to the mixture of both fcc and hard tetragonal (sigma) phases. This study indicates that the CrMnFeCoNi alloy is stable even when Ni content is low.

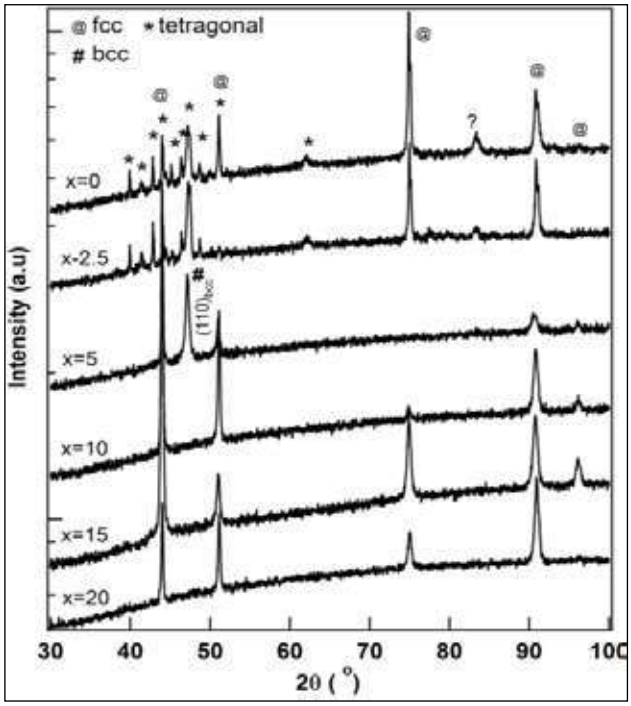

Fig. 1 Superimposed XRD profiles of the as-cast $(CrMnFeCo)_{1-x}Ni_x$ high entropy alloy as a function of Ni content

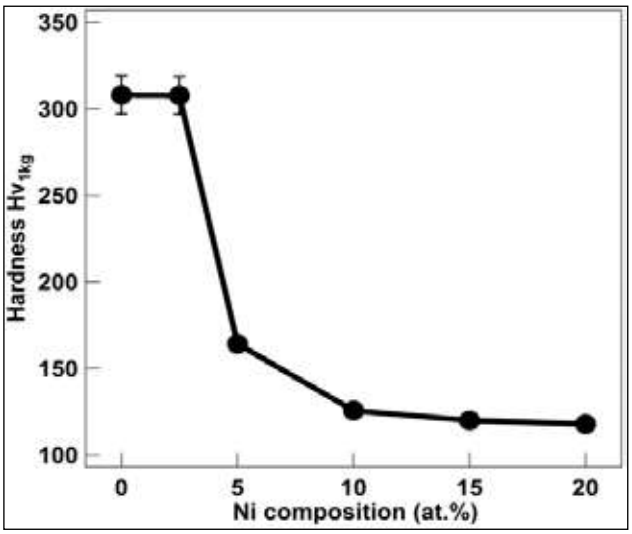

Fig. 2 Superimposed XRD profiles of the as-cast $(CrMnFeCo)_{1-x}Ni_x$ high entropy alloy as a function of Ni content

Additive manufacturing of IN718 Ni-base superalloy using powder synthesized in-house

IN718 is a prominent superalloy that was introduced nearly 50 years ago but constitutes half of superalloy tonnage even today. The primary alloying elements are Cr, Fe, Nb, Al, Ti, Mo and C. Cr, Fe and Mo dissolve in the Ni matrix and offer solid solution strengthening, while Cr provides resistance to high temperature oxidation and corrosion. Strengthening of IN718 at elevated temperatures is primarily due to the presence of γ" and γ' precipitates and the superior mechanical properties up to 650°C are especially due to γ" that has high solvus temperature. C aids in formation of NbC that gets precipitated along grain boundaries and aids in restricting high temperature deformation by arresting grain boundary sliding. IN718 is used in the manufacture of aerospace components such as engine shafts, combustion chambers and guide vanes.

Additive manufacturing (AM), commonly termed as a disruptive technology, has the ability to create components with net shape directly from raw material in the form of powder, wire or rod. AM offers advantages such as creation of complex geometries that would otherwise not be possible by conventional techniques, consumption of very low quantities of raw materials, and very little wastage. Further, AM allows the cost-effective manufacture of components even when the required numbers are low and hence the aerospace industry has swiftly adopted this technology due to these advantages. Metal powder-based AM has gained prominence due to its ability to create fine features with good surface finish.

IN718 powder has been synthesized in ARCI using the inert gas atomization technique. The powder is classified to start with and a suitable size range is selected to meet the requirements of the processing unit. A powder bed-based AM machine of SLM make was employed to build horizontal coupons. Coupons were made using IN718 powder produced in-house, as well as with commercial powder certified by the manufacturer of the AM unit, and the as-build microstructure of the bulk thus produced was studied. Figure 3a shows the melt pool morphologies captured along the cross-section of the coupon. When observed at higher magnification using a scanning electron microscope, the as-processed coupons were found to have fine dendritic microstructure as shown in Figure 3b, a typical feature of IN718 solidification. Further observations confirm the presence of NbC and the Laves phase (Ni3Nb), since the final liquid that solidifies in the inter-dendritic region gets enriched with Nb and other elements. Coupons generated from both the powders have identical microstructural features. In order to dissolve the Laves phase that consumes Nb needed for γ" precipitation, the coupons are subjected to solutioniziing at 1080°C followed by a double age treatment consisting of soaking at 720°C for 8h and final soaking at 620°C for 8 hrs. Figure 3c shows transmission electron microscopy (TEM) image after double aging depicting γ" and γ'. Figure 3d shows tensile test results of both samples which show a marked increase in strength after precipitation hardening. From these observations it can be said that the powder manufactured in-house at ARCI has responded similarly to that of the commercial powder for which the machine manufacturer has established the process parameters to build bulk IN718 Ni based superalloy.

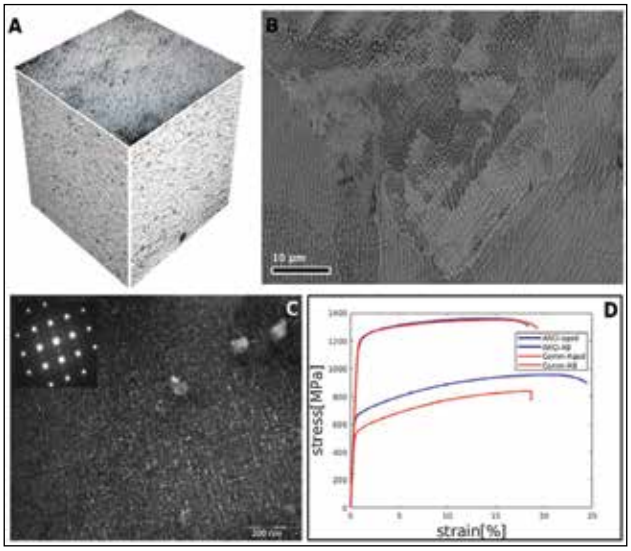

Fig. 3 (a) 3D perspective of as-build coupon showing melt pool morphology. (b) BSE image depicting cellular structure in as-build material. (c) TEM image of homogenized and aged sample showing presence of γ" and γ'. Same is confirmed by SAED shown in the inset. (d) Tensile test results of samples made from ARCI-powder and commercial powder in as-build and aged condition

Effect of dilution on the microstructure of laser clad Inconel 625 layers

Inconel 625 is a nickel based superalloy with good high temperature strength, excellent corrosion resistance, high ductility and good resistance to stress corrosion cracking. Laser cladding of Inconel has several advantages over competing coating techniques such as plasma cladding, arc welding and thermal spraying. In this work, we explore this material in coated form by laser cladding for high temperature applications in the power industry.

Inconel 625 was deposited on a 0.27% carbon steel substrate with the powder being precisely fed into the laser-substrate interaction zone using an off-axis nozzle. The effect of laser power P (W) on the microstructure was

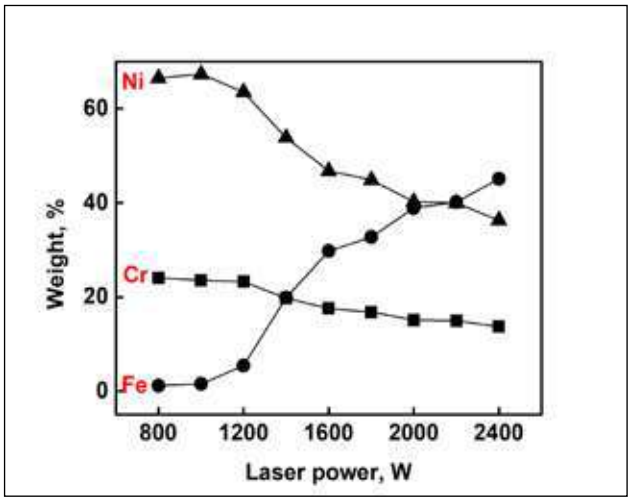

Fig. 4 Variation in the content of major elements of the laser clad layers with laser power

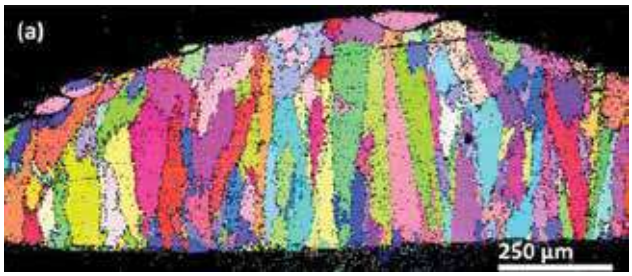

Fig. 5 Inverse pole figure images of laser clad layer processed at (a) 1000 W and (b) 2400 W

studied by varying the continuous wave laser power from 800 W to 2400 W in 200 W increments while the scanning speed V (8 mm/s) and powder feed rate (16 g/min) were maintained constant. The dilution from the substrate increased from about 1 % at 800 W to nearly 40 % at 2400 W. The corresponding variation in the chemistry of the major elements as measured using energy dispersive spectroscopy (EDS) is shown in Fig. 4. It is observed that beyond 2000 W, the clad layer is no longer Nickel rich but Iron rich. The microstructure studied using Electron back scattered diffraction showed typical columnar growth of the grains at all the conditions (Fig. 5). Laser clad layers processed at higher laser power showed grains with smaller aspect ratio (length/width) as compared to layers processed at lower laser power. Microstructure at higher magnification revealed a considerable variation in the amount and distribution of Molybdenum and Niobium rich precipitates. In the clad processed at lower laser power, the precipitates were discontinuous and fewer in number. With increasing laser power, the content of precipitates gradually increased and also formed in a network. The effect of this microstructure on the mechanical and corrosion properties is part of on-going research.

An Electrochemical Impedance Spectroscopy Study of corrosion behavior of WC-(W,Cr)2C-Ni coatings on Mild Steel

High durability coatings are developed continuously in order to increase the wear and corrosion resistance of different materials. Short-term test methods are very essential to evaluate the corrosion properties of coatings/metal systems in order to design the systems for long term durability. Electrochemical impedance spectroscopy (EIS) is a powerful non-destructive test method where corrosion processes and kinetics of coated systems can be studied, in which the impedance of an electrochemical system is studied as a function of the frequency of an applied AC signal.

Two different types of coatings of WC-20Cr-7Ni and WC-12Co cermet powders were deposited on mild steel substrates by the Detonation spray coating technique (DSC) with a coating thickness of 320 ± 20 µm. The corrosion behaviour of coatings was studied by EIS using an electrochemical interface SI1287 (Solartron) with SI1260 impedance analyser. Samples are tested in a three electrode cell using 3.5% NaCl solution as the electrolyte. The Nyquist plots obtained from impedance tests on bare, WC-(W,Cr)2C-Ni and WC-12Co coatings are shown in Fig. 6. The Nyquist plots are fitted with the suitable equivalent circuit, shown as an inset in the figure. In this model, Rs is the resistance of solution, Roxide and Coxide correspond to resistance and capacitance of the oxide layer, while Rct and Cdl are charge transfer resistance and capacitive behaviour at coating-solution interaction region. The $\chi 2$ values shown in Table 1 indicate the goodness of fit data where the very small values validate the proposed equivalent circuit. The Roxide value is high for bare MS sample and low for coatings, indicating the formation of a thick oxide layer on the bare MS sample as compared to the coatings. Among the coatings, the Roxide value of WC-(W,Cr)2C-Ni coating is half of the Roxide value of WC-12Co, from which it can be inferred that a very thin oxide layer has formed on the former coating. Moreover, the WC-(W,Cr)2C-Ni coating exhibited highest charge transfer resistance (Rct) value of 55,783 Ω.cm2 when compared to the WC-12Co coating (1498 Ω·cm2) indicating that the electrochemical reaction speed was less in WC-(W,Cr)2C-Ni coating as compared to the WC-12Co coating. The 'n' value of WC-12Co in the coating part of circuit is less than WC-(W,Cr)2C-Ni coating and bare MS samples may be due to combination of Co matrix and presence of defects in the WC-Co coatings. It is clear from the results that the WC-(W,Cr)2C-Ni coating exhibits significantly improved corrosion resistance which is attributed to the presence of matrix carbide phase (W,Cr)2C accompanied by high charge transverse resistance at coating-solution and thin oxide layer on the coating surface.

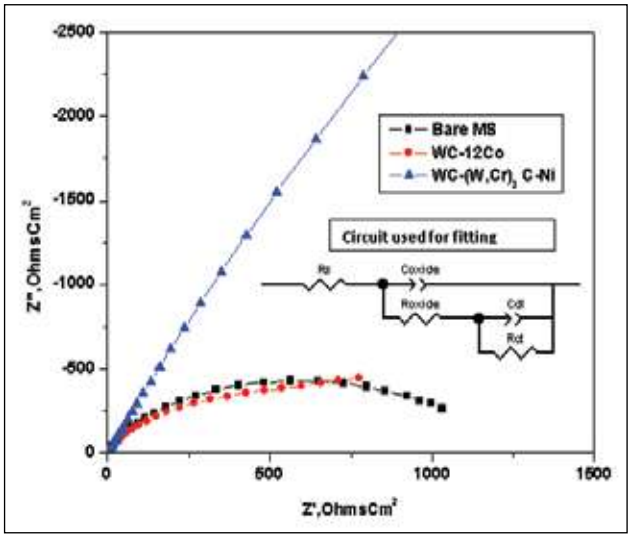

Fig. 6. Nyquist plots of bare, WC-12Co, WC-(W-Cr)2 C-Ni coated samples after 24 hrs exposure to 3.5% NaCl. The circuit used for fitting the data is shown as an inset.

Table 1 Equivalent circuit fit values of impedance test results on substrate and coatings after immersion in 3.5 wt% NaCl solution for 24 h.

Sample ID	*Rs Ω·cm²*	*Coxide F/cm²*	*n*	*Roxide Ω·cm²*	*Cdl F/cm²*	*n*	*Rct Ω·cm²*	*χ^2*
Bare MS	*0.91*	*4.2E-4*	*0.89*	*87.6*	*4.3E-4*	*0.66*	*1130*	*0.004*
WC-12Co	*0.94*	*3.1E-3*	*0.98*	*24.36*	*1.3E-3*	*0.50*	*1498*	*0.001*
WC-(W,Cr) 2C-Ni	*1.49*	*2.7E-6*	*0.99*	*12.92*	*7.7E-5*	*0.77*	*55,783*	*0.002*

Centre for Technology Acquisition and Transfer

Centre for Technology Acquisition and Transfer (CTAT) facilitates the utilization of R & D results and associated Intellectual Property (IP) developed at ARCI. ARCI's commitment to support the creation of new ventures / advanced materials R & D commercialization is reflected by strategies that are continuously being evolved. Processes and value addition requirements for technology development, demonstration and transfer have been thoroughly understood, especially for a laboratory like ARCI, to create Intellectual Property Development Indices (IPDIs) from level 1 to 10. Engagement models are available to capture different scenarios of partnerships from early stages to the technology transfer in the IPDI value chain. These models support the utilization of available intellectual property by envisaging multiple partnership situations involving industrial organizations, academic institutions and other R & D organizations. Creative partnerships are structured based on the unique nature of each case followed by negotiation and finalization of the agreements. CTAT also reviews the invention disclosures for commercial potential and patentability. IP filing and prosecution process has accordingly been designed. Major partnership MoUs/agreements for the following technological areas were signed during 2018-19:

- Laser softening process on high-strength steel sheets
- Sol-gel coatings on cold rolled and close annealed and galvanized iron steel sheet
- Powders for additive manufacturing and application development
- Porous carbon materials for high performance supercapacitor
- Demonstrate the unique capabilities of thermal spray coating technologies, develop aerospace applications, supply the coated parts
- Powder Bed Additive Manufacturing Technology
- Antibacterial coatings on scrub pads
- Fe based alloys
- Absorber coatings sol composition and coating technique for selective absorber coatings on SS 304 substrate for solar thermal application
- Biomedical Materials/Coatings/Devices

Inputs were provided in more than 20 cases for R & D planning, patent filing, publications/technical discussions through analysis conducted using patents and other non-patent sources. 9 national patents were filed. ARCI was granted 9 patents during the year. Over 60 leads were generated by sustained outreach efforts such as participation in exhibitions, delivering invited lectures, making presentations, and sharing perspectives as invited speaker in panel discussions. Major exhibitions in which ARCI showcased its technologies and knowledge-base were International Conference on Surface Engineering (INCOSURF – 2018) Bengaluru; Rural innovators start-up conclave 2018 at National Institute of Rural Development and Panchayati Raj (NIRDPR) at Hyderabad; Laser world of Photonics India at Bengaluru; International Exhibitions and Conferences on Materials, Engineering, Technology & Heat Treatment at Mumbai; FISITA World Automotive Congress 2018 organized by Society of Automotive Engineers (SAE) at Chennai; 4th Indian International Science Festival (IISF) at Lucknow; International Welding Symposium – IWS2k18 at Mumbai; Aerospace & Defence Innovation Summit (ADIS) and ADIS Exhibition 2018 at Hyderabad and 8th International Engineering Sourcing Show (IESS) at Chennai. Business Workshop on Metal Powders was organized during September 2018 to finetune the R & D programmes aimed at development of such powders. Health Innovation Summit was organized in association with IIT Bombay Alumni Association during November 2018. ARCI was a technical partner for 28th International Conference on Management of Technology (IAMOT) 2019 organized in April 2019. Working groups have been making efforts to intensify interactions with the stakeholders of aerospace, biomedical and sensor domains. Costing of over 50 technical projects / technologies was conducted.

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Fig. 1 Schematic showing IPDIs , milestones and value addition activities carried out by CTAT

IPDI →	1	2	3	4	5	6	7	8	9	10
Activities →	Basic concepts and understanding of underlying scientific principles	Shortlisting possible applications	Research to prove technical feasibility for targeted application	Coupon level testing in simulated conditions	Check repeatability/ consistency in Lab at coupon level	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	
Possible Contractual Agreement →	• Cooperative R&D • R&D Consortium • Inter- Institutional • Sponsored R & D • Contract R & D					• Joint Demonstration • Technology Demonstration and Transfer • Knowledge Transfer • Option			• Option • Technology Transfer	
Role of CTAT →	• Competitive Intelligence • Identification of possible collaborators • Selecting appropriate engagement model (decision variables: IPDIs, Collaborators, IP ownership & licensing methodology, deliverables, milestones, financials etc.) • Preparing/ finalizing contractual Agreements • Patent analysis & filing • Cost estimates of products associated with the technology					• Activities mentioned from IPDI 1to 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 1-8 • Receivable management (collection of technology transfer fees/royalties) even beyond IPDI 10	

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 17 technologies to 29 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	*Laser Cladding Technology for burner tip nozzles*	*Thermal Power Plants Applications*	*Ongoing*
31	*Selective absorber coatings on SS 304 substrate for*	*Solar Thermal Application*	*Ongoing*
32	*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.	**Advanced Detonation Spray Coating Technology (DSC) MARK-II** **Intellectual Property Development Index (IPDI):** Process parameters were optimized. Coating quality, repeatability and reliability studies were completed.	**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.*

S. No	Technology and Related Issues	Key Features and Applications	
2.	**Micro Arc Oxidation** **Intellectual Property Development Index (IPDI):** Technology transferred to 3 companies and is available for transfer	**Key Features:** - *Ability to coat Al, Ti, Mg and Zr metals and their alloys* - *Ease to coat complex shapes and difficult to access regions* - *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 industries such as textile, automobile etc.*
3.	**Cold Gas Dynamic Spray Technology** **Intellectual Property Development Index (IPDI):** Reassessing feasibility (IP, Competition, Technology, Commercial)	**Key Features:** - *Indigenously developed state of the art PLC based automated Portable control panel (Max Pressure – 20 bar)* - *Different set of nozzles* *a. For low melting materials (polymer based)* *b. High deposition rate or coverage area* *c. Low deposition rate or coverage area* *d. For Ni based materials, Steels (Optional)* - *Compressed AIR as process and carrier gas* - *Max. Pressure- 20 bar; Max. Temp.-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, biomedical,sputter target* - *Cathodic Protection coatings* - *Anodic Protection coatings* - *Wear resistant coatings* - *Nanostrcutured / amorpohous coatings* - *High Entropy Alloy Coatings for High Temperature Applications*
4.	**Electro Spark Coating (ESC) Equipment Manufacturing Technology** **Intellectual Property Development Index (IPDI):** Technology transferred to one company and is available for transfer	**Key Features:** - *Simple and cost effective* - *Metallurgical bonded coatings with low heat input to the substrate* - *Any electrically conductive material available in electrode form can be coated on any conductive substrate* - *Equipment is portable and lends itself easily to automation for ensuring reproducibility* - *Capable of providing coating thickness in the range of 10 to 130 µm*	**Possible Applications:** - *Component refurbishment and to combat severe conditions of wear* - *Can be used for enhancing life of cutting tools such as end mills, taps and lathe bits*
5.	**Transparent Ceramics** **Intellectual Property Development Index (IPDI):** Ready for Technology Transfer	**Key Features:** - *Capability to fabricate polycrystalline transparent ceramic specimens of transparent alumina, aluminium oxynitride (AlON), spinel ($MgAl_2O_4$) through slip casting and Hot Isostatic Pressing* - *Capability to fabricate transparent zinc sulphide (ZnS) ceramics through Chemical Vapour Deposition (CVD)* - *Specific parameters depends on ceramic formulation*	**Possible Applications:** - *Dental Ceramics and Artificial Gem Stones* - *Solar Absorber Tubes and Lamp Envelops* - *IR sensor envelops* - *High temperature Furnace windows*
6.	**Electrochemical Methanol Reformation (ECMR) for Hydrogen Generation** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial)	**Key Features:** - *Energy consumption for Hydrogen production was found to be low, about 1/3rd of water electrolyzer.* - *Hydrogen can be produced at much lower temperature and pressure, unlike methanol reformer.* - *The hydrogen produced is highly pure and Hydrogen separation steps are not required.* - *Carbon based materials can be used for stack fabrication*	**Possible Applications:** - *ECMR can be integrated with renewable energy sources like wind, solar to store the energy in the form of hydrogen and it can be used in fuel cells.* - *In Power station as coolant* - *In Semiconductor industry as a reducing agent*

S. No	Technology and Related Issues	Key Features and Applications	
7.	**PEM Fuel cell Powered Materials Handling Devices** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** - *Air cooled/ closed loop liquid cooled PEMFC stacks to be developed.* - *PEMFC stacks with reduced weight and volume would be developed* - *Control system development for the battery fuel cell hybrid system.* - *PEMFC stack would operate optimum efficiency at variable operating loads.*	**Possible Applications:** - *Application in material handling devices like Forklifts* - *Application in recreational vehicles like Go Karts, Golf- Carts etc.* - *Power source for all mobile applications.* - *Power source for auxiliary units in mobile applications.*
8.	**PEM Fuel Cell based Power Supply Systems** **Intellectual Property Development Index (IPDI):** 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:** - *As decentralised 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 back up power for telecom industries.*
9.	**Sintered Silicon Carbide (SiC) Components** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** - *Tuneable 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 diameter.* - *Critical SiC parts can be manufactured.*	**Possible Applications:** - *Mechanical seals particularly for corrosive environment.* - *Impact and abrasion resistance parts.* - *Light-weight structural parts for aerospace applications.* - *Impact and wear resistant parts.*
10.	**Decorative Nanocomposite Coatings On Glass and Ceramics** **Intellectual Property Development Index (IPDI):** Prototype testing in real-life conditions	**Key Features:** - *Tuneable transmission and refractive index* - *Coating colour can be controlled by suitable choice of dopants* - *UV, temperature stable and weather proof* - *Easy recyclability due to complete degradation of organic constituents at low temperatures* - *Opaque coatings possible with high temperature durability*	**Possible Applications:** - *Tiles for aesthetic or decoration* - *Scratch resistant, coloured coatings for glass bottles used in various industries for storing perfume, medicines etc.*
11.	**Hard Coatings on Plastics** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** - *High scratch hardness and abrasion resistance* - *Long life* - *Good adhesion* - *Coloured coatings possible* - *Can be coated on Polycarbonate, PMMA etc* - *Can be made easy-to-clean with low surface free energy*	**Possible Applications:** - *Road transport: Road and pavement markers* - *Helmet visors* - *Automotive headlamps/ windshields* - *Coloured head lamps for improved aesthetic appeal and style* - *Ophthalmoscopic lenses* - *Bi-aspheric lenses used in indirect ophthalmoscopy* - *Aircraft canopy*
12.	**Solar Selective Coatings for Stainless Steel and Aluminium Substrates** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** - *94 ± 1 % absorbance in 300-1500 nm range* - *14 ± 1 % Thermal IR emittance* - *Withstood 20 cycles of thermal cycling at 350°C* - *Withstood 80 h of salt spray test as per ASTM B117* - *Non-toxic and environmental friendly*	**Possible Applications:** - *Solar selective coatings on absorber tubes of Concentrated Solar Power plant (Non-evacuated up to 250 deg C and evacuated up to 400 deg C)* - *Solar selective coatings on metal tubes for water heating applications (up to 100 deg C)*

S. No	Technology and Related Issues	Key Features and Applications	
13.	**Highly Transparent Weather Resistant Easy to Clean Coating Technology for High Performance of PV Modules & Other Applications** **Intellectual Property Development Index (IPDI):** Ready for Transfer	**Key Features:** *- Highly transparent (no loss in transmittance)* *- Hydrophobic Property > 1100 WCA* *- High Weather Stability* *- High mechanical stability* *- Easy to coat and curable at ambient conditions* *- Low cost production*	**Possible Applications:** *- Solar PV Panels* *- CSP mirrors (aluminum and glass)* *- Automobiles* *- Textiles* *- Plastics*
14.	**Self-cleaning smart carbon-based TiO2 for indoor and outdoor paints and other applications** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** *- Self-clean property under visible and sunlight* *- Good dispersion in solvents* *- High stability in visible and sunlight* *- Easy to incorporate into any object*	**Possible Applications:** *- Ceramic tiles* *- Indoor and outdoor paints* *- Anti-bacterial and anti-fouling applications*
15.	**Medium & Low temperature stable solar absorber tubes for solar thermal applications** **Intellectual Property Development Index (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*
16.	**High performance anti-fogging and antireflective coatings for optical, solar and display applications** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** *- High transmittances in visible and solar regions: >98 % (in visible) >96% (in solar)* *- Low temperature curable (80-1000 C)* *- High temperature stability: Max up to 10000C* *- Weather stability: > 200 hrs withstand in high humidity (>90%) at 500 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*
17.	**Nanosilver Impregnated Ceramic Candle Filter** **Intellectual Property Development Index (IPDI):** Technology transferred to one company and is available for transfer on non-exclusive basis	**Key Features:** *- Successfully field tested at various villages in Andhra Pradesh with a non-governmental organization* *- Non electrical power and pressurized water required* *- Ease in maintenance* *- Commercially attractive {very low amount of silver used (0.2 wt %), Cost increase: candle (30-50%) and filter assembly (3-5%)}* *- Replacement needed once in six months*	**Possible Applications:** *- Ceramic candles for drinking water purification*
18.	**High Performance Varistors made from Doped ZnO Nanopowders** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	**Key Features:** *- Patented technology* *- Lower sintering temperature and time compared to micron powders* *- Order of magnitude higher breakdown field, 2-3 times coefficient of nonlinearity and comparable leakage current density*	**Possible Applications:** *- Power engineering* *- Automobile industry* *- Household electronics* *- Telecommunications*

S. No	Technology and Related Issues	Key Features and Applications	
19.	**2D-Nanolayered Transition Metal Sulfides (2D-NTMS)** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial) after completing field trials	**Key Features:** - *Synthesis of pure as well as mixed WS_2/ 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*	**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* - *Electrocatalyst for HER* - *Li-ion battery electrode* - *Self-lubricating composites and coatings (metallic/ceramics/ polymer)* - *Sensors and actuators*
20.	**Fe- based Cerametallic Friction Pads for Clutch Plates of Heavy Vehicles** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial) after completing field trials	*K*ey **Features:** - *Use of non carcinogenic materials* - *Improved wear and coefficient of friction* - *Fe-based sintered pad* - *Flexibility of single or dual sintered friction pads* - *Indigenous equipment for processing* - *Reduced post sintering operations* - *Production level manufacturing process*	**Possible Applications:** - *Clutch and brakes of heavy commercial vehicles* - *Aircraft brakes* - *Passenger vehicles like buses* - *Wind mill applications* - *Railways* - *Military tanks*
21.	**Multifunctional Titania (TiO_2) Microspheres for Self Cleaning Applications** **Intellectual Property Development Index (IPDI):** Checking repeatability/consistency at prototype level.	**Key Features:** - *Titania microspheres suspension in water at neutral pH* - *Efficient photocatalyst* - *Anti-bacterial* - *UV absorber* - *Visible light reflector* - *Simple and scalable chemical synthesis* - *Novel process for which patent is applied*	**Possible Applications:** - *Self cleaning textiles* - *Air purification* - *Water purification* - *Organic effluent treatment* - *Additive to exterior building paint for self cleaning walls*
22.	**Laser Welding and Laser-MIG Hybrid Welding** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	*K*ey **Features:** - *High power density* - *Single pass welding of thick* - *sections* - *Controlled heat input welding* - *with precision* - *No vacuum requirement*	**Possible Applications:** - *Tailor welded blanks for automotive applications etc.* - *Can weld a wide variety of materials and thicknesses* - *Can weld magnetic materials unlike electron beam welding* - *Steel plates, thick section welds, ship building etc.*
23.	**Laser Surface Hardening Treatment** **Intellectual Property Development Index (IPDI):** Check repeatability / consistency at prototype level	*K*ey **Features:** - *Selective localized area hardening with minimal heat input* - *No quenchant requirement* - *No surface damage* - *Excellent reproducibility with ease of automation* - *Negligible post process machining requirement* - *Controlled case depth* - *Refined homogenous microstructures* - *Minimal distortion* - *Chemical Cleanliness*	**Possible Applications:** - *Suited for wide range of steels, cast irons and profiles* - *The process can be developed for hardening of a variety of components such as crankshafts, camshafts, piston rings, tooling and dies, bearing steels, steam turbine blades, sheet metal etc.*
24.	**Laser Surface Coating (Alloying and Cladding)** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial) after completing field trials	**Key Features:** - *Material to be coated is fused using a laser beam and deposited on a substrate with good metallurgical bonding but with minimal base metal dilution* - *Low heat input resulting in fine microstructures* - *Provides crack-free clad layers without porosity*	**Possible Applications:** - *Wear plates for different applications* - *Component repair and refurbishment*

S. No	Technology and Related Issues	Key Features and Applications	
25.	**Laser Drilling** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial) after completing field trials	*Key Features:* - *Non-contact drilling method* - *Holes of large aspect ratio and very small diameter (0.3 mm) can be drilled* - *Precise control of heat input* - *Holes can be drilled at shallow angles to the surface*	**Possible Applications:** - *A wide variety of materials such as metals, ceramics and composites etc., can be drilled* - *The process can be used for specific applications such as drilling of fine holes on high pressure nozzle guided vanes and combustion liners for aero-engine applications*
26.	**Exfoliated Graphite and its value added products** **Intellectual Property Development Index (IPDI):** Technology transferred to one company and is available for transfer	**Key Features:** - *Impermeable to fluids* - *Leak proof sealing under low turning torque* - *Easily cut and punched* - *Can withstand temperature range from -200°C to +500°C in oxidizing and up to 3000°C in inert atmosphere* - *Excellent thermal shock resistance. Does not age or creep* - *Cannot be wetted by molten glass, metal etc., self-lubricating, and resistant to all chemicals*	**Possible Applications:** - *Fuel Cells* - *Automotive* - *Oil refineries* - *Petrochemical industries etc.*
27.	**Know-How for Lithium Ion Cell Manufacturing** **Intellectual Property Development Index (IPDI):** Prototype testing in real-life conditions	**Key Features:** - *Prototype cells of 10 Ah have been fabricated and they exhibited a capacity retention of >80% after 1000 cycles with a Columbic efficiency of about 99%.* - *15 Ah SS-LIB cells have been fabricated and successfully optimized the formation cycles. 48V, 15Ah (720 Wh) battery pack was assembled and its performance test with e-cycles under off-line/on-line conditions has been carried out.* - *Fabrication of 30 m length LTO electrode using indigenous LTO materials by Li-ion pilot plant unit*	**Possible Applications:** - *EV Manufacturers* - *Grid storage for solar power* - *Solar Street light,* - *Telecom towers* - *Household or industry UPS power back up*
28.	**Development of Indigenous Electrode Materials for EV Applications** **Intellectual Property Development Index (IPDI):** Prototype testing in real-life conditions	**Key Features:** - *Large scale production of both anode and cathode materials.* - *Simple, economic and scalable processing method.* - *Performance of these materials as LIB electrodes are better than the comm'l ones*	**Possible Applications:** - *EV Manufacturers* - *Grid storage for solar power* - *Solar Street light,* - *Telecom towers* - *Household or industry UPS power back up*
29.	**Ceramic Inserts For Anti-mine Boots** **Intellectual Property Development Index (IPDI):** Initiate technology transfer	**Key Features:** - *Ceramic honeycomb inserts : A new concept* - *Sacrificial inserts and no splinters* - *Flexible in design* - *Light weight* - *Reflection of shock waves by air in channels* - *General Staff Quality Requirements (GSQR) 1095 -Qualified*	**Possible Applications:** - *Defence* - *Mining*
30.	**Ceramic Honeycomb Based Energy Efficient Air Heaters and** **Eco-friendly Sanitary Napkin Incinerators** **Intellectual Property Development Index (IPDI):** Support in stabilizing production	**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:** - *Incinerator manufacturers* - *Hostels* - *Hospitals* - *Household*

S. No	Technology and Related Issues	Key Features and Applications	
31.	**Lead Free Copper Alloys for Bimetallic Bearings** **Intellectual Property Development Index (IPDI):** Initiate technology transfer	**Key Features:** - *Make-in-India* - *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: 18μm/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*
32.	**New Magnetic Steel for Automotive Applications** **Intellectual Property Development Index (IPDI):** Prototype testing in real life conditions	**Key Features:** - *Cost effective soft magnetic material* - *Indigenous technology* - *Low Hc (<1 Oe) High permeability (> 103)* - *Relatively low core loss (~210 W/kg @ 1T, 1kHz)*	**Possible Applications:** - *Soft magnetic Stators and Rotors of AC/DC Motors* - *Rotor Claw pole of Lundell alternator* - *Magnetic relays, Actuator applications*
33.	**Pulse Electrodeposition (PED)** **Intellectual Property Development Index (IPDI):** Prototype testing in real life conditions	**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*
34.	**Repair and Refurbishment of Pressure Die Casting Die Components using Laser Material Deposition (Laser Cladding)** **Intellectual Property Development Index (IPDI):** Reassessing Feasibility (IP, competition, technology, commercial)	**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*	**Possible Applications:** - *Pressure die casting tools* - *High Temperature Extrusion tools* - *Hot Forging tools* - *Hot forming and Punching tools*

Support Groups

Electrical and Civil Maintenance

The Electrical and Civil Maintenance group is responsible for the operation and maintenance of basic infrastructural systems at ARCI. The group also builds new systems, with various augmentations and alterations in order to keep pace with the latest needs of various Centres of Excellence (COEs) at ARCI. The areas under which the group does development and maintenance work are electrical, civil, water supply and air conditioning.

Under electrical maintenance, the main activity comprises of operation and maintenance of the HT 33 KV & 11 KV systems and the LT 0.415 KV system, that distribute power to various equipment at the shop floor and also to electrical systems such as lights, fans and air conditioners at various COEs. During the year, the group carried out the regular preventive maintenance jobs of the 33 KV & 11 KV vacuum circuit breakers (VCB- Siemens make), air circuit breakers (L&T make) and completed replacement job of 33 KV incoming VCB. The group has taken up power quality studies of different electrical loads as a part of its activities and developed electrical distribution systems for newly constructed canteen building and for the new equipment installations at various COEs.

2500KVA (1x1500 KVA + 2x500 KVA) Diesel Generator Captive Power Plant (CPP) is maintained by the group which provides emergency power supply, during power outages, for the smooth operation of critical equipment at various COEs. In this connection, the group manages the regular preventive maintenance of the DG sets by the OEM and procurement and storage of HSD and other consumables.

Under maintenance of water supply system, which is spread across 30 acres within ARCI campus, the group makes sure that there is uninterrupted water supply to various users of cooling water for equipment and potable water supply to all COEs. Through continuous monitoring and maintenance, the group makes sure that the daily usage of water is maintained within the maximum demand of 250 KL per day from HMWS&SB. The group also carried out a number of repair and replacement jobs without causing service interruptions to users by planning the work during holidays. The group maintains 33 numbers of Aqua-guard water purifiers located at all buildings to provide safe drinking water.

Under civil maintenance, the group constructs new buildings expanding the existing infrastructure of various COEs and also alterations and modifications to existing spaces so that changing needs can be accommodated. During the year, the group executed modification work for canteen building and the old CEC building. Old CEC building was modified to accommodate the CITS group. Canteen modification work was aimed at improving the ambiance and user and environment friendliness. Taken up minor repairs and modification works of the existing about 25000 sqmts of built up area. Necessary co-ordination provided for construction of a novel sewerage treatment system (Phytorid) that is being built at ARCI.

Under air-conditioning system maintenance, the group carried out maintenance and repair work of air conditioners at different COEs (a total of 330 units and with total capacity of 580 tons). The group installed and maintained water dispensers/coolers connected with the Aqua-guard water purifiers at 36 buildings across the campus.

ARCI joined the National Solar Mission under National Action Plan on Climate Change (NAPCC). The NAPCC gives the direction, which India needs to take, to mitigate and adapt to climate change. Under this mission, the ECI group has taken up a project to set up 500 KWp grid connected Roof Top Solar (RTS) plant. This plant will be spread over three rooftops at Centre for Nanomaterials, Center for Engineered Coatings and Centre for Sol-gel Processing.

ECI group along with BHEL has already installed a 380 KWp plant over the Centre for Sol-gel Processing and Nano Centre buildings and also started generation. Another 120 KWp installation is in progress on the rooftop of the Nano Centre and Centre for Engineered Coatings buildings. 1580 numbers of mono & poly crystalline type solar panels tested at the electro luminescence (EL) test facility, developed by the group, as part of quality assurance plan of the ongoing RTS plant installation work.

The group is also working on an infrastructural system renovation project, for upgrading and renovating the control & protection systems of Electric substations (33/11 KV & 11/0.415 KV), DG sets as back up for selected users. ARCI is planning to execute this with the help of a consultancy firm.

Nano Building Solar Plant

Sol Gel Building Solar Plant

EL Test Facility

Technical Information Centre

The mandate of the Technical Information Centre (TIC) is to provide access to important scientific and technological information to the ARCI family, which is fulfilled through both print and online resources. TIC continues to make progress with the acquisition of new books, and through online subscriptions of many journals and databases.

Collection: The present collection stands at 1667 books and 2307 bound volumes of journals. Subscriptions to over 20 National and International print journals are now available in areas of relevance to ARCI and in addition, TIC also subscribes to several e-journals to meet its requirements.

Journal Consortium: ARCI is a member of National Knowledge Resource Consortium (NKRC), a group of the research laboratories of both CSIR and DST for subscription and sharing of electronic journals and databases. ARCI continues its partnership with NKRC, and currently has access to over 2000 e-journals of major Science, Technology and Medicine (STM) publishers such as American Chemical Society (ACS), American Institute of Physics (AIP), Elsevier, IEEE, Nature Publishing Group (NPG), Royal Society of Chemistry (RSC), Springer, Taylor & Francis and Wiley. In addition to the journal literature, ARCI also has access to abstracting databases Scopus and Web of Science (WoS). All these e-resources were well used by the ARCI community.

Services Offered by TIC:

- Lending Service: All the Scientists, Technical Officers, and Research Scholars are allowed to borrow three books at a time, and other members can borrow two books at a time.
- OPAC: Under the Online Public Access Catalogue (OPAC) service, users can browse and search the library catalogue from any computer terminal that is on ARCI's Local Area Network (LAN).
- Document Delivery Services: The information needs of the scientific community of ARCI are continuously growing and to meet these, TIC provides shared resources. Close relations are being maintained with libraries of Institutions under DST and CSIR, as well as other National Laboratories of the country, and through these libraries, users in ARCI can obtain relevant published scientific literature on Inter-Library Loan (ILL) basis. A number of ILL requests are also fulfilled by TIC each week to help users in other Institutions.
- Plagiarism Detection Service: All manuscripts from ARCI earmarked for publication in journals and conferences proceedings, as also research reports and book chapters are scanned using Plagiarism Detection Software to check for possible plagiarized content, before communication to publishers. Plagiarism check is also mandatory for student theses and project reports before they are submitted to the respective Universities or Institutions. TIC undertakes the responsibility of scanning the documents and identifying areas that may show a match with published content, and provides suggestions to the authors so that suitable changes can be made as may be necessary.
- Scientometric Analysis: TIC extends its support to the scientific community by way of scientometric analyses to understand current global research pathways in the core research areas of relevance to ARCI, and also help members keep abreast of the trends in science policy that may have a direct impact on the research fields.
- Training programmes: TIC periodically organizes training programmes in the use of database software, especially when upgrades are available.

Table: e-resources subscribed by TIC though NKRC

#	*e-resource*
1	*American Chemical Society (ACS)*
2	*American Institute of Physics (AIP)*
3	*ASTM Digital Lirbary*
4	*Elsevier Science*
5	*IEE Xplore*
6	*IoP Science*
7	*JCCC*
8	*Nature Publishing Group*

#	*e-resource*
9	*Oxford University Press*
10	*Royal Society of Chemistry*
11	*SciFinder*
12	*Scopus*
13	*Springerlink*
14	*Taylor & Francis*
15	*Web of Science (WoS) & Derwent Innovations Index (DII)*
16	*Wiley-Blackwell*

Events, Data and Statistics

Major Events

Jayanti Celebrations

Dr. B.R. Ambedkar, Dr. Babu Jagjivan Ram and Mahatma Jyothirao Phule Jayanthi celebrations were held at ARCI on April 14, 2018. Dr. K. Murugan, President ARCI SC/ST Employees Welfare Association welcomed the gathering. Dr. T. Narasinga Rao, Dr. Roy Johnson, Associate Directors including ARCI SC/ ST Employees Welfare Association members paid rich floral tributes and spoke about the contributions made by Dr.Ambedkar, Dr.Babu Jagjivan Ram and Mahatma Jyothirao Phule towards the upliftment of downtrodden and women.

Dr. T Narasinga Rao and Dr. Roy Johnson paying tributes on the occasion of Dr. BR Ambedkar, Dr. Babu Jagjivan Ram and Mahatma Jyotirao Phula's Jayanthi celebrations at ARCI

International Yoga Day

"International Yoga Day" (IYD) was celebrated on June 21, 2018 at ARCI, Hyderabad. As part of celebrations, Smt. Chitra Ananth, Senior Teacher from the institute of Art of Living, Hyderabad delivered a lecture on "Coping with Workplace Stress". She also demonstrated few important yoga Asanas which was well attended by the staff members and research students. ARCI Chennai Centres celebrated IYD on June 21, 2019. All the staff members and students participated in a lecture and yoga practice session conducted by Mr. Krishna from Inspiring Fitness Services OPC Pvt. Ltd., Chennai.

Smt. Chitra Ananth with employees of ARCI on the occasion of International Yoga Day celebrations at ARCI

Independence Day

ARCI celebrated Independence Day on August 15, 2018. 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.

Annual Medical Check-up

Annual Medical Check-up (AMC) programme for ARCI employees for the year 2018 was carried out during September 18-19, 2018. Medical tests were carried-out for the employees categorized under two age groups i.e. below 45 years and 45 years & above. Apart from prescribed medical tests under AMC, special tests such as 2D Echo, Liver function tests, Vitamin D 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 all the women employees.

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. The minutes of the meeting were sent to DST and Quarterly reports on Hindi works were sent to DST, Department of Official Language (D.O.L), Regional Implementation Office (South), Bengaluru with a copy to Town Official Language Implementation Committee (TOLIC-3) and by online to D.O.L. Ministry of Home Affairs, Govt. of India for review. During the year ARCI issued 4734 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 to the nominated research students. ARCI has also been imparting regular training in Hindi to its employees under the Hindi Teaching Scheme. Employees who have successfully completed Prabodh, Praveen and Pragya were given cash awards and incentives as per norms. To encourage the employees to carry out their day-to-day official works in Hindi, a cash incentive scheme is in place and four employees received cash awards, during the year for carrying out official works in Hindi.

One Day Scientific & Technical Hindi Seminar: Under the auspices of TOLIC-Hyderabad (3), ARCI independently organized one day Scientific & Technical Hindi Seminar on "Role of Scientific Organizations in Nation's Development" on 6th June, 2018 at ARCI, Hyderabad. The main aim of this one day seminar was to disseminate the outcome of research activities being carried in national R&D

One Day Scientitic and Technical Hindi Seminar, Hindi Saptha Celebration and Release of 1st Annual Hindi Magazine

laboratories among the common public as Hindi plays a vital role in making them to understand better. Shri B.S. Rawat, Joint Secretary (Admin. & O.L.), Department of Science and Technology, Govt. of India, New Delhi was the Chief Guest. A tremendous response was received from government R&D institutes of Hyderabad. From 31 R&D institutes about 60 participants have attended the seminar. 29 research papers were presented in Hindi, out of which 7 research papers were from ARCI. On this occasion, a souvenir was released by the Chief Guest and Director, ARCI.

Hindi Saptha Celebrations: ARCI celebrated "Hindi Saptha" during September 11-20, 2018. As part of Hindi Saptha 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. Shri Eashwar Chandra Mishra, Assistant Director, Central Translation Bureau, Bengaluru was the chief guest for the occasion. He delivered a lecture on "Possibility of Usage of Hindi in Writing Scientific Research Articles". Shri Naveen Naithali, Hindi Lecturer, Central Hindi Teaching Scheme, Hyderabad, conducted the quiz programme. All the nominated employees and research students actively participated in the Hindi Saptha celebrations which concluded on September 20, 2018. All the winners were given prizes.

Release of Annual Hindi Magazine: In continuation to ARCI's efforts in 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, 1st edition of Hindi magazine "SRUJAN" was published on March 29, 2019 in a grand function by the Chief Guest Shri Gyanshyam Sharma, Principal Government Women's College, Hyderabad. Dr. Tata Narsinga Rao and Dr. Roy Johnson, Associate Directors, OLIC members and the staff members participated in the function.

Swatch Bharat Abhiyan at ARCI

As part of 'Swatch Bharat Mission', ARCI regularly observed cleanliness. All the staff members of ARCI Hyderabad, Chennai Centres and Gurugram Offices actively participated in the "Swatchhta Pakhwada" campaign held from May 1-15, 2018. The Swatchhta Pakhwada began with a mass pledge administered by the Director, ARCI to the employees and students. A work order was given to CSIR-NEERI for construction of Phytorid Sewage Treatment plant. During the entire period of pakhwada, cleaning activity of each of the Centres were carried out by the respective staff members and a mass cleaning activities throughout ARCI campus were coordinated

Order placement of Phytorid Sewage Treatment Plant on CSIR-NEERI at ARCI by Dr. G. Padmanabham, Director-ARCI on the occation of Swatchhta Pakhwada Week. The Committee members are also seen in the picture

by the committee. Slogan & Essay writing/Drawing competitions were conducted for the employee's children, followed by their visit to the various centres of excellence, where they had a rare opportunity to view live demonstrations of various sophisticated equipments and they interacted with scientists and research students. As part of plastic hazardous awareness programme, 500 jute bags with a slogan printed as "No to plastic bag" were distributed to everyone in the campus. On daily basis, reports on the activities carried out by ARCI during Swatchhta Pakhwada were sent to Department of Science & Technology, New Delhi.

Technology Day Celebrations

On the occasion of technology day celebrations, Dr. Roy Johnson, Associate Director, ARCI inaugurated Solar Power facility at Centre for Sol-gel Coatings, ARCI on May 11, 2018. Mr. V. Balaji Rao, Scientist "F" demonstrated solar power generation plant and interacted with employees children who attended the programme. Apart from the above live technology demonstrations activities were also organized for the students.

Technology day lecture was delivered by Dr. S. Ramakrishnan, Vikram Sarabhai Distinguished Professor, Vikram Sarabhai Space Centre, Trivandrum on "Launching A Satellite – An Overview of Rocket Science & Launch Vehicle Technology". Staff members and research students participated in technology day celebrations.

Mass Tree Plantation

Under Government of Telangana's 4th phase Haritha Haram programme, ARCI has taken up mass tree plantation programme on July 26, 2018. Dr. G. Padmanabham, Director, ARCI inaugurated the programme by planting a sapling. In his address, to the gathering, he emphasized on the importance of greenery and environment in our daily life. Mr. Paul Rajkumar, Special Officer, Haritha Haram was the Special Guest on the occasion. Dr. Tata Narasinga Rao and Dr. Roy Johnson, Associate Directors also spoke on the occasion and emphasized the importance of trees in maintaining the ecological balance. All the staff members, research students and outsourced employees actively participated in the programme and around 1000 saplings were planted in the campus.

Vigilance Awareness Week

Vigilance Awareness Week was observed at ARCI from October 29, 2018 to November 03, 2018. The theme of Vigilance Awareness Week was “Eradicate Corruption – Build a New India". The messages from the honourable President, honourable Vice President and CVC were read by Dr. R. Vijay, Scientist “F”& Vigilance Officer, ARCI. Dr. T. Narasinga Rao, Associate Director administered the

Saplings being planted by Dr. G. Padmanabham, Dr. T Narasinga Rao, Mr. Paul Rajkumar and employees of ARCI

pledge to all the employees, project staff and students and they were also encouraged to take the e-pledge. The pledge was also administered at ARCI-Chennai and ARCI-Gurugram. As part of the Vigilance Awareness Week, Mr. A.Y.N. Krishna, IPS, Joint Director, Central Bureau of Investigation (CBI), Hyderabad delivered a lecture on October 31, 2018 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.

The Vigilance Awareness pledge being administered at ARCI-Hyderabad, Chennai and Gurugram offices

Annual Day

The 22nd Annual Day was celebrated at ARCI, Hyderabad on December 28, 2018. The annual day program began with plantation. On this occasion, Dr. Joydip Joardar, Scientist "F" and Chairman, Annual Day Committee welcomed the gathering. Dr. G. Padmanabham, Director, ARCI briefed about the major achievements of ARCI during the year. Dr. T. Narasinga Rao and Dr. Roy Johnson, Associate Directors also addressed the gathering. Various cultural events including songs, dances, recitation and skits were organized as part of the Annual Day Celebrations and many employees and students actively participated in these events along with their children and family members. Prizes were distributed to all the winners. The celebrations concluded with vote of thanks by Dr. Dibyendu Chakravarty.

Dr. G. Padmanabham, Director-ARCI lighting the lamp on the occasion of Annual Day Celebrations at ARCI

ARCI Chennai Centres celebrated Annual day on January 25, 2019. Dr. D. Prabhu, Scientist "D" welcomed the gathering. Dr. G. Sundararajan, Distinguished Emeritus Scientist and Dr. R. Gopalan, Associate Director addressed the gathering and briefed about the achievements of Chennai Centres. All the staff members along with some of their family members participated in outdoor games such as Cricket, Indoor games like Badminton, Table Tennis and other fun events.

Republic Day

ARCI celebrated Republic Day on January 26, 2019. Mr. D. Ramesh, Security, Fire & Safety Officer welcomed the gathering, Dr. T. Narasinga Rao, Associate Director, ARCI hoisted the National Flag and addressed the gathering. Dr. Roy Johnson, Associate Director also addressed the gathering.

Dr. T. Narasinga Rao, Associate Director-ARCI hoisting the National Flag

National Science Day

National Science Day (NSD) was celebrated at ARCI during February 27-28, 2019. This year's theme for NSD was "Science for the People and People for the Science". The celebrations began on February 27, 2019 with Dr. P.K. Jain, Scientist "F" and Chairman of the NSD Committee welcoming the gathering consisting of staff members, research students etc. Dr. G. Padmanabham, Director ARCI briefed about the importance of National Science day Celebrations in the country and the important contributions of the scientists in the nation's development. On this occasion, Prof. P. Rama Rao, Distinguished ARCI Chair delivered a talk on "Plutonium (Pu): The Man made Wonder Material". On February 28, 2019, B.Tech., and M.Sc., students from few selected colleges in Hyderabad were invited for the celebrations. The Senior and Junior Research Fellows of ARCI had taken the students on tour to visit various centres of excellence, wherein they had opportunity to view various sophisticated equipment and live technology demonstrations. A slide show on Dr. CV Raman's life and his achievements was displayed on all the digital boards.

Fire and Safety

As part of fire and safety awareness programme at ARCI, a training on fire fighting was conducted by Shri D. Ramesh, Security, Fire and Safety Officer in all the Centres of Excellence in ARCI during the period 30th January, 2019 to

Prof. P. Rama Rao, Distinguished ARCI Chair delivering a talk. (Inset Prof. P. Rama Rao was felicited with a 3D model of his face profile by metal Additive Manufacturing [left] and Wax 3D Model [right]

Director-ARCI with students from B.Tech and M.Sc., college students on the occasion of National Science Day celebrations at ARCI

February 12, 2019. Employees, Project staff and research students attended the programme.

Safety Day Celebrations: ARCI observed National Safety Week during March 4-10, 2019. As part of 48th National Safety Day celebrations which was held on March 5, 2019, Dr. Roy Johnson, Associate Director and Chairman, Safety Committee, welcomed the gathering and in his address emphasized on various steps adopted for proper implementation of safety aspects at ARCI. Dr. T. Narasinga Rao, appreciated the various steps taken by the Safety Committee in implementing proper safety at ARCI. Shri V. Mahender, Technical Officer "C" & Safety Coordinator, and Shri D. Ramesh, Security, Fire and Safety Officer(SF&SO) and Shri P. Shiva Prasad Reddy administered safety pledge in Hindi and English respectively to the employees and research students. Shri D. Ramesh made a presentation on "Safety related activities at ARCI". Dr. Y. Srinivasa Rao, Scientist "F" and Dr. Prasenjit Barrick, Scientist "D", delivered talks on the safety practices at ARCI. Dr. Ritesh Vijay, Principal Scientists, CSIR-NEERI, Nagpur delivered a talk on "Waste Water Management". On this occasion Revised Safety Manual and ARCI Safety Policy were also released. Competition on Safety Slogan was conducted in three categories, about 85 participants actively took part in this event. Winner of each category were rewarded with prizes. The event concluded with vote of thanks by Smt. S. Nirmala, Scientist "E" & Safety Coordinator.

ARCI Internal Complaints Committee (AICC)

Internal Complaints Committees (AICCs) are functioning both at ARCI, Hyderabad and at ARCI Chennai, Centres. Both these Committees are actively involved in promoting awareness regarding Sexual Harassment of Women at Workplace. Bilingual awareness posters were displayed at prominent locations in ARCI Hyderabad and Chennai campuses. A One-day in-house awareness programme was organized for effective implementation of zero tolerance on "Sexual Harassment of Women at Workplace" for all the employees, research students etc. on December 27, 2018. A separate awareness programmes were also organized for all the outsourced staff on February 12, 2019. Timely awareness is created among the newly joined research fellows/project students and trainees.

At ARCI-Chennai, International Women's Day was celebrated on March 7, 2019. Dr. K. Ramya, Senior Scientist and Chairperson, AICC welcomed the gathering. Ms. Mahalakshmi Saravanan, Founder – Women Entrepreneurs India, Chennai was the Chief Guest. In the interactive session, she shared her life experiences about her start-up business and the problems which she faced and how her determination and perseverance made a breakthrough in her carrier. All the employees and research students of both the Chennai Centres have attended the celebrations.

Dr. Roy Johnson and Dr. T. Narasinga Rao, Associate Directors with the participants at the National Safety day celebrations at ARCI

Dr. R. Gopalan, Associate Director-ARCI and Ms. Mahalakshmi Saravanan, Founder–Women Entrepreneurs India, Chennai with the employees at ARCI-Chennai

Mrs. K Rama Devi giving her inspirational talk on the occasion of International Women's Day Celebrations at ARCI

International Women's Day was celebrated at ARCI, Hyderabad on March 8, 2019. Dr. Malobika Karanjai, Scientist "F" and Chairperson, AICC welcomed the gathering. Mrs. K. Rama Devi, Founder and President of Association of Lady Entrepreneurs of India (ALEAP) and high level Task Force Member for Micro Small Medium Enterprises (MSME), was the Chief Guest on this occasion. She delivered an inspirational talk on real time problems faced by start-up lady entrepreneurs with emphasis on imparting training and scientific basis and skill required to sustain and constant business growth, based on her own life. Employees, project staff and research students actively participated in large numbers.

Sports

Sports and games were inaugurated on March 15, 2019 by Dr. T. Narasinga Rao and Dr. Roy Johnson Associate Directors and they emphasized on the importance of sports and physical fitness in our daily life. The event began with 2K walkathon in which staff members and students participated in large numbers. A talk on "Physical Activity, Fitness and Health" was delivered by Mr. Manish Kumar Sharma, Chief Drill Instructor, Sardar Vallabhai Patel National Police Academy, Hyderabad. In all 13 different games and sports events such as Volleyball, Football, Cricket, Badminton, Tennikoit, Carom, Chess, Table Tennis, Athletics, quiz etc,. were conducted, in which employees, project staff, research fellows and students actively participated.

Inauguration of the Sports and Games at ARCI

2K Walkathon by employees and students at ARCI

Mr. Manish Kumar Sharma, Chief Drill Instructor, Sardar Vallabhai Patel National Police Academy givng a talk

Workshops/Seminars Conducted by ARCI

- **Brainstorming meeting to discuss and deliberate upon development of metal powders at ARCI**

  Brainstorming meeting to discuss and deliberate to generate a road map for development of metal powders including design of new alloys for applications such as additive manufacturing, conventional powder metallurgy and coatings was organized by ARCI on September 05, 2018 at Centre for Nanomaterials, ARCI. The meeting was attended by representatives from PM industries, R&D institutes, DRDO, Government Establishments/Undertakings and Powder metallurgy association of India (PMAI). The meeting started with a visit to Centre for Nano Materials (CNM), Centre for Laser Processing of Materials (CLPM) and Centre for Engineered Coatings (CEC) during which processing equipments along with their functionality and capabilities with respect to development of powders as well as components were explained.

Visit of the delegation to Flame Spray Pyrolysis and Inert Gas Atomiser at Centre for Nanomaterials, Cold Dynamic Spray Coating System at Centre for Engineered Coatings and Additive manufacturing facility at Centre for Laser Processing of Materials

Dr. G. Pamanabham, Director, ARCI emphasized the need to generate a roadmap for development of metal powders at competitive cost with thrust on application areas. He suggested that addition of nano powders could be embarked upon to improve or develop newer materials with improved properties, processability and sinterability. A brief status of Indian and world metal powder production scenario with areas where ARCI had already contributed or undertaken some initiatives and its capability was presented by ARCI to the delegates.

Upon detailed discussion, it emerged that there is a need to concentrate on R&D efforts on developing powders of specialty alloys, superalloys, stellites, steels, Ti alloys to cater to powder metallurgy, thermal spray, MIM, AM, biomedical and strategic applications. It is also suggested to develop PM parts with nano additives to achieve the density as comparable to forged parts.

- **Workshop on Empowering next generation power systems with Hydrogen in India**

Centre for Fuel Cell Technology (CFCT) conducted a one-day workshop on 'Empowering next generation power systems with hydrogen in India' on October 8, 2018. This workshop was conducted to commemorate the 'National Hydrogen and Fuel Cell day' which was created to raise awareness of a clean energy technology based on Hydrogen. Globally, October 8th (10.08) was chosen as a National Hydrogen and Fuel Cell day in reference to the hydrogen's atomic weight (1.008 amu). The aim and objective of this workshop is to encourage, develop and promote hydrogen energy and fuel cell and its applications in the country.

Dr. G. Padmanabam and Dr. R. Gopalan welcomed the delegates and delivered a brief introduction about ARCI and about CFCT in particular. The workshop was inaugurated by the Chief Guests, Prof.G.Sundararajan, Former Director, ARCI and Distinguished Emeritus Scientist, ARCI and Dr. Vijayamohanan K Pillai, Director, CSIR-CECRI, Karaikudi. The workshop was well thought-out with serious of invited lectures by few eminent industrialists/academicians/researchers who are forefront in the hydrogen and fuel cell technology development. Invited speakers included directors, scientist and managerial heads from premier institutions like CSIR-CECRI, CSIR-IMMT, VSSC-ISRO, ARAI, GAIL, TATA-GTIO, Thermax, BHEL, Mahindra & Mahindra and IOCL. The lectures delivered had insights on various focuses from the research standpoint to development and application of Fuel cell systems. About 70 participants (20 Faculties and 50 students) attended the workshop from various institutions across the country like IITs (Madras, Bombay, Gandhinagar, Mandi), Gandhigram rural institute, Alagappa university, SRM, SSN, VIT, VELS university, MS university, KLU, Kalasalingam and CSIR-CECRI.

The workshop also included a lab visit to the CFCT and demonstration of 5kW PEMFC stack for the participants and delegates. The workshop had an inspirational take away for the future generation of energy power systems.

Inauguration of H2FC 2018-workshop

Human Resource Development

ARCI-IIT Fellowship Programme

ARCI continues to sponsor fellowship programmes at Indian Institute of Technology (IIT) – Bombay, IIT-Hyderabad and IIT-Madras. As a part of these ARCI–IIT Fellowships, ARCI supports the doctoral study of talented students selected as ARCI Fellows to work in areas of immediate interest to ARCI under the expert guidance of an identified Faculty member. The ARCI support includes stipend, procurement of consumables and essential equipment. After successful completion of the programme, the ARCI Fellow is awarded a Ph.D. degree by the respective academic institution.

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.

01. Indian Institute of Technology – Bombay
02. Indian Institute of Technology – Kharagpur
03. Indian Institute of Technology – Kanpur
04. Indian Institute of Technology – Hyderabad
05. Indian Institute of Technology – Madras
06. National Institute of Technology – Warangal
07. National Institute of Technology – Tiruchirappalli
08. Visvesvaraya National Institute of Technology – Nagpur
09. University of Hyderabad (Central University) – Hyderabad
10. Andhra University – Visakhapatnam

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	02
SERB – National Post Doctoral Fellowship	-
INSA Visiting Scientist Fellowship	-
Post Doctoral Fellows/Research Scholars	05
DST Women Scientist – A (WOS – A)	-
Senior Research Fellow	15

Junior Research Fellow	01
Post Graduate Trainees	07
Graduate and Diploma Trainees	35
M.Tech Project Students	23
B.Tech. / M.Sc. Projects Students	20
Summer Research Interns	43

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	Low Cost Aqueous Binders for the Application of Lithium Ion Batteries	National Institute of Technology, Warangal
2.	JA Prithi	Cathode Materials for Improved PEMFC Performance & Impurity Tolerance	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 CIGS Thin Film Solar Cells	Indian Institute of Technology, Bombay

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Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
7.	Vallabharao Rikka	Study on Ageing Mechanism of Lithium Ion Battery	Indian Institute of Technology, Bombay
8.	Kumari Konda	Eectrochemical Performance of various Cathode Materials using Half and Full Cell	Indian Institute of Technology, Bombay
9.	S. Vasu	Structure – Electrochemical Property Correlation of layered Oxide & Lithium rich layered Oxide as a Cathode Materials for LIB Electric Vehicle Applications	Indian Institute of Technology, Madras
10.	Srinivasa Rao Atchuta	Development of Stable Selective Solar Absorber Coating for Concentrated Solar Thermal Application	CSIR – National Aerospace Laboratories, Bengaluru
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, Madra
14.	Puppala Laxman Makanta	Development of High Energy Density Electrode Materials for Sodium Ion Battery	Indian Institute ofTechnology, Madras
15.	S. Ramakrishnan	Hot Corrosion Studies on Thermal Barrier Coatings	Indian Institute of Technology, Kanpur
16.	Md. Ayub Shareef	Ongoing Course work	Idian Institute of Technology, Madras
17.	Minati Tiadi	Ongoing Course work	Indian Institute of Technology, Madras

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

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
1.	Bolla Reddy	Uniaxial Compression and Spherical Indentation Behaviour of Porous Copper	Indian Institute of Technology, Hyderabad
2.	L. Subhashini	Laser- MIG Hybrid Welding of Thick Sections of High Alloy Steels in a Single Pass	University of Hyderabad, Hyderabad
3.	NS Anas	Microstructure, Mechanical and Tribological Properties of Al Alloy-CNT Composites	University of Hyderabad, Hyderabad
4.	Puneet Chandran	Design and Development of Hard Protective Coatings on Cutting Tools for Dry Machining Applications	National Institute of Technology, Warangal
5.	E. Hari Mohan	Synthesis and Characterization of Nano Structured Electrodes for Li-s Batteries	National Institute of Technology, Warangal
6.	P. Tejassvi	Electro Spun Nano Fibrous Materials Li-ion and Li-s Batteries	National Institute of Technology, Warangal
7.	Anusree Unnikrishnan	Polymer Electrolyte Membrane Fuel Cells: Impurity Studies Experimental and Modelling Investigations	Indian Institute of Technology, Hyderabad
8.	S. Bhuvaneshwari	Structure, Morphology and Electrochemical performance Correlation in Metal Doped Spinel (Li Mx Mn2-x O4) (M = Transition metals) as Li ion Battery Cathode Materials	Indian Institute of Technology, Madras

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
9.	T. Ramesh	Activated Carbon for Energy Storage	National Institute of Technology, Warangal
10.	N. Manjula	Studies on Depolariser Assisted Water Electrolysis for Hydrogen Generation	National Institute of Technology, Warangal
11.	PM Pratheeksha	Development of Nano Structured Electrodes for High Energy Density Lithium Ion Battery Applications	National Institute of Technology, Warangal
12.	VV Ramakrishna	Structure and Electrochemical Property Correlation of Ni rich layered Oxides for Lithium Ion Battery Applications	National Institute of Technology, Thiruchirappalli
13.	S. Sasikala	Design, Development, Performance evaluation of Optimization of Engineering Parameters of Thermoelectric Generator System for Automotive Exhaust Waste Heat Recovery	Indian Institute of Technology, Madras
14.	S. Harish	Studies on Metal-Air Battery	Indian Institute of Technology, Madras
15.	Imran Karajagi	Nano Clay-based Self-Healing, Corrosion Protection Coatings on Aluminium Alloys AA2024-T4 and A356.0	Indian Institute of Technology, Bombay
16.	S. Manasa	Nano Clay-based Self-Healing, Corrosion Protection Coatings on Aluminium Alloys AA2024-T4 and A356.0	National Institute of Technology, Warangal
17.	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
18.	T. Mitravinda	Design and Development of Electrode Active Materials for Supercapacitor Application	Indian Institute of Technology, Hyderabad
19.	Brijesh Singh Yadav	Development and detailed Investigation of Chalcopyrite CIGS Absorber layer	Indian Institute of Technology, Hyderabad
20.	B. Jayachandran	Interface Engineering of High Temperature Thermoelectric Materials and its effect on the Thermoelectric Device Performance.	Indian Institute of Technology, Bombay
21.	M. Shiva Prasad	Development of Solar Selective Absorber Coatings for Concentrating Solar Power Applications	National Institute of Technology, Warangal
22.	B. Priyadarshini	Investigation of Thermoelectric Properties in Magnesium Silicides	National Institute of Technology, Thiruchirappalli
23.	Keerthi Sangamitra Kollipara	Study of Thermo- physical Properties of Aerogel Products for Thermal Insulation Application	National Institute of Technology, Warangal
24.	Shaik Mubina	Development of CNFs Dispered Sic Composites with Optimized Properties	National Institute of Technology, Warangal
25.	Y. Madhavi	Influence of Process Parameters on Properties and Performance of Micro Arc Oxidation Coatings	National Institute of Technology, Warangal
26.	Swapnil Hanmant Adsul	Nano Clay- based Self – Healing Corrosion Protection Coatings on Magnesium Alloys	National Institute of Technology, Warangal
27.	Adigilli Harish Kumar	2D-Nanolayered WS2 based Self Lubricating Composites	National Institute of Technology, Warangal

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
28.	Mohd. Aqeel	Suitability of Laser Hybrid Welding of Inconel 617 Alloy for Steam Boilers	University of Hyderabad, Hyderabad
29.	E. Anusha	Optimization and Control of Heat Input in Laser Based Manufacturing Processes	National Institute of Technology, Warangal
30.	VP Madhurima	Syntheisis of Carbon Nano Materials and their Composites	National Institute of Technology, Warangal
31.	Santwana H. Dhongade	Processing and Characterization of Solid Electrolytes for Energy Applications	National Institute of Technology, Warangal
32.	P. Samhita	Electro Deposited Nano Metal Oxides for Super Capacitor Applications	Indian Institute of Technology, Hyderabad
33.	KK Phani Kumar	Nano Composite Based Solar Selective Absorber Coatings	Indian Institute of Technology, Bombay
34.	P. Sreeraj	Studies on Precious Component recovery form PEM Fuel Cell/Electrolyser stack	Indian Institute of Technology, Bombay
35.	Narendra Chundi	Development of Anti Soiling Coatings and their Evaluation for Applications in Photovoltaic Modulus	Indian Institute of Technology, Bombay
36.	Battula Ramya Krishna	Detailed Investigation on the Degradation of Organo Metal Halide Perovskite Solar Cells	Indian Institute of Technology, Madras
37.	Surabattula Yasodhar	Studies on Electrolytic Hydrogen Generation Compression	Indian Institute of Technology, Madras
38.	V. Sai Harsha Swarna Kumar	Metallic flow field plates for PEM Based Electrolyser for Hydrogen Production	Indian Institute of Technology, Madras
39.	Gudimella Tirumala Harini	Synthesis of Ti Foams as Gas Diffusion Electrodes-cum-Flow Field Plates	Indian Institute of Technology, Madras
40.	AB Aravind	Electrochemical studies on Non- Aqueous electrolytes	National Institute of Technology, Thiruchirappalli
41.	M. Tarun Babu	Structure Property Correlation of Cold Sprayed Aluminium Alloys	Indian Institute of Technology, Madras
42.	D. Chandrakala	Studies on the Effect of Processing Parameters and Evaluation of Properties for the development of low Dielectric Materials	National Institute of Technology, Thiruchirapalli
43.	D. Nazeer Basha	Laser Surface Texturing of Automotive Engine Components using Ultrafast Laser	Indian Institute of Technology, Madras
44.	Bathini Lava Kumar	Fatigue and Corrosion Fatigue of PED Coated Monolayer and Multilayer Ni-W Coatings	Indian Institute of Technology, Bombay
45.	K. Sriram	Design & Development of Metallic Bipolar Plates by Hydroforming for PEM Fuel Cells	Indian Institute of Technology, Madras
46.	M. Venkatesh	Development of Sodium Transition Metal Layered Oxides as a Cathode Materials for Sodium Ion Batteries	Indian Institute of Technology, Madras
47.	Vikrant Trivedi	Synthesis of Nano Thermoelectric Materials and Module Fabrication	Indian Institute of Technology, Madras
48.	P. Raju	Fabrication, Property Evaluation & Comparison of Alumina (Al2O3) and its Composites by using Conventional Slip Casting and Pressure Slip Casting Processes	National Institute of Technology, Warangal

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
49.	DM Santoshsarang	Design and Modelling of Residual Stresses for Additive Manufacturing	Indian Institute of Technology, Madras
50.	S. Mamatha	Nearness shaping of Simple and Complex Ceramic Parts by 3D Printing and Investigations of the Thermo/ Mechanical and Microstructural Properties	University of Hyderabad, Hyderabad
51.	Jyoti Gupta	Electro-catalytic Hydrogen Generation via Dichalco Genides	University of Hyderabad, Hyderabad
52.	K. S. Srin	Ongoing Course Work	Indian Institute of Technology, Kanpur

Visits by Students and Faculty to ARCI

1. 42 B. Tech. (Mechanical Engineering) students & faculty from Avanthi Institute of Engineering & Technology, Hyderabad visited ARCI on April 12, 2018.
2. 22 M. Tech. (Nanotechnology) students & faculty from Visvesvaraya Technological University, Bengaluru visited ARCI on May 25, 2018.
3. 42 B. Tech. (Mechanical & Electrical Engineering) students & faculty from Sphoorthy Engineering College, Hyderabad visited ARCI on August 10, 2018.
4. 40 B. Tech. (Mechanical Engineering) students & faculty from Jayamukhi Institute of Technology, Hyderabad visited ARCI on September 7, 2018.
5. 26 Officers who participated in MDP on "Advance Materials in Defence Application" at National Academy of Defence Production (NADP), Nagpur visited ARCI on September 25, 2018.
6. 28 M. Tech. (Nano Technology) students & faculty from Vellore Institute of Technology, Vellore visited ARCI, Chennai on October 23, 2018.
7. 25 Scientist/Engineers from various Govt. Organizations who participated in ASCI's programme on "Science Administration and Research Management" visited ARCI on October 24, 2018.
8. 18 B. Tech. (Mechanical Engineering) students & faculty from Narasimha Reddy Engineering College, Hyderabad visited ARCI on October 26, 2018.
9. 72 B. Tech. (Mechanical, Civil, Electronics & Communication) students & faculty from Bharat Institute of Engineering & Technology, Hyderabad visited ARCI on October 31, 2018.
10. 54 M. Tech (Nanotechnology) students & faculty from Jawaharlal Nehru Technological University, Hyderabad visited ARCI on November 30, 2018.
11. 35 Engineering faculties from various engineering colleges under Osmania University and Jawaharlal Nehru Technological University, Hyderabad who participated in Faculty Development Programme (FDP) on "Recent Trends in Mechanical and Industrial Engineering (RTMIE 2018)" visited ARCI on December 13, 2018.
12. 100 UG Teachers from various colleges who participated in Osmania University's "Faculty Development Programme in Chemistry for UG Teachers: A Re-Orientation to the Restructured CBCS Curriculum" visited ARCI on December 17, 2018.
13. 30 Science Faculty Members from various colleges who participated in Osmania University's "UGC-Refresher Course on Materials Science" visited ARCI on January 08, 2019.
14. 34 Assistant Professors from various universities who participated in University of Hyderabad's "UGC-Refresher Course on Materials Science" visited ARCI on February 04, 2019.
15. 38 B. Tech (Mechanical Engineering) students & faculty from Sphoorthy Engineering College, Hyderabad visited ARCI on February 08, 2019.
16. 50 B.Sc. Students & faculty from Little Flower Degree College, Hyderabad visited ARCI on February 15, 2019.
17. 50 B.Sc. & M.Sc. (Chemistry) students & faculty from Anwarul-uloom College, Hyderabad visited ARCI on March 01, 2019.
18. 19 B. Tech (Mechanical Engineering) students & faculty from National Institute of Technology Puducherry, Karaikal visited ARCI on March 12, 2019.
19. 23 M.Sc. (Physics) students & faculty from Osmania University, Hyderabad visited ARCI on March 13, 2019.
20. 60 B.Sc. students & faculty from Government Degree College for Women, Hyderabad visited ARCI on March 15, 2019.
21. 15 M. Tech (Mechanical Engineering) students & faculty from National Institute of Technology, Warangal visited ARCI on March 20, 2019.
22. 52 B.Sc. students & faculty from M.V.S. Government Degree College, Mahabubnagar visited ARCI on March 29, 2019.

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 2018. 43 students, who were selected, have attended the programme from 17th May, 2018 for a period of minimum 45 days to a maximum period of 60 days. The selected students initially underwent

Dr. G Padmanabham, Director-ARCI with the studnets of Summer Research Programme conducted at ARCI, Hyderabad

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.

Appointments

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

Employee Name	Designation	Date of Joining
Ch. Venugopal	Assistant "A"	22.06.2018
Edunuri Ramesh	Assistant "A"	04.07.2018
Achinta Mondal	Assistant "A"	27.07.2018
D. Ramesh	Security, Fire and Safety Officer	30.07.2018
Paila Santosh Kumar	Technical Assistant "A"	09.08.2018
G. Ravi Shankar	Senior Finance & Admin. Officer	17.08.2018
Dr. Rambha Singh	Junior Hindi Translator	19.12.2018
A. Balraj	Assistant "A"	24.01.2019

Superannuation

Employee Name	Designation Held	Date of Superannuation
G. Ramesh Reddy	Officer "B"	31/05/2018
Ch. Venkateswara Rao	Technician "C"	31/06/2018
R. Vijay Kumar	Chief Finance & Accounts Officer	31/08/2018

Resignations

Employee Name	Designation Held	Date of Relieving
K. Subba Rao	Technician "C"	23/06/2018
Ms. K. V. Sri Vidya	Assistant "A"	16/08/2018
Dr. Rambha Singh	Hindi Translator (Contract)	17/12/2018

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 18.29%, S.T is 4.27%, OBC is 26.82% and that of persons with disabilities is 1.83% as on March 31, 2019.

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.

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 2018-19:

Name of the Promotees	Effective Date	Promotion for the post	
		From	To
B. Laxman	July 1, 2018	Assistant "B"	Officer "A"
P. Kamal Vaishali	July 2, 2018	Officer "A"	Officer "B"
Dr. G. Ravi Chandra	October 1, 2018	Scientist "F"	Scientist "G"
Dr. Pawan Kumar Jain	October 1, 2018	Scientist "F"	Scientist "G"
Dr. Ravi Nathuram Bathe	October 1, 2018	Scientist "E"	Scientist "F"
Dr. G. Siva Kumar	October 1, 2018	Scientist "E"	Scientist "F"
Dr. Srinivasan Anandan	October 1, 2018	Scientist "D"	Scientist "E"
S. Nirmala	October 1, 2018	Scientist "D"	Scientist "E"
Dr. P. Suresh Babu	October 1, 2018	Scientist "D"	Scientist "E"
Dr. Krishna Valleti	October 1, 2018	Scientist "D"	Scientist "E"
Dr. M. Buchi Suresh	October 1, 2018	Scientist "D"	Scientist "E"
Dr. D. Prabhu	October 1, 2018	Scientist "C"	Scientist "D"
K. Rama Chandra Somaraju	October 1, 2018	Technical Officer "D"	Technical Officer "E"
V.C. Sajeev	October 1, 2018	Technical Officer "C"	Technical Officer "D"
C. Karunakar	October 1, 2018	Technical Officer "B"	Technical Officer "C"
P.V.V. Srinivas	October 1, 2018	Technical Officer "A"	Technical Officer "B"
B. Hemanth Kumar	October 1, 2018	Technician "C"	Technician "D"
J. Venkateswara Rao	October 1, 2018	Technician "C"	Technician "D"
A. Praveen Kumar	October 1, 2018	Technician "C"	Technician "D"
K. Satyanarayana Reddy	October 1, 2018	Technician "C"	Technician "D"
D. P. Surya Prakash Rao	October 1, 2018	Technician "C"	Technician "D"
Prabir Kumar Mukhopadhyay	October 1, 2018	Technician "B"	Technician "C"
Shaik Ahmed	October 1, 2018	Technician "B"	Technician "C"
K. Ashok	October 1, 2018	Technician "B"	Technician "C"
E. Yadagiri	October 1, 2018	Technician "B"	Technician "C"

Lectures by Indian and Foreign Visitors

1. Dr. Sebastian Peter, Faculty Fellow, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bengaluru, delivered a lecture on "Non-Platinum based Nanoparticles as Low Cost, Highly Efficient and Robust Catalyst Alternative to Platinum in Fuel Cell Applications" on April 05, 2018.
2. Dr. S. Ramakrishnan, Vikram Sarabhai Distinguished Professor, Vikram Sarabhai Space Centre (VSSC), Thiruvanathapuram, delivered a lecture on "Launching a Satellite- An Overview of Rocket Science & Launch Vehicle Technology" on May 10, 2018.
3. Dr. David Frazer, University of California, Berkeley, USA delivered a lecture on "Small Scale Mechanical Testing of Ceramics for Nuclear Applications" on June 13, 2018.
4. Dr. Kuppusamy K, Senior Scientist, Swiss Federal Institute of Technology, Switzerland delivered a lecture on "Solar Generation of Hydrogen from Sun-

Water Photoelectrolysis" on July 12, 2018.

5. Prof. Tatsuo Kaneko, Japan Advanced Institute of Science and Technology (JAIST), Japan delivered a lecture on "Solid Electrolytes for Next Generation Li Batteries" on July 20, 2018.
6. Dr. K. Kalyanasundaram, Scientific Advisor, Laboratory for Photonics and Interfaces, Swiss Federal Institute of Technology, Switzerland delivered a lecture on "Recent Advances in the Design of High Efficiency Organohalide Perovskites based Thin Film Solar Cells"on July 27, 2018.
7. Dr. Florian from Horiba Ltd, France delivered a talk on "Raman Spectroscopy" on October 09, 2018.
8. Prof. Horst Hahn, Karlsruhe Institute of Technology (KIT), Germany delivered a lecture on "High Entropy Oxides with Tailorable Properties: Fundamental Aspects and Prospects" on November 15, 2018.
9. Prof. Pravansu Mohanty, Paul K. Trojan Collegiate Professor of Engineering, University of Michigan, USA delivered a lecture on "The Digital Thread for Additive Manufacturing- Challenges and Potential Solutions" on November 19, 2018.
10. Dr. Lale, Institute of Research on Ceramics (IRCER), France delivered a lecture on "Polymer-Derived Mesoporous Ceramics as Catalysis Supports and Co-catalysts for Hydrogen Generation" on November 29, 2018.
11. Prof. Nikolai Gaponenko, Laboratory of Nanophotonics, Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus delivered a lecture on "Synthesis and Optical Properties of Photonic Crystals" on December 06, 2018.
12. Prof. Arumugam Manthiram, Texas Materials Institute, USA delivered a lecture on "Near-Term and Long-Term Perspectives of Battery Technologies" on January 02, 2019.
13. Dr. Debasis Chakraborty, Outstanding Scientist and Group Director, Design - Defence Research and Development Laboratory (DRDL), Hyderabad delivered a lecture on "Aerodynamics and Propulsion Design of Missiles through CFD Simulation" on February 25, 2019.
14. Dr. Marshal Dhayal, Associate Professor, School of Biomedical Engineering, Indian Institute of Technology (IIT), Varanasi delivered a lecture on "Micro-Nano Engineered Functional Materials for Biomedical and Energy Application" on March 22, 2019.

Indian and Foreign Visitors for Technical Discussion

1. Mr. Huang Zhengyao (Dany), CTO, Xiamen TOB New Energy Technology Co Ltd., China and Dr. Samuel Varghese, CEO of Matlabs Technologies, Mumbai visited on May 09, 2018.
2. Dr. Naoto Sasaki, Vice President & SBU, Toyota Tsusho Corporation, Japan on June 26, 2018.
3. Dr. D. Mandal, Head- Alkali Material & Metal Division, Bhabha Atomic Research Centre (BARC), Mumbai visited ARCI on July 09, 2018.
4. Dr. Ramakrishna from SOFC Fuel Cell Company, Singapore visited on July 11, 2018.
5. Dr. Ashutosh Sharma, Secretary, Department of Science and Technology (DST), New Delhi visited on July 16, 2018.
6. Dr. Nikhil Naik, Project Engineer, Indian Institute of Astrophysics (IIAP), Bengaluru visited on July 25, 2018.
7. Dr. K. Kalayansundaram, Scientific Advisor, Laboratory for Photonics and Interfaces, Swiss Federal Institute of Technology, Switzerland visited on July 29, 2018.
8. Mr. Ananth, Assistant Finance Officer, DST, New Delhi visited on August 07, 2018.
9. Dr. V. Sivaramakrishnan, Manager R& D, Aqua Works Pvt. Ltd, Bengaluru visited on September 12, 2018.
10. Dr. K. Ashok Kumar & Mr. Sreedhar Kumar, Centre of Excellence on Welding Engineering & Technology, PSG College of Technology, Coimbatore visited on September 28, 2018.
11. Dr. V. M. Kamath, Director General, Defence Research and Development Organisation (DRDO) visited on October 05, 2018.
12. Mr. T.K. Balaji, Chairman, Lucas TVS, Chennai visited on October 06, 2018.
13. Mr. Sudhir Kumar Dixit, General Manager (Electrical), GAIL India Ltd, Pata and Ms. S. Barathy, Deputy General manager, R&D GAIL India Ltd., Delhi visited on October 09, 2018.
14. Dr. Sergio Coronado Hortal, Dr. David Pappas (Duracell, US) and Dr. S. Venkatraman Duracell R&D, India visited on October 23, 2018.
15. Mr. Arjun Rumalla, Director- Manufacturing, Mr. Sanjeev Karhallikar, General Manager, FMC Technologies India Pvt Ltd, Hyderabad and Mr. Kevin Long, Director Engineering Technip FMC, USA visited ARCI on October 26, 2018.
16. Mr. Mattaia Hein from Newport Corporation, USA visited on November 14, 2018.
17. Mr. Dinesh Tyagi, Director, Ms. Pamella Tikku, Senior General Manager and Mr. Devesh Pareek, Manager, International Centre for Automotive Technology (ICAT), Gurugram visited on November 16, 2018.
18. Mr. Dalton Maurya, Scientist E, Gas Turbine Research Establishment (GTRE), Bengaluru visited during November 2018.

19. Prof. Nikolai Gaponenko, Head of Laboratory of Nanophotonics, Belarusian State University of Informatics and Radioelectronics (BSUIR), Minsk, Belarus visited under Indo-Belarus Bilateral Research Cooperation during December 03-07, 2018.
20. Dr. Xavier Kennedy from Carborundum Universal Limited (CUMI), Chennai visited on December 04, 2018.
21. Dr. Adrain Panow, Director, Deakin Engineering and Ms. Geetha Mittal, Manager, Deakin University, Australia visited on December 14, 2018.
22. Dr. Arihiro Nakamura, Director and Senior Vice President, Chiyoda Corporation, Mr. Osama Ikeda, Group Leader, Hydrogen Business Planning and Development, Mr. Hirokazu Ipponsagi, Group Leader Marketing, Ms. Vinita Kher, Manager, Mitsubishi Corporation India Pvt Ltd visited on December 18, 2018.
23. Dr Bijoy Kanatt, Head-R&D, SheenLac Paints Ltd, Chennai visited on December 21, 2018 and March 05, 2019.
24. Mr. M. Viswanathan, Managing Director, Renesol Power (P) Ltd visited on December 28, 2018.
25. Mr. V. Ramesh, Assistant General Manager (Sales), Jyotech Engineering and Marketing Consultants visited on January 03, 2019.
26. Dr. V. Natarajan, Director, Research & Innovation Centre (DRDO) IIT Madras Research Park, Chennai visited on January 28, 2019.
27. Dr. Srikant Pooram, Director, Pooram and Pooram, Bengaluru visited on February 01, 2019.
28. Mr.Christoph Schuetz, Managing Director, Greenlight Innovation GmbH, Germany visited on February 11-15, 2019.
29. Dr. Koteswara Rao, Faculty, University of Hyderabad, Hyderabad visited on February 18, 2019 .
30. Mr. Bentivegna Sylvain, Managing Director, MPA Industries, France visited on February 26, 2019.
31. Mr. Mark Sirota from Thirty Meter Telescope (TMT) Observatory Corporation, USA visited on March 07, 2019.
32. Prof. S. Suresh, General Manager and Head, Centre of Excellence on Welding Engineering and Technology, PSG College of Technology, Coimbatore visited on March 12, 2019.
33. Mr. Rajesh Bhatia, General Manager, RVB Shorlube Pvt. Ltd, Kanpur visited on March 28, 2019.

Visits Abroad

1. Dr. Y. Srinivasa Rao visited Germany during April 09-19, 2018 to participate in the 'Ceramic Industrial Exhibition (CERAMITEC 2018)' held at Munich and delivered an invited lecture on "Pressure Slip Casting- An Adoptable Manufacturing Technique for Advanced Ceramics". He also visited SAMA Maschinenbau GmbH, Weissenstadt and JSJ Jodeit GmbH, Jena for technical discussion.
2. Dr. S. Kavitha visited Marina Bay Sands, Singapore during April 23-27, 2018 to participate in the 'IEEE International Magnetics Conference (INTERMAG 2018)' and presented a paper on "Low Field and Large Magnetocaloric Effect in Ni-Mn-Sn (Fe-B) Alloys".
3. Mr. Puneet Chandran (Dr. Krishna Valleti) visited San Diego, USA during April 24-27, 2018 to participate in the '45th International Conference on Metallurgical Coatings and Thin Films' and presented a paper on "Development of Novel Gradient C-CrAlSiN based Cathodic Arc PVD Coatings for High Speed/Dry Machining Applications".
4. Dr. G. Padmanabham visited Changwan, South Korea during May 13-16, 2018 to attend the '2nd INAE-NAEK Joint Workshop' organized by the National Academy of Engineering of Korea and the Indian National Academy of Engineering.
5. Mr. E. Hari Mohan (Dr. T. N. Rao) visited Seattle, USA during May 13-17, 2018 to participate in the '233rd ECS Meeting' and presented a paper on "Development of Sulfur Cathode Comprising Biomass Derived Activated Carbon as Host for Improved Lithium-Sulfur Battery Performance".
6. Mr. Vallabha Rao Rikka visited Denver, USA during June 11 - 14, 2018 to participate in the '48th Power Sources Conference' and presented a paper on "Effect of State of Charges and Depth of Discharge on the Cycle Life of LiFePO4/ Graphite Cell at Fast Charging for Electric Vehicle Applications".
7. Dr. Raman Vedarajan visited Ishikawa, Japan during June 23-30, 2018 to participate in the 'International Symposium on Polymer Electrolytes (ISPE 17)' and delivered a lecture on "Multifunctional Role of Organoboron Compounds in LiB Electrolyte".
8. Dr. V. Ganapathy visited Durban, South Africa during June 25-29, 2018 to participate in the '3rd BRICS Young Scientist Conclave'.
9. Dr. Manjusha Battabyal visited France during July 01-05, 2018 to participate in the '37th International Conference on Thermoelectrics (ICT-2018)' and presented a paper on "Synergistically Enhancement of Thermoelectric Properties in Partially filled CoSb3 Skutterudites through Simultaneous Doping and Nanostructuring".
10. Dr. R. Gopalan visited Singapore during July 22 - 27, 2018 to participate in the '12th International Conference on Ceramic Materials and Components for Energy and Environmental Applications (CMCEE-2018)' and delivered lectures on "High ZT Materials and Demonstration of Thermoelectric

Generator" and "Carbon Coated LiB Electrode Materials and LiB Fabrication for EV Applications"

11. Dr. D. Prabhu visited Beihang University, China during August 22-31, 2018 to participate in the 'International Conference on Rare Earth Permanent Magnets (REPM 2018)' and delivered an invited talk on "Towards Sintered Sm-Fe-N magnet". He also participated in technical discussion at Beihang University as a member of the BRICS Project.
12. Dr. K. Suresh visited Japan, during August 25-September 01, 2018 for pre-dispatch inspection of 'High Flux XRD System with Non-Ambient Stage' at Rigaku Factory, Tokyo.
13. Dr. G. Ravi Chandra visited Sydney, Australia during September 09-14, 2018 to participate in the '19th International Microscopy Congress (IMC)' and delivered a talk on "Electron Backscatter Diffraction Study of Recovery and Recrystallization in Oxide-Dispersed Strengthened Steels".
14. Dr. R. Balaji visited University of Surrey, England during September 10-12, 2018 to participate in the 'International Conference on Advanced Energy Materials 2018 (AEM-18)' and presented a paper on "Hydrogen Production by Electrochemical Methanol Reformation using Alkaline Anion Exchange Membrane based Cell".
15. Dr. S. Kavita visited Darmstadt, Germany during September 16-20, 2018 to participate in the 'THERMAG VIII, International Conference on Caloric Cooling ' and presented papers on "Martensite Structure Modulation and Inverse Magnetocaloric Effect in Melt-Spun Ni-Mn-In, Ni-Mn-Sn and Ni-Fe-Ga Ribbons" and "Giant Inverse Magnetocaloric Effect in Ni-Mn-Sn-(Fe-B) Alloys".
16. Dr. N. Rajalakshmi visited University of Camerino, Italy during September 17-19, 2018 to participate in the 'Bilateral Italy-India Workshop on Renewable Energy Technologies at the Crossroads of "Glocal" Energy Grids' and delivered a talk on the " Use of Renewable Energy from the Fuel Cells Perspective".
17. Dr. R. Subasri visited Minsk, Belarus during September 22-30, 2018 to participate in the '8th International Scientific Conference on Actual Problems of Solid State Physics SSP-2018' and presented a paper on "Sol-Gel derived Solar Control Coatings on Glass for Architectural and Automobile Applications". She also participated in technical discussions on implementation of the Indo-Belarus joint project at Belarusian State University for Informatics and Radioelectronics (BSUIR), Belarus.
18. Dr. Sanjay R. Dhage visited Brussels, Belgium during September 24–28, 2018 to participate in the '35th European PV Solar Energy Conference and Exhibition (EU PVSEC-2018)' and presented a paper on "Molybdenum Bilayer Thin Film on Large Area by Cylindrical Rotating DC Magnetron Sputtering for CIGS Solar Cell Application".
19. Dr. K. Suresh and Mr. Ravi Gautham visited Hamburg, Germany during October 02-04, 2018 to carry out experiments at Petra-III.
20. Ms. P. M. Pratheeksha (Dr. Srinivasan Anandan) visited New Castle, Australia during October 30-November 02, 2018 to participate in the 'International Conference on Emerging Advanced Nanomaterials (ICEAN 2018)' and made a poster presentation on "Lithium Titanate a Zero Strain Material as a Promising Anode for Lithium Ion Battery Applications".
21. Dr. G. Padmanabham visited Aachen, Germany during January 22-24, 2019 to participate in the General Body Meeting of Indo-German Science and Technology Centre (IGSTC) as a member of the Governing Body.
22. Dr. E. Ganesan visited Tsukuba, Japan during February 25-29, 2019 to participate in the '20th Green International Symposium' and presented a paper on "CoNi Nanosheets as Support for Pt Electrocatalyst with Low Loading for ORR".
23. Dr. R. Vijay visited Dallas, USA during March 08 - 18, 2019 to participate in the '148th Annual Meeting of the Minerals, Metals and Materials Society (TMS) 2019' and presented a paper on "Structure and Properties of Oxide Dispersion Strengthened Austenitic Stainless Steels".
24. Dr. G. Padmanabham visited Texas, USA during March 10-22, 2019 to participate in the '148th Annual Meeting of the Minerals, Metals and Materials Society (TMS) 2019'. He also attended the review meeting of 'Joint Technology Demonstration Centre for Advanced Nanomechanical Characterization under Extreme Conditions (ANCC)' and attended the launch of advanced version of 'Nano Indenter'.
25. Ms. S. Manasa (Dr. R. Subasri) visited Seoul, South Korea during March 24-31, 2019 to participate in the 'International Conference SURFCOAT – 2019' and presented a paper on "Synergistic Effect of Different Nanocontainers for Self-Healing Corrosion Protection Coatings on AA2024-T4".

Lectures by ARCI Personnel in India

1. Dr. N. Rajalakshmi delivered an invited lecture on "Electric Vehicles and Fuel Cells' at Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya University (SCSVMV), Kancheepuram on April 02, 2018.
2. Dr. S. Sakthivel delivered an invited lecture on "Role of Nanostructure Materials and Coatings for Concentrated Solar Thermal Power (CSP) and Photovoltaic (PV) Applications" at the 'National Symposium on Sustainable Energy Conversion

and Storage Materials' held at Sathyabama Institute of Science and Technology, Chennai during April 05-06, 2018.

3. Dr. N. Rajalakshmi delivered an invited lecture on "Development of Activated Carbon from Jute for Energy Storage Application" at Ministry of Textiles, Kolkata on April 09, 2018.
4. Dr. Mani Karthik delivered an invited lecture on "Nano and Nanostructured Materials for Energy Conversion and Storage" at the 'Faculty Development Programme on Emerging Trends in Nanoscience and Nanotechnology' held at Adi Shankara Institute of Engineering & Technology, Kalady, Kerala during April 17-21, 2018.
5. Dr. R. Subasri delivered an invited lecture on "Smart Technologies for a Smart Life Style" at 'Dr. A. S. Rao Council Awards 2018' held in Hyderabad on April 28, 2019.
6. Dr. N. Rajalakshmi delivered an invited lecture on "Green and Sustainable Energy: Fuel Cells and Electrochemistry" at the 'Workshop on Recent Trends in Sustainable Green Technologies' held at Dayalbagh Educational Institute (DEI), Agra on May 05, 2018.
7. Dr. V. Ganapathy delivered an invited lecture on "Nanostructured Materials for Photovoltaic Application" at the 'International Conference on Nanomaterials: Synthesis, Characterization and Applications' held at Mahatma Gandhi University, Kottayam during May 11-13, 2018.
8. Dr. V. Ganapathy delivered an invited lecture on "Recent Solar Technologies and the Future Perspectives" at the 'Seminar on Recent Advances in Mechanical Engineering' held at Geetanjali College of Engineering and Technology, Hyderabad during May 11-15, 2018.
9. Dr. R. Gopalan made a presentation on "Ultimate Rare Earth Magnet Technology" at the 'REPM Technology Meeting' held at Niti Aayog, New Delhi on May 12, 2018.
10. Dr. R. Prakash delivered an invited lecture on "Li-Ion Battery Development at ARCI for Electric Mobility" at the '2nd IESA ICAT EV Conclave' held at Gurgaon during May 17 - 18, 2018.
11. Dr. Malobika Karanjai delivered an invited lecture on "Women in STEM" under a DST residential orientation program held at IIT, Hyderabad on May 18, 2018 for 35 meritorious girl students of 11th standard for motivation on scientific career.
12. Dr. Tata N. Rao delivered an invited lecture on "Application of Nanomaterials in Energy, Health and Environment" at the 'National Conference on Smart Materials for Device Perspective and Research Direction' held at AISECT University, Bhopal on May 19, 2018.
13. Dr. Sanjay Bhardwaj made presentation on "Intellectual Capital Utilization in the Public-Funded R & D Organizations" (in Hindi) at the 'Scientific and Technical Seminar 2018' held at ARCI, Hyderabad on June 06, 2018.
14. Dr. Gururaj Telasang delivered a lecture on "Laser Assisted Processes for Tooling Applications" at the 'GDC TECH – Pune: One Day Conference -Technology Day' held at Pune on June 21, 2018.
15. Dr. E. Ganesan delivered an invited lecture on "Efficient Electrocatalytic Activities of Boron Nitride based Electrocatalyst – Fuel Cell Applications" at the 'National Conference on Energy Materials' held at Manonmaniam Sundaranar University, Tirunelveli during June 28-29, 2018.
16. Dr. S. Sakthivel delivered an invited lecture on "Role of Nanofunctional Coatings for Solar Thermal and PV Applications" at the 'Workshop on Fabrication of Thin-films and Optoelectronics Devices through Hands-on-Experience' held at National Institute of Technology (NIT), Warangal during July 03-08, 2018.
17. Dr. R. Balaji delivered a guest lecture on "Opportunities and Challenges in Hydrogen Fuel Cell Technology Development" at the 'International Conference on Emerging Trends and Innovations in Engineering & Technological Research' held at Toc H Institute of Science and Technology, Ernakulum on July 11, 2018.
18. Dr. R. Gopalan delivered a guest lecture on "Automotive Energy Materials" at St. Joseph's College of Engineering, Chennai on July 12, 2018.
19. Dr. R. Vijay delivered an invited lecture on "Nanomaterials and Components for High Performance Applications" at the 'All India Seminar on Advances in Metallurgy and Manufacturing Process' held at the Institution of Engineers India, Hyderabad during July 13-14, 2018.
20. Dr. G. Padmanabham delivered a keynote address on "Challenges in Metal Additive Manufacturing" at the 'All India Seminar on Advances in Metallurgy and Manufacturing Process' held at the Institution of Engineers India, Hyderabad during July 13-14, 2018.
21. Dr. G. Sivakumar delivered an invited lecture on "Thermal Spray Coatings" at the 'All India Seminar on Advances in Metallurgy and Manufacturing Process' held at the Institution of Engineers India, Hyderabad during July 13-14, 2018.
22. Dr. Nitin P. Wasekar delivered an invited lecture on "Pulsed Electrodeposition of Coatings" at the 'All India Seminar on Advances in Metallurgy and Manufacturing Process' held at the Institution of

Engineers India, Hyderabad during July 13-14, 2018.

23. Dr.Gururaj Telasang delivered a lecture on "Metal Additive Manufacturing for Aerospace Applications" at the 'One-Day Seminar on Additive Manufacturing Technologies for Aerospace Application' held at the Institute of Engineers , Hyderabad on July 15, 2018.
24. Dr.R.Gopalan delivered an invited lecture on `Magnets, Li-Ion Battery and Thermoelectric Materials for Automotive Applications' at the 'Indo-Japan Bilateral Symposium on Futuristic Materials and Manufacturing' held at IIT Madras, Chennai during July 16-17, 2018.
25. Dr. G. Padmanabham delivered a keynote address on "Research, Innovation and Technology Transfer" at the 'International Conference on Transformations in Engineering Education (ICTIEE AP 2018)' held at SRM University, Vijayawada on July 17, 2018.
26. Dr. G. Padmanabham delivered an invited lecture on "Laser based Manufacturing Solutions for Mobility" at the 'International Conference on Advances in Design, Materials, Manufacturing and Surface Engineering for Mobility (ADMMS'18)' held at Chennai on July 21, 2018.
27. Dr. G. Siva Kumar made a technical presentation on "Development of New TBC Materials with Enhanced CMAS Infiltration Resistance through Atmospheric Plasma Spraying" at the '2nd International Conference on Structural Integrity and Exhibition (SICE 2018)' held at DMRL, Hyderabad during July 25-27, 2018.
28. Dr. P. Suresh Babu made a technical presentation on "Influence of Substrate Properties on the Deformation Behavior of TiN Coating under Cyclic Impact Testing" at the 'SICE 2018' held at DMRL, Hyderabad during July 25-27, 2018.
29. Dr. Gururaj Telasang delivered a lecture on "Structural Mechanical Behavior of Additive Manufactured IN 718 Super Alloy" at the 'SICE 2018' held at DMRL, Hyderabad during July 25-27, 2018.
30. Dr. Sanjay Bhardwaj delivered invited lectures on "R & D Assessment", "Enhancing the Impact of Intellectual Capital" and "Technology Transfer in the Indian Scenario: A Case Study" at the 'Workshop on the Process of Steering Medical Ideas to Commercialization" organized by All India Institute of Medical Sciences (AIIMS) Patna and IIT Patna at Patna on July 28, 2018.
31. Dr. Tata N. Rao delivered an invited lecture on "Indigenization of Li-Ion Battery Electrode Material for EV Application" at the 'DST-SERB Sponsored Seminar on Challenges in Materials for Energy Conversion Storage & Enhancement Applications' held at the National Engineering College, Kovilpatti, Tamilnadu during August 10-11, 2018.
32. Dr. N. Rajalakshmi delivered an invited lecture on "Fuel Cell Technology for Electric Vehicles" at the 'India EV Summit 2018' held at Chennai during August 17-18, 2018.
33. Dr. Joydip Joardar delivered an invited lecture on "Two-Dimensional X-Ray Diffraction: Basics and Case Studies" at the 'Workshop on Diffraction and Microscopy (WDM 2018)' held at VNIT-Nagpur during August 25-29, 2018.
34. Dr. Raman Vedarajan delivered an invited lecture on "High Performance Nanocatalysts for ORR in Fuel Cells" at the 'International Conference on Advanced Nanomaterials for Energy, Environment and Healthcare Applications (ANEH – 2018)' held at K.S.R College of Arts and Science for Women, Tiruchengode during August 31–September 01, 2018.
35. Dr. Gururaj Telasang delivered a lecture on "Additive Manufacturing Activity at ARCI" at a 'Workshop on Advanced Micro / Nano Fabrication and Characterization Techniques' organized by the Centre for Nano Science and Engineering (CeNSE) and IISc at Bengaluru on September 05, 2018.
36. Dr. Tata N. Rao delivered an invited lecture on "Translational Nanomaterials Research (from Laboratory to the Market)" at the 'Annual Students Symposium of Department of Materials Engineering' held at IISc, Bengaluru on September 06, 2018.
37. Dr.G.Padmanabham delivered an invited lecture on "Metal Additive Manufacturing: Applications and Challenges" at the '8th International Conference on Additive Manufacturing Technologies' held at Bengaluru during September 07-08, 2018.
38. Dr. D. Prabhu delivered an invited lecture on "Unveiling Some Truths in Magnetic Materials through 3DAP" at the 'Workshop on Atom Probe Tomography' held at ARCI, Hyderabad on September 07, 2018.
39. Dr. N. Rajalakshmi delivered an invited lecture on "Nanotechnology for Energy Conversion Devices" at AMET University, Chennai on September 08, 2018.
40. Dr. G. Padmanabham delivered an invited lecture on "Materials for Energy and Environment" at the 'International Conference on Advanced Ceramics & Nano Materials for Sustainable Development (ACeND2018)' held at Christ University, Bengaluru

on September 19, 2018.

41. Dr. R. Balaji delivered a guest lecture on "Energy Storage Devices- An Overview" at a 'Seminar on Renewable Energy' held at S.A. Engineering College, Chennai on September 19, 2018.
42. Dr. Gururaj Telasang delivered a lecture on "How to Adopt Metal Printing to Improve and Innovate Production?" at the 'Laser World of Photonics 2018, 3D Manufacturing Summit 2018' held at Bengaluru on September 26, 2018.
43. Dr. G. Padmanabham delivered a keynote lecture on "Materials for Energy and Environment" at the 'Two-day National Workshop of Powder Metallurgy & Advanced Composites (PMAC-2018)' held at Rajiv Gandhi University of Knowledge Technologies (RGUKT), Basar, Telangana during September 27-28, 2018.
44. Dr. B. P. Saha delivered an invited lecture on "Non-Oxide Ceramics for Advanced Applications: Process Optimization and Product Development" at the 'PMAC-2018' held at RGUKT, Basar, Telangana during September 27-28, 2018.
45. Dr. Y. Srinivasa Rao delivered an invited lecture on "Innovative Processing of Oxide Ceramic for Advanced Applications" at the 'PMAC-2018' held at RGUKT, Basar, Telangana during September 27-28, 2018.
46. Dr. R. Vijay delivered an invited lecture on "Powder Metallurgy Products for New Generation Reactors" at the 'PMAC-2018' held at RGUKT, Basar, Telangana during September 27-28, 2018.
47. Dr. Malobika Karanjai delivered an invited lecture on "Composites-Conventional and Niche Applications" at the 'PMAC-2018' held at RGUKT, Basar, Telangana during September 27-28, 2018.
48. Dr. R. Gopalan delivered an invited lecture on "APT of Magnetic Materials" at the 'APT Workshop' held at IISc, Bengaluru on October 09, 2018.
49. Dr. Roy Johnson delivered a plenary lecture on "Advanced Ceramic Materials: Processing and Applications" at the 'International Conference on Recent Trends in Material Science and Technology (ICMST-18)' held at Thiruvanathapuram during October 10-13, 2018.
50. Dr. N. Rajalakshmi delivered an invited lecture on "Recent Developments and Challenges in Fuel Cells" at the 'Workshop on Technologies to Address the Energy Needs of India' held at Bengaluru during October 11-12, 2018.
51. Dr. Malobika Karanjai delivered an invited lecture on "Friction Materials and Composite" at the 'Powder Metallurgy Short Term Course (PMSC 2018)' held at Pune during October 12-15, 2018.
52. Dr. Tata N. Rao delivered an invited lecture on "Application of Nanomaterials (Fundamentals & Applications)" at the 'Padmabhushan Dr. B.V. Raju Memorial Lecture' held at Shri Vishnu College of Pharmacy, Bhimavaram on October 15, 2018.
53. Dr. Sanjay Bhardwaj delivered an invited lecture on "R & D Assessment: A Value Addition Perspective" for the scientists /engineers participating in the DST sponsored programme on 'Science Administration and Research Management' conducted by Administrative Staff College of India, Hyderabad on October 24, 2018.
54. Dr. Malobika Karanjai delivered an invited lecture on "Fe Powder Production from Direct Reduction of Ores" at the '2-day International Conference' held at Bhilai on October 26, 2018.
55. Dr. R. Gopalan, delivered an invited lecture on "R&D Plan for National Mission on e-Mobility" at New Delhi on October 30, 2018.
56. Dr. K. Suresh delivered an invited lecture on "Design and Fabrication of Magnetic Field Sensor use Magnetic Tunnel Junctions" at University of Hyderabad, Hyderabad on October 30, 2018.
57. Dr. P. K. Jain delivered an invited lecture on "Innovation in Materials Sciences" at MVSR Engineering College, Hyderabad on October 31, 2018.
58. Mr. Vallabha Rao Rikka delivered an invited lecture on "Li-Ion Battery-Sustainable Energy Stored System for EV and Grid Applications" at Vellore Institute of Technology (VIT), Vellore on November 08, 2018.
59. Dr. P. Sudharshan Phani delivered a lecture on "Latest Advances in Nanomechanical Testing" at ARCI, Hyderabad on November 12, 2018.
60. Dr B. P. Saha delivered a guest lecture on "Emerging Trends of Nanocomposites and Nanotechnology and its Applications" at the Holy Mary Institute of Technology and Science, Hyderabad on November 14, 2018.
61. Dr. Roy Johnson delivered a guest lecture on "Emerging Trends of Nanocomposites and Nanotechnology and its Applications" at Holy Mary Institute of Technology and Science, Hyderabad on November 14, 2018.
62. Dr. G. Padmanabham delivered a keynote lecture on "Metallurgical Aspects of Additive Manufacturing" at the '56th National Metallurgist Day & 72nd Annual Technical Meeting of the Indian Institute of Metals' held at Kolkata during November 14-16, 2018.
63. Dr. G. Padmanabham delivered an invited lecture on "Laser Metal Deposition for Repair and Refurbishment" at the 'International Welding

Symposium (IWS 2K18)' held at Mumbai during November 27-29, 2018.

64. Dr. Sanjay Bhardwaj delivered a plenary lecture on "A Methodology for Strengthening the Translational Research Process" at the 'PANIIT International Management Conference 2018' held at IIT Roorkee on November 30, 2018.

65. Dr. Tata N. Rao delivered an invited lecture on "Translational Material Research (from Laboratory to the Market)" at the '10th Bengaluru India Nano 2018' held at Bengaluru during December 06-07, 2018.

66. Dr. Manjusha Battabhyal delivered an invited lecture on "Design and Development of Skutterudite Thermoelectric Materials and Devices for Waste Heat Recovery" at the 'Symposium on Thermoelectrics, Materials, Systems and Device' held at PSG College of Technology, Coimbatore during December 11-12, 2018.

67. Dr. D. Sivaprahasam delivered an invited lecture on "Challenges in Fabrication of Mid-Temperature Thermoelectric Modules for Automotive Applications" at the 'Symposium on Thermoelectrics, Materials, Systems and Device' held at PSG College of Technology, Coimbatore during December 11-12, 2018.

68. Dr. Tata N. Rao delivered an invited lecture on "Translational Nanomaterials Research (from Laboratory to the Market)" at the 'DAE Solid State Physics Symposium' held at Hisar, Haryana during December 18-22, 2018.

69. Dr. Srinivasan Anandan delivered an invited lecture on "Development of Advanced Nanostructured Materials for Self-Cleaning Photocatalytic Applications" at the '4th International Conference on Chemical and Environmental Research (ICCER-2018)' held at Jamal Mohamed College, Tiruchirappalli on December 19, 2018.

70. Dr. G. Ravi Chandra delivered an invited lecture on "Introduction to Materials Characterization and Advances in Electron Microscopy" at a 'Refresher Course on Material Science' organized by Osmania University at Hyderabad during December 19, 2018 - January, 11, 2019.

71. Dr. Sanjay Bhardwaj delivered invited lectures on "Analysis of Technology Transfer Cases" and "Commercializing the Scientific Knowledge" at a 'Refresher Course on Material Science' organized by Osmania University at Hyderabad during December 19, 2018 – January 11, 2019.

72. Dr. Y.Srinivasa Rao delivered invited lectures on "Ceramic and Advanced Ceramics-from a Physicist's View of Material Science" and "Technology Development in Advanced Ceramics-Few Case Studies, Material Science" at a 'Refresher Course on Material Science' organized by Osmania University at Hyderabad during December 19, 2018 - January, 11, 2019.

73. Dr. Malobika Karanjai delivered an invited lecture on "Powder Metallurgy Science and Composites" at a 'Refresher Course on Material Science' organized by Osmania University at Hyderabad during December 19, 2018 - January, 11, 2019.

74. Dr. Malobika Karanjai delivered an invited lecture on "Composites: Spread in Present and Future Engineering Applications" at the '2-day National Seminar on Recent Trends in Materials Research for Science and Engineering Applications (RTMRSEA-2018)' held at M.V.S.R. Engineering Collage, Hyderabad during December 20-21, 2018.

75. Dr. Pramod H. Borse delivered an invited lecture on "Nanostructuring Photoelectrocatalyst for Efficient Solar Hydrogen Energy Generation" at the 'RTMRSEA-2018' held at M.V.S.R. Engineering Collage, Hyderabad during December 20-21, 2018.

76. Dr. Neha Hebalkar delivered invited lectures on "Amazing Nanomaterials" and "Nanotechnology for Better Life" at the 'DST Inspire Science Camp' organized by Dayanand Science College, Latur, Maharashtra on December 22, 2018.

77. Dr. Sanjay Bhardwaj delivered the Indian Institute of Chemical Engineers (IIChE) National Award lecture on "Intellectual Property Development Indices (IPDIs) for Excellence in Process / Product Development" at the 'CHEMCON 2018 - International Conference on Seemless Chemical Engineering in Service of Humanity: Innovations, Opportunities & Challenges' held at Dr. B. R. Ambedkar National Institute of Technology (NIT), Jalandhar during December 27 - 30, 2018.

78. Dr. Y.Srinivasa Rao delivered an invited lecture on "Processing of Advanced Ceramics-Issues in Technology Development, Advanced Engineering Materials" at the 'Two-day National Workshop' held at Vignan University, Guntur on December 28, 2018.

79. Dr. R. Prakash delivered an invited lecture on "Development of Electrode for Fabrication Lithium Ion Batteries for Electric Vehicle Application" at the 'Conclave on Materials and Technologist in Energy Conversion & Storage (MTECS 2018)' held at Indian Institute of Information Technology Design and Manufacturing, Kancheepuram during December 28 - 29, 2018.

80. Dr. R. Gopalan delivered a plenary lecture on "Materials and Components for Sustainable Energy

Applications" at the 'International Workshop on Crystalline Materials and Applications' held at Anna University, Chennai during January 03-05, 2019.

81. Dr. Gururaj Telasang delivered a lecture on "Metal Additive Manufacturing Aspects and Applications" at the 'National Workshop on Advances in Digital Additive Manufacturing: 3D Printing (ADAM)' held at Annamalai University, Annamalai on January 04, 2019.

82. Dr. G. Padmanabham delivered an invited talk on "Metal Additive Manufacturing" at University of Hyderabad, Hyderabad on January 17, 2019.

83. Dr. G. Ravi Chandra delivered an invited lecture on "Materials Characterization and Nano Indentation" at the 'Refresher Course on Material Science with HRDC' at University of Hyderabad, Hyderabad during January 19-30, 2019.

84. Dr. R. Prakash delivered an invited lecture on "Development of Materials and Components for Clean Energy Applications" at the 'National Conference on Renewable Energy and its Applications in Mitigation of Climate Changes' held at PSGR Krishnammal College of Women, Coimbatore during January 21 - 22, 2019.

85. Dr. G. Sivakumar delivered an invited lecture on "Nanostructured Thermal Barrier Coatings for Functional Applications" at the 'Processing and Applications of Functional Materials' held at Coimbatore during January 21-25, 2019.

86. Dr. Joydip Joardar delivered an invited lecture on "Material X-Ray Diffraction: Basics and Case Studies" at the 'UGC-Refresher Course on Material Science' held at University of Hyderabad, Hyderabad on January 22, 2019.

87. Dr. Nitin Wasekar an invited lecture on "Corrosion Behaviour of Pulsed Electrodeposited Ni-W/SiC Nanocomposite Coatings" at the 'National Conference on Industrial Coatings' held at CSIR-Institute of Minerals & Materials Technology, Bhubaneswar during January 24-25, 2019.

88. Dr. Tata N. Rao delivered a keynote lecture on "Indigenous Nanomaterials - based Technologies, a Make in India Initiative" at the 'National Conference on Nanomaterials, NCN-2019' held at LRG Govt. Arts College for Women, Tirupur on January 25, 2019.

89. Dr. R. Balaji delivered an invited lecture on "Hydrogen-A Promising Energy Storage Solution" at the 'National Seminar Energy Storage Devices' held at Sri Renganathar Institute of Engineering and Technology, Coimbatore on January 30, 2019.

90. Dr. S. Sakthivel delivered an invited lecture on "Functional Coating Development from Laboratory to Industrial Scale for Solar Thermal and PV Applications" at the 'International Conference of Advanced Materials Chemistry at the Interfaces of Energy, Environment and Medicine (ACMI-2019)' held at Manonmanium Sundaranar University, Tirunelveli during January 30-31, 2019.

91. Dr. Roy Johnson delivered an invited lecture on "Advanced Ceramic Materials" at the 'Refresher Course in Material Science' held at the University of Hyderabad, Hyderabad on January 31, 2019.

92. Dr. Srinivasan Anandan delivered an invited lecture on "Large Scale Synthesis of Nanostructured Materials for Electrical Vehicles (EVs) Application" at the 'National Conference on Advances in Nano and Functional Materials (NCANFM-2019)' held at Osmania University, Hyderabad on January 31, 2019.

93. Dr. R. Balaji delivered an invited lecture on "Hydrogen Energy Technology Development" at a 'Seminar on Renewable Energy Pathways for Rural Development' held at Gandhigram Rural Institute, Gandhigram on January 31, 2019.

94. Mr. K V Phani Prabhakar delivered an invited lecture on "Laser Joining" at MVSR Engineering College, Hyderabad on February 04, 2019.

95. Dr. V. Ganapathy delivered an invited lecture on "Moisture Resistant Quasi-Two Dimensional Perovskite and Carbon Electrodes for Stable Perovskite Solar Cells" at the 'International Conference on Advanced Nanomaterials for Energy, Environment and Healthcare Applications (ANEH-2019)' held at Bishop Heber College of Engineering, Tiruchirappli during February 04-06, 2019.

96. Dr. Raman Vedarajan delivered an invited lecture on "High Performance Electrocatalyst for Fuel Cells" at the 'ANEH-2019', held at Bishop Heber College of Engineering, Tiruchirappli during February 04-06, 2019.

97. Dr. E. Ganesan delivered an invited lecture on "Tuning the Insulator to an Electrocatalyst" at the 'ANEH-2019', held at Bishop Heber College of Engineering, Tiruchirappli during February 04-06, 2019.

98. Dr. G. Padmanabham delivered an invited lecture on "Development of Powders for Metal Additive Manufacturing" at the 'Indo-German Bilateral Workshop on Additive Manufacturing of Metal: Current Issues and Way Forward' held at CSIR-NML, Jamshedpur during February 04-06, 2019.

99. Dr. Mani Karthik delivered invited lectures on "Nanoporous Materials-Characterization Signification and Applications" and

"Supercapacitor: Basics to Applications" at the Centre for Nanotechnology Research, VIT, Vellore during February 07 - 08, 2019.

100. Dr. G. Padmanabham delivered and invited lecture on "Interdisciplinary in Science, Engineering and Education" at the Birla Institute of Technology and Science (BITS), Pilani on February 08, 2019.

101. Dr. K. Ramya delivered an invited lecture on "Synthesis Characterization and Application of Quarternized Poly (Phenylene Oxide) based Anion Exchange Membranes" at the 'International Conference on Advancements in Polymeric Materials' held at Chennai during February 08 - 10, 2019.

102. Dr. Tata N. Rao delivered a keynote lecture at the 'First Indian Materials Conclave and 30th Annual General Meeting (AGM) of Materials Research Society of India (MRSI)' held at Bengaluru during February 12-15, 2019.

103. Dr. R. Gopalan, delivered an invited lecture on "Thermoelectric Materials and Development of Thermoelectric Generator" at the 'First Indian Materials Conclave and 30th AGM of MRSI' at Bengaluru during February 12-15, 2019.

104. Dr. Neha Hebalkar delivered a lecture in Marathi on "Nanotechnology for Better Life" on Occasion of International Day for Women and Girls in Science held to encourage girls in Science education and carrier, organized by a social work NGO 'Anam Prem' at Mumbai on February 16, 2019.

105. Dr. R. Gopalan, delivered an invited lecture on "Green Energy Materials" at the 'Global Smart Cities Meet' held at Mumbai on February 17, 2019.

106. Dr. G. Padmanabham delivered a plenary session talk on "Metal Additive Manufacturing Challenges" at the '5th International Conference on Powder Metallurgy in Asia (APMA 2019)' held at Pune during February 19-21, 2019.

107. Dr. Roy Johnson delivered a keynote address on "Polycrystalline Transparent Ceramics" at 'APMA-2019' held at Pune during February 19-21, 2019.

108. Dr. R Vijay presented a keynote lecture on "Nanostructured Materials for High Temperature Applications" at 'APMA-2019' held at Pune during February 19-21, 2019.

109. Dr. Malobika Karanjai presented a keynote lecture on "Design of a Novel Progressive Reactive Hot Press for Powder Metallurgy Alloys and Composites" at 'APMA-2019" held at Pune during February 19-21, 2019.

110. Dr. R. Prakash delivered a keynote lecture on "Li-Ion Batteries for Green Energy Applications" at the 'National Symposium on Green Energy and its Green Chemistry for Sustainable Future (GEGCS 2019)' held at Menakshi College for Women, Chennai during February 22-23, 2019.

111. Dr. Raman Vedarajan delivered an invited lecture on "One-Pot Green Synthesis of Electrocatalyst for Fuel Cell Application" at the 'GEGCS 2019' held at Menakshi College for Women, Chennai during February 22-23, 2019.

112. Dr. K. Ramya delivered an invited lecture on "Ordered Support Materials and Catalysts for Oxygen Reduction Reaction in Electrochemical Systems" at the '7th National Conference on Hierarchically Structured Materials (NCHSM 2019)' held at SRM Institute of Science and Technology, Chennai during February 22-23, 2019.

113. Dr. R. Balaji delivered a guest lecture on "Hydrogen-A Promising Fuel and Energy Storage Solution" at a 'Seminar on Energy Storage' held at Alliance University, Bengaluru on February 23, 2019.

114. Dr. R. Balaji delivered an invited lecture on "Hydrogen and Fuel Cells – Fundamentals to Applications" at the 'Faculty Development Programme on Energy Storage Applications' held at Thiyagaraja College of Engineering, Madurai on February 24, 2019.

115. Dr. R. Prakash delivered an invited lecture on "Li-ion Batteries and Beyond" at the 'Workshop on Batteries, Innovation and Safety, going beyond Lithium' held at New Delhi during February 25 - 27, 2019.

116. Dr. Tata N. Rao delivered an invited lecture on "Batteries: Li-Ion Batteries and Beyond (Materials Aspects)" at the 'Electric Vehicle India Summit' held at Delhi during February 25-27, 2019.

117. Dr. R. Gopalan delivered an invited lecture on "Li-Ion Battery Technology for EV Application" at the 'EV Technology Conference' held at Bengaluru on February 27, 2019.

118. Dr. Gururaj Telasang delivered an invited lecture on "Laser Metal Additive Manufacturing: Process and Build Properties" at the 'International Conference on Materials and Manufacturing Technology Theme: 3D Printing A to Z' held at Pune during February 27- 28, 2019.

119. Dr. B. V. Sarada delivered an invited lecture on "Materials for Clean Energy" at the 'One Day Seminar on Role of Science in Technology Development' held at Methodist College of Engineering and Technology, Hyderabad on the occasion of National Science Day on February 28, 2019.

120. Dr. R. Gopalan delivered the chief guest lecture on "Nano Functional Materials and their Application' at the 'International Conference on Nano Materials'

held at AMET University, Chennai on March 01, 2019.

121. Dr. S. Sakthivel delivered an invited lecture on "Cost Efficient Absorber and Easy to Clean Coating Technology for Eco-Friendly Concentrated Solar Thermal (CST) and PV Applications" at the 'National Conference on Novel Chemical System for Therauptic and Energy Applications' held at Sardar Patel University, Gujarat during March 01-02, 2019.
122. Dr. R. Gopalan, delivered a keynote lecture on "Mathematics in Materials Science" during the 'One-Day Orientation Programme on Higher Education in Basic Sciences' held at Satyabama University, Chennai on March 06, 2019.
123. Dr. Bijoy Kumar Das delivered an invited lecture on "Electrochemical Energy Storage Systems-Materials Challenges and Developments" at VIT, Vellore on March 08 2019.
124. Dr. R. Balaji delivered an invited lecture on "Life-Limiting Aspects of the Corrosion of Components for PEM Fuel Cell" at the 'National Seminar on Electrochemical Corrosion and its Impacts on Industries in Tamilnadu' held at S.A. Engineering College, Chennai on March 08, 2019
125. Dr. Mani Karthik delivered an invited lecture on "Opportunities and Challenges of Supercapacitor Technology for Real-World Applications" at the 'International Conference of Supercapacitor, Energy Storage and Applications (ICSEA-2019)' held at Thrissur, Kerala during March 08-10, 2019.
126. Dr. Raman Vedarajan delivered an invited lecture on "Hybridization of Fuel Cells and Supercapacitor for Electric Vehicle Application" at the ' ICSEA-2019', held at Thrissur, Kerala during March 08-10, 2019.
127. Dr. R. Prakash delivered an invited lecture on "Green Technology Development at ARCI" at the 'National Conference on Global Warming, Green Energy and Environmental Pollution- Go Green 2018' held at Velammmal Institute of Technology, Chennai on March 09, 2018.
128. Dr. R. Prakash delivered an invited lecture on "Li-ion Battery for Electric Mobility" at the 'eVIT Conclave 2018' held at VIT, Chennai on March 10, 2018.
129. Dr. B. V. Sarada delivered an invited lecture on "Science and Engineering Aspects of Nanostructured Materials: Advance Characterization Techniques" at the 'National Seminar on Insights into Materials Characterization (IMC-2019)' held at MGIT, Hyderabad on March 11, 2019.
130. Mr. Manish Tak delivered an invited lecture on "Additive Manufacturing and Refurbishment: Challenges and Way Forward" at the 'International Conference on Future of Advanced Manufacturing' held at IIT Madras Research Park, Chennai on March 15, 2019.
131. Dr. R. Prakash delivered an invited lecture on "Li-ion Batteries for Electric Vehicles" at the 'Workshop for ETWDC' held at Kongu College of Engineering, Erode on March 15, 2019.
132. Mr. Vallabha Rao Rikka delivered an invited talk on "Fundamental Studies on Li-ion Battery and Battery Management System for EV Applications" at the 'Workshop-1 of ETWDC, SAE India' held at Kongu Engineering College, Erode during March 16-19, 2019.
133. Dr. Srinivasan Anandan delivered an invited lecture on "Large Scale Synthesis of Nanostructured Materials for Electric Vehicles (EVs) Application" at the 'National Conference on Advanced Research and Technology in Chemical Engineering & its Allied Fields' held at the Department of Chemical Engineering, CBIT Hyderabad on March 22, 2019.
134. Dr. R. Gopalan delivered the chief guest lecture on "Energy Materials for Energy Saving Application" at the 'National Seminar on New Engineering Materials and their Application' held at Valliammal Engineering College, Chennai on March 23, 2019.
135. Dr. R. Gopalan delivered an invited lecture on "Tuning of Microstructure in Functional Materials for Sustainable Application" at the 'Indo-German Workshop' held at IIT Madras, Chennai during March 25-27, 2019.
136. Dr. Malobika Karanjai delivered a talk on "Commercially viable Technologies from ARCI, GOI" at an 'Awareness Program on Food Processing, Life Sciences and MSMEs' held at Vijayawada on March 26, 2019.
137. Mr. Vallabha Rao Rikka delivered an invited talk on "Investigation of Ageing Mechanism and Safety Studies of Li-ion Battery for EV Applications" at the 'Workshop-2 of ETWDC, SAE India' held at Dr. Sivanthi Aditanar College of Engineering, Tuticorin during March 30-31, 2019.

Papers Presented at Indian Conference/ Symposia

1. Mr. P. Vijendar Reddy (Dr. V. Ganapathy) presented a paper on "Fabrication of Large Grain Perovskite Films for Highly Efficient and Stable Perovskite Solar Cells" at the '3rd International Conference on Nanomaterials: Synthesis, Characterization and Applications (ICN-2018)' held at Mahatma Gandhi University, Kottayam during May 11-13, 2018.
2. Ms. T. Mitravinda (Dr. T. N. Rao) presented a paper on "Design and Development of Nitrogen Doped Nano

Porous Activated Carbon as Electrode Active Material for Super Capacitor" at 'Chemference 2018' held at IIT Bombay, Mumbai during May 19 - 20, 2018.

3. Ms. S. Manasa (Dr. R. Subasri) presented a paper on "Development of Self Healing, Corrosion Protection Coatings on AA2024-T4 by Electrophoretic Deposition" at the 'National Conference on Frontiers in Corrosion Control of Materials (FCCM-2018)' held at NIT, Warangal during June 28 - 29, 2018.
4. Mr. Swapnil H. Adsul (Dr. R. Subasri) presented a paper on "Effect of Inhibitor Loaded Halloysite Nanoclay on Corrosion Protection Property of Sol-Gel Coatings on Mg Alloy AM50" at the 'FCCM-2018' held at NIT, Warangal during June 28 - 29, 2018.
5. Dr. L. Venkatesh presented a paper on "Physical Sciences & Engineering Materials – Thin films, Coatings, Surface and Interfaces" at the 'International Conference on Electron Microscopy' held at Bhubaneswar during July 18 - 20, 2018.
6. Mr. Mohd Aqueel (Mr. K. V. Phani Prabhakar) presented a paper on "Laser Hybrid Welding of Inconel 617 for Advanced Ultra Super Critical Boiler (A-USC) Applications" at 'SICE-2018' held at DMRL Hyderabad during July 25 - 27, 2018.
7. Mr. B. Vignesh (Dr. P. Sudharshan Phani) presented a paper on "High Speed Nano Mechanical Property Mapping of Thermal Barrier Coating" at 'SICE-2018' held at DMRL, Hyderabad during July 25 - 27, 2018.
8. Ms. B. Ramya Krishna (Dr. R. Easwaramoorthi) presented a paper on "Moisture and Temperature Induced Degradation in Organometal Halide Perovskites" at the 'International Conference on Sustainable Chemistry for Health, Environment and Materials (SuChem2018)' held at CSIR-IICT, Hyderabad during August 05-08, 2018.
9. Dr. R. Subasri presented a paper on "Development of Durable Superhydrophobic Coatings on Aluminum Alloy and SS 304 Substrate" at the 'International Conference on Surface Engineering (INSURF 2018)' held at IISc, Bengaluru during August 09-11, 2018.
10. Mr. K. R. C. Soma Raju made a poster presentation on "Sol-gel Spectrally Selective Coatings for Solar Thermal Applications" at 'INSURF 2018' held at IISc, Bengaluru during August 09-11, 2018.
11. Ms. J.A. Prithi presented a paper on "Polymer Coated Carbon as Corrosion Resistance Support for Platinum Electro Catalyst in PEMFC" at 'INSURF 2018' held at IISc, Bengaluru during August 09-11, 2018.
12. Mr. T. Ramesh (Dr. N. Rajalakshmi) presented a paper on "Jute Deprival Activated Carbon Fibres for High Performance Supercapacitor" at the 'International Conference on Advanced Nanomaterials for Energy, Environment and Healthcare Applications (ANEH – 2018)' held at K.S.R College of Arts and Science for Women, Tiruchengode during August 31-September 01, 2018.
13. Mr. S. Ramakrishnan presented a paper on "Concentration Profile and Spatial Distribution of Elements in PEM Fuel Cell Catalyst and Metallic Flow Field Plate" at the 'Workshop on Atom Probe Tomography (APT)' held at ARCI, Hyderabad on September 07, 2018.
14. Mr. V.V. Ramakrishna (Dr. S. Kavitha) presented a paper on "Effect of Samarium Doping in Manganese Bismuth Melt-Spun Ribbons" at the 'International Conference on Science, Technology and Applications of Rare Earths (ICSTAR 2018)' held at Tirupati during September 23-25, 2018.
15. Mr. A. Vivek (Dr. Pramod H. Borse) presented a paper on "Deposition of Nanostructure Nickel Phosphide File on Laser Patterned Metal Substrate for Improved Hydrogen Evolution" at the 'International Conference on Nano Science and Engineering Applications (ICONSEA 2018)' held at Jawaharlal Nehru Technological University Hyderabad (JNTU), Hyderabad during October 04-06, 2018.
16. Mr. Balaji Padya presented a paper on "Preparation of Multifunctional Graphene Flakes Via solution-phase Exfoliation through Wet-Miling for Energy Storage Application" at 'ICONSEA 2018' held at JNTU, Hyderabad during October 04-06, 2018.
17. Mr. Ravi Kiran (Dr. P. K. Jain) presented a paper on "Experimental Investigation of Friction and Wear Properties of Few-Layer Graphene in Engine Oil for Steel-Steel Contacts" at 'ICONSEA 2018' held at JNTU, Hyderabad during October 04-06, 2018.
18. Mr. M. Sagar (Dr. P.K. Jain) presented a paper on "Synthesis of MnO2 Nano-Flakes for High Performance Supercapacitor Application" at 'ICONSEA 2018' held at JNTU, Hyderabad during October 04-06, 2018.
19. Mr. Kezil Mathew Varghese (Mr. Pandu Ramavath) presented a paper on "Evaluation of Sintering Kinetics of Sub-Micron Alumina (Al2O3) and Zirconia toughened Alumina (ZrO2-Al2O3) based on the Construction of Master Sintering Curve" at the 'International Conference on Recent Trends in Materials Science and Technology 2018 (ICMST 2018)' held at Thiruvananthapuram during October 10-13, 2018.
20. Mr. M. Rajkumar presented a paper on "Design and Formability of Metallic Bipolar Plates for Proton Exchange Membrane Fuel Cell with Flow Analysis using ANSYS Fluent" at the 'National Conference on Recent Advances in Material Science and

Manufacturing Engineering – RAMME 2018' held at Annamalai University, Chidambaram during October 15-16, 2018.

21. Mr. V.V.N. Phani Kumar presented a paper on "Polyvinyl Alcohol and Sodium Alginate as Alternate Green Binders Pf Lithium Titanium Oxide Anode for Lithium Ion Batteries" at the '3rd National Conference on Materials for Energy Conversion and Storage at School of Materials Science' held at IIT (BHU), Varanasi during October 18 - 20, 2018.
22. Mr. P. Laxman Mani Kanta presented a paper on "Carbon Coated Na2Ti3O7 as a Potential Anode Material for Sodium Ion Battery" at the '3rd National Conference on Materials for Energy Conversion and Storage at School of Materials Science' held at IIT (BHU), Varanasi during October 18-20, 2018.
23. Dr. Papiya Biswas presented a paper on "Field Assisted Sintering of Magnesium Aluminate Spinal Ceramics" at the '3rd International Conference on Advanced Materials and Manufacturing Processes for Strategic Sectors (ICAMPS 2018)' held at Thiruvananthapuram, Kerala during October 25-27, 2018.
24. Mr. E. Anbu Rasu presented a paper on "Joining of Tube to Fin Made of Carbon Steel using Hybrid CO2–Laser–MIG Welding" at the '8th International Welding Symposium 2018 (IWS 2K18)' held at Mumbai held during November 27 - 29, 2018.
25. Ms. B. Ramya Krishna (Dr. R. Easawaramoorthi) made a poster presentation on "Nanocrystaline TiO2 Electron Transport Layer for Improved Performance of Perovskite Solar Cells" at the '10th Bengaluru India Nano' held at Bengaluru during December 05-07, 2018.
26. Mr. Narendra Chundi (Dr. S. Sakthivel) made a poster presentation on "Dual Functional Nanocasting for Self-Cleaning and Anti-Reflective Applications" at the '10th Bengaluru India Nano' held at Bengaluru during December 05-07, 2018.
27. Ms. P. Samhita (Dr. B.V. Sarada) made a poster presentation on "Effect of Substrate Surface Porosity on Enhanced Specific Capacitance of NiCo2O4 Nanosheet Electrodes for Super Capacitors" at the '10th Bengaluru India Nano' held at Bengaluru during December 05-07, 2018.
28. Dr. Pavan Srinivas Veluri made a poster presentation on "Increasing the Energy Density of Supercapacitors using a Battery Electrode in Asymmetric Configuration for Electric Vehicle Application" at the 'Carbon MEMS: New Horizons' held at IIT, Hyderabad during December 05-07, 2018.
29. Mr. K. Nanaji presented a paper on "Three Dimensional Ordered Mesoporous Carbons with Tunable Pore Sizes as Efficient Electrode Material for Improved Lithium Ion Battery and Supercapacitor Applications" at the 'Carbon MEMS: New Horizons' at held IIT, Hyderabad during December 05-07, 2018.
30. Dr. D. Prabhu presented a poster on "Nanocrystalline Soft and Hard Magnetic Materials for Automotive Applications" at the "Bengaluru Nano 2018" held at Bengaluru during December 05-07, 2018.
31. Dr. D. Prabhu presented a poster on "Effect of Quaternary Sm-Cu-Fe-Al Eutectic Alloy Binder on the Magnetic Properties of Sm-Fe-N" at the 'International Conference on Magnetic Materials and Applications (ICMAGMA 2018)' held at Bhubaneswar during December 09-13, 2018.
32. Mr. V.V. Ramakrishna (Dr. S. Kavitha) made a poster presentation on "Rare-Earth Free Mn-Bi Alloy prepared by Induction Meeting" at 'ICMAGMA 2018' held at Bhubaneswar during December 09-13, 2018.
33. Mr. G. Vijayaragavan made a poster presentation on "Effect of Quaternary Sm-Cu-Fe-Al Eutectic Alloy Binder on the Magnetic Properties of Sm-Fe-N Powder" at 'ICMAGMA 2018' held at Bhubaneswar during December 09-13, 2018.
34. Dr. S. Kavita presented a paper on "Room Temperature Giant Magneto Caloric Effect in Mn-Fe-P-Si-Ge Alloys" at 'ICMAGMA 2018' held at Bhubaneswar during December 09-13, 2018.
35. Ms. G. Anusha (Dr. S. Kavitha) presented a paper on "Room Temperature Giant Magneto Caloric Effect in Mn-Fe-P-Si-Ge Alloys" at 'ICMAGMA 2018' held at Bhubaneswar during December 09-13, 2018.
36. Dr. R. Prakash presented a paper on "Development of Electrode and Binder Materials for Lithium-Ion Battery for Electric Vehicle Application" at the 'International Meeting on Energy Storage Devices (IMESD) – 2018' held at IIT, Roorkee during December 10-12, 2018.
37. Mr. Sumit Ranjan Sahu presented a paper on "Synthesis of Bare and Metal Decorated Graphene Sheets from Single Walled Carbon Nanohorns for Lithium-Ion Battery Applications" at 'IMESD- 2018' held at IIT, Roorkee during December 10–12, 2018.
38. Ms. B. Divya (Dr. B. V. Sarada) made a poster presentation on "Electro deposition of ZnS Thin-Films: Influence of Organic Acids on the Structural and Optical Properties" at the 'Telangana State Science Congress (TSSC-2018)' held at NIT, Warangal during December 22–24, 2018.
39. Mr. Brijesh Singh Yadav (Dr. Sanjay R Dhage) presented a paper on "Bottlenecks in the Development of Inkjet Printed CIGSe2 Thin Film Solar Cell" at the '3rd International Conference on Optoelectronic and Nano Materials for Advanced Technology' held at Kochi during January 02–05, 2019.

40. Mr. S. Ramakrishnan presented a paper on "Electrodeposition of Conducting Polymer over Metallic Bipolar Plate for PEM Fuel Cell Application-Preliminary Analysis" at the 'National Conference on Recent Advances in Chemistry (RAC-19)' held at Anna University, Chennai during January 04 - 05, 2019.
41. Dr. M. Sreekanth presented a paper on "CIGS Thin Films Solar Cells on Flexible Substrates by Pulse Electro Deposition" at the '12th International Symposium on Advances in Electrochemical Science and Technology' held at Chennai during January 08–10, 2019.
42. Ms. J. A. Prithi presented a paper on "Polymer Coated Vulcan Carbon as Corrosion Resistant support for Platinum Electro Catalyst" at the '12th International Symposium on Advances in Electrochemical Science and Technology' held at Chennai during January 08 -10, 2019.
43. Mr. Swapnil H. Adsul (Dr. R. Subasri) presented a paper on "Evaluation of Corrosion Protection Ability of different Corrosion Inhibitor Loaded Halloysite Nanoclay based Sol-Gel Coatings on Mg Alloy AZ91D" at the 'National Conference on Industrial Coatings (NCIC-2019)' held at CSIR – IMMT, Bhubaneswar during January 24-25, 2019.
44. Mr. K. K. Phani Kumar (Dr. S. Sakthivel) presented a paper on "Development of Solar Selective Absorber Coatings by Wet Chemical Process on Different Substrates" at the ' ASAR-International Conference on Renewable Energy, Green Technology and Environmental Science (ICREGTES)' held at Pune on January 27, 2019.
45. Mr. V. Tarun Kumar made a poster presentation on "Engineering Gas Diffusion Layer for Water Management in Proton Exchange Membrane Fuel Cell" at the 'Advanced Nanomaterials for Energy Environment and Health Care Applications' held at Bishop Heber College, Tiruchirappalli during February 04 - 06, 2019.
46. Mr. Srinivas Rao Atchuta presented a paper on "Ternary transition Metal based Spinel Nanocomposite Solaar Selective Absorber Coatings for Concentrated Solar Thermal Application" at the 'First Indian materials Conclave and 30th Annual General Meeting (AGM) of Materials Research Society of India (MRSI)' held at IISc, Bengaluru during February 12-15, 2019.
47. Ms. B. Divya (Dr. B. V. Sarada) made a poster presentation on "Electro Deposition of Device Quality Thin Films for the Solar Cell Photovoltaic Applications" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
48. Dr. Manjusha Battabyal made a poster presentation on "Enhancement of Thermoelectric Properties in p-type Mg3Sb2 through Band Engineering and Nanostructuring" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
49. Ms. Priyadarshini B. (Dr. Manjusha Battabyal) made a poster presentation on "Microstructure Stability and Enhanced Thermoelectric Properties in Carbon Nanotube Dispersed ZnSb Thermoelectrics" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
50. Mr. B. Prasanth (Dr. D. Sivaprahasam) made a poster presentation on "Microstructure Thermoelectric Properties Correlation of N-type Mg2Si0.4Sn0.6 Solid Solutions prepared by Melt Route" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
51. Mr. S. Harish (Dr. D. Sivaprahasam) made a poster presentation on "Design, Development and performance Evaluation of Thermoelectric Generator Test Rig with Bi2Te3 Thermoelectric Modules" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
52. Mr. B. Jayachandran (Dr. D. Sivaprahasam) made a poster presentation on "Influence of Bonding Techniques on the Specific Contact Resistance of Pb0.5Sn0.5Te/Cu Thermoelectric Joints" at the 'First Indian Materials Conclave and 30th AGM of MRSI' held at IISc, Bengaluru during February 12-15, 2019.
53. Ms. Keerthi Sanghamitra. K (Dr. Neha Y. Hebalkar) presented a paper on "Thermographic Studies of Aerogel Composites" at the '2nd International Conference on New Frontiers in Chemical, Energy and Environmental Engineering (INCEEE-2019)' held at NIT, Warangal during February 15 - 16, 2019.
54. Dr. Joydip Joardar presented a paper on "Nano Structured 2D- Tungsten Disulfide based Composite" at the '5th International Conference on Powder Metallurgy in Asia + Exhibitions (APMA 2019)' held at Pune during February 19-21, 2019.
55. Dr. Dibyendu Chakravarty presented a paper on "Development of Tungsten based Plates by Spark Plasma Sintering" at 'APMA 2019' held at Pune during February 19 - 21, 2019.
56. Dr. Gururaj Telasang presented a paper on "Dissimilar Metals Additive Manufacturing: Stainless Steel on Copper Alloy Plate" at the 'APMA 2019' held at Pune during February 19 - 21, 2019.
57. Ms. K. Divya presented a paper on "Design for Additive Manufacturing: Self Supporting Feature" at the 'APMA 2019' held at Pune during February 19 - 21, 2019.
58. Dr. Bijoy Kumar Das made a poster presentation on

"Development of Low Cost Sodium Ion Batteries for Grid and Off-Grid Storage Application" at the '2nd International Meeting on Clean Energy Materials Innovation Challenge' held at IIT Delhi, New Delhi during February 21-22, 2019.

59. Ms. Shaik Mubina (Dr. B. P. Saha) presented a paper on "Influence of Nanofibers on the Mechanical Properties of CVD Coated SiC-CNF Composites" at the '6th International Conference on Recent Advances in Composite Materials (ICRACM-2019)' held at IIT (BHU), Varanasi during February 25 - 28, 2019.
60. Ms. V. P. Madhurima (Dr. P. K. Jain) presented a paper on "Optimization of Buffer Gas Pressure and Arc Voltage for Carbon Nanotubular Structures Growth and their Energy Storage Studies" at the 'International Conference on Advanced Functional Materials and Devices (ICAFMD - 2019)' held at NIT, Warangal during February 26 - 28, 2019.
61. Mr. Balaji Padya presented a paper on "Insights into Processing and Influence of Calcinations Temperature on Pseudo Capacitance Properties of 1-D Spinel – NiCo2O4 Rods" at the 'ICAFMD-2019' held at NIT, Warangal during February 26 - 28, 2019.
62. Ms. S. Bhuvaneswari (Dr. Raju Prakash) presented a paper on "Scandium – Doped LiMn2O4 Spinel as Stable Cathode for Lithium Ion Batteries" at the 'ICAM-2019' held at Jamia Millia Islamia (A Central University), New Delhi during March 06 - 07, 2019.
63. Dr. Bharathi Sankar (Dr. Mani Karthik) presented a paper on "Design, Development and Real–Time Demonstration of Supercapacitor Powered Electric Bicycle" at the 'International Conference on Supercapacitors, Energy Storage and Applications (ICSEA-2019)' held at Thrissur, Kerala during March 08-09, 2019.
64. Mr. K. Nanaji presented a paper on "Graphene Sheets like Nanoporous Carbon Derived from Agricultural Biowaste (Jute Stick) as Electrode Material for High Performing Super Capacitors" at the 'ICSEA-2019' held at Thrissur, Kerala during March 08-09, 2019.
65. Mr. S. Vasu presented a paper on "In-Situ Carbon Coating on Metal Oxide Based Cathode Materials for Improved Electrochemical Properties of Lithium-Ion Battery" at the 'ICSEA-2019' held at Thrissur, Kerala during March 08-09, 2019.
66. Ms. Shaik Mubina (Dr. B. P. Saha) presented a paper on "Optimization of Processing Parameters, Physical and Mechanical Properties of SiC-CNF Composites using Taguchi Approach" at the '9th International Conference on Materials Processing and Characterization (ICMPC – 2019)' held at Gokaraju Rangaraju Institute of Engineering & Technology, Hyderabad during March 08-10, 2019.
67. Mr. T. Ramesh (Dr. N. Rajalakshmi) presented a paper on "Hierarchical Porous Carbon Microfibers Derived from Tamarind Seed Coat for High-Energy Supercapacitor Application" at the '19th Annual Research Awards 2018-19' held at Dr. K.V. Rao Scientific Society, Hyderabad on March 09, 2019.
68. Ms. N. Manjula (Dr. R. Balaji) presented a paper on "Development of Advanced Electrochemical Methanol Reformation for Hydrogen Production in PEM Electrolysis Cell" at the '19th Annual Research Awards 2018-19' held at Dr. K.V. Rao Scientific Society, Hyderabad on March 23, 2019.
69. Ms. P. Samhita (Dr. B. V. Sarada) made a poster presentation on "Efficient Utilization of Oxygen Vacancies Enabled NiCo2O4 Electrode for High Performance Pseudo Capacitor" at the '3rd In-house Symposium' held at IIT, Hyderabad on March 30, 2019.

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

1. Mr. V. Balaji Rao, Ms. V.Uma and Mr. V.C. Sajeev attended the 'Workshop on Assessing Performance of PV Modules in the Field' at the National Centre for Photovoltaic Research and Education (NCPRE), IIT Bombay, Mumbai during April 06- 07, 2017.
2. Ms. S. Nirmala, Mr. Ch. Sambasiva Rao and Ms. N. Aruna attended the 'Key Sight 2017 Aerospace & Defence Symposium' held at Hyderabad on April 13 2017.
3. Dr. Easwaramoorthi Ramasamy attended 'Workshop on R&D Activities on Solar Photovoltaics in India' organized by SERIIUS at IIT Bombay, Mumbai on April 24, 2017.
4. Mr. G. M. Rajkumar and Mr. Anirban Bhattacharjee attended the 'National Conference on GST Programme' held at Hyderabad on May 12, 2017.
5. Dr. S. M. Shariff attended the 'Workshop on Challenges in Joining of Advanced Materials (CJAM)' held at Hyderabad on May 26, 2017.
6. Dr. S. Sakthivel and Dr. Easwaramoorthi Ramasamy attended the 'Conference on Green Power: Challenges and Innovation' held at NTPC, Noida during June 08-09, 2017.
7. Mr. Manish Tak, Ms. K. Divya and Mr. E. Anbu Rasu attended the 'Workshop on Research Methodology and Faculty Advisers Forum' held at Hyderabad during June 19-24, 2017.
8. Dr. R. Subasri, Dr. L. Ramakrishna, Mr. Manish Tak and Mr. K.R.C. Soma Raju attended the 'Seminar on Creating Capabilities with MSME's' held at Hyderabad on July 14, 2017.
9. Mr. Sai Kishore attended the 'Seminar on TDS' held at Hyderabad on August 08, 2017.
10. Dr. Papiya Biswas attended 'CEP Workshop on 3D Printing' held at IIT-Bombay, Mumbai during August 21-22, 2017.

11. Dr. T. N. Rao attended the '2nd Edition of Energizing South - Conference on Economic Growth: Smart, Reliable & Sustainable Power' held at Visakhapatnam during September 01-02 , 2017.
12. Dr. K. Suresh, Ms. K. Divya, Dr. S B Chandrasekhar, Mr. Sai Karthik and Dr. Uday Bhaskar, attended a 'Seminar on Heat Treatment of Steels and other Alloys-Latest Trends and Opportunities' held at Hyderabad on September 04, 2017.
13. Mr. Anbu Rasu attended the course on 'Advanced Welding Technology' held at IIT Bombay, Mumbai during September 12- 16, 2017.
14. Dr. N. Rajalaskshmi and Dr. M.B. Sahana attended a 'Workshop on Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) Act, 2013' held at Chennai on September 13, 2017.
15. Mr. K. V. Phani Prabhakar and Mr. Manish Tak attended the 'National Seminar on Failure Analysis and Advances in Welding Technologies for Aero Engine' held at HAL, Koraput, Odisha on September 15, 2017.
16. Dr. Pramod H. Borse attended the 'Workshop on Scale up of Hydrogen Production through Photo-Electro-Chemical (PEC) Water Splitting' held at Indian Oil Corporation-R&D Centre, Faridabad during November 06, 2017.
17. Dr. Sanjay R. Dhage and Ms. Priya Anish Mathews attended 'One Day Conclave on Connecting the Dots in Telangana's Defence & Aerospace Sector' held at Hyderabad on November 16, 2017.
18. Ms. S. Nirmala, Mr. Sambasiva Rao and Ms. Aruna attended the 'One Day Workshop on Emerging Trends in Intelligent Machines' held at Hyderabad on December 02, 2017.
19. Mr. A. Srinivas and Dr. Rambha Singh attended the 'Regional Official Language Conference of South and South-East' held at Vishakhapatnam on December 8, 2017.
20. Mr. Sai Kishore attended 'One-Day Workshop on Tax Related Issues' held at Chennai on January 11, 2018.
21. Mr. K. Srinivasa Rao attended a 'Two Day Workshop on Metal Finishing Technologies on Electroplating-2018' held at IISc, Bengaluru during February 01-02, 2017.
22. Mr. Sudheendra attended "One Day Hindi Workshop' organized by Town Official Language Implementation Committee' at Hyderabad on February 02, 2018.
23. Dr. S.Kavita attended the 'Indo-US Symposium on Magnetism' held at IIT Mumbai, Bombay during February 05-06, 2018.
24. Dr. R. Gopalan attended the 'Indian Analytical Science Congress (IASC-2018)' held at Kottayam during February 08-10, 2018.
25. Dr. G. Ravi Chandra attended the 'Annual General Body Meeting of the Materials Research Society of India and the National Symposium on Advanced in Functional and Exotic Materials' held at Tiruchirapally during February 14-16, 2018.
26. Dr. Kaliyan Hembram attended the '3rd International Exhibition and Conference on Medical Device Sector (Indian Medical Device 2018)' held at Bangalore International Exhibition Center, Bengaluru during February 15-17, 2018,
27. Mr. Manish Tak attended a 'National Seminar on Emerging Trends in Repair, Reclamation and Life Extension of Helicopters Aero Engines and their Aggregates' at the 3-Base Repair Depot, Chandigarh on February 19, 2018.
28. Dr. Malobika Karanjai chaired the Plenary session talk at the 'International Conference on Powder Metallurgy and Particulate Materials (PM 18)' held at Navi Mumbai during February 21-22, 2018.
29. Dr. Rambha Singh attended one day Workshop on 'How to Draft Replies for Questionnaire on Parliament Official Language Committee' held at Hyderabad on February 22, 2018.
30. Dr. M. Buchi Suresh and Mr. M. Ramakrishna attended the 'National Seminar on Development Processing and Application of High Temperature Materials-Current Trends and Challenges Ahead' held at Hyderabad during February 22-23, 2018.
31. Mr. K.V. Phani Prabhakar and Dr. S. M. Shariff attended the 'International Conference on Aluminium & Magnesium the Sustainable Light Weight Solutions for Transport Sector' held at Pune during February 23-24, 2018.
32. Dr. Raman Vedarajan participated in 'National Seminar on Development of Aluminum Alloys and Downstream Products of Defence, Aerospace and Other Strategic Applications' at the Jawaharlal Nehru Aluminum Research Design and Development Centre, Nagpur during February 23-24,2018.
33. Mr. B. Balaji Rao, Ms. V. Uma, Mr. V C Sajeev and Mr. A. R. Srinivas attended the 'International Conference on Engineer Infinite and 'Product Exhibition at ELECRAMA 2018' held at New Delhi during March 10-14, 2018.
34. Mr. Manish Tak attended 'Indo-Australian Workshop on Advances in Materials and Additive Manufacturing (AM2)' held at IIT Madras, Chennai during March 21-22, 2018.

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

1. Mr. K.R.C. Soma Raju, Dr. Sreekanth Mandati, and Mr. K. Nanaji attended a 'Workshop on Electron Microscopy (WEM-2018)' held at the Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), Nagpur during April 19-21, 2018.
2. Dr. Malobika Karanjai attended a 'Workshop on RTI

Act and Sexual Harassment of Women at Workplace Act' held at New Delhi during June 07-09, 2018.

3. Mr. S. Vasu attended a 'Workshop on Thermal Analysis of Materials using DSC, TGA & Dilatometer' held at IIT, Hyderabad during June 25-30, 2018.
4. Dr. D. Prabhu attended a two-day 'Workshop on E-Procurement & E-Reverse Auction for Project Contracts and Effective Contract Implementation' held at Chennai during June 28-29, 2018.
5. Mr. V. Balaji Rao, Dr. B. V. Sarada and Dr. Easwaramoorthi R. attended the '3rd Edition CII Energizing South Conference on India @ 75: Smart, Sustainable & Affordable Power" held at Hyderabad during August 10-11, 2018.
6. Mr. S. Ramakrishnan attended a 'Workshop on Concentration Profile and Spatial Distribution of Elements in PEM Fuel Cell Catalyst and Metallic Flow Field Plate at Atom Probe Tomography (ATP)' held at ARCI, Hyderabad on September 07, 2018.
7. Dr. Sanjay Bhardwaj, Mr. S. Arun and Mr. N. Srinivas participated in the 'World Automotive Congress 2018 Exhibition' held at Chennai during October 02-05, 2018.
8. Mr. P. Santosh Kumar attended "21st National Convention on Knowledge, Library and Information Networking (NACLIN 2018)" held at GITAM College, Vishakhapatnam during October 04-06, 2018.
9. Mr. Naveen M. Chavan, Dr. Prasenjit Barick and Dr. L. Venkatesh attended the 'Conference on India International Science Festival 2018' held at Indira Gandhi Praatishthan, Lucknow during October 05-08, 2018.
10. Ms. K. Divya attended the 'DAE-BRNS Workshop on Laser Additive Manufacturing and Allied Technologies (LAMAT-2K18)' held at Indore during October 08-12, 2018.
11. Mr. S. Ganesh attended the programme on "Powder Metallurgy Association of India (PMAI) course on Powder Metallurgy (PMSC'18)" at Pune during October 12-15, 2018.
12. Dr. Roy Johnson and Dr. Y. Srinivasa Rao attended an event on 'IRDE Industry Institute Interaction Meet (I4M-2018)' held at Instruments Research & Development Establishment (IRDE), Dehradun on October 25, 2018.
13. Dr. S. Sakthivel attended the 'Conference on IP Generation (MIPCON 2018: Accelerating Innovation & Entrepreneurship by Managing IP Creation)' held at Hyderabad on October 31, 2018.
14. Mr. Manish Tak attended the '56th National Metallurgist Day & 72nd Annual Technical Meeting of the Indian Institute of Metals' held at Kolkata during November 14-16, 2018.
15. Dr. Tata N. Rao, Dr. Sanjay Bhardwaj and Dr. B. V. Sarada attended the "Health Innovation Summit' organized by IITB Alumni Association at HITEX Convention Centre, Hyderabad on November 17, 2018.
16. Dr. Ravi N. Bathe and Dr. Gururaj Telasang attended the 'Summit on Additive Manufacturing' held at ISRO Headquarters, Bengaluru on November 28, 2018.
17. Dr. V. Ganapathy attended a workshop on 'BRICS Young Scientist Conclave (YSF)' held at NIAS, Bengaluru during December 02–04, 2018.
18. Mr. Manish Tak attended the '27th DAE-BRNS National Laser Symposium (NLS-27)' held at Indore during December 03-06, 2018.
19. Dr. T. N. Rao, Dr. R. Vijay, Dr. Neha Yeshwanta Hebalkar, Dr. Srinivasan Anandan and Mr. Sheik Nagpur Baba attended the 'Bengaluru Nano 2018' held at Bengaluru during December 05-07, 2018.
20. Mr. U. Gowtham attended a 'Conference on Nano for a Better World' held at Bengaluru during December 05-07, 2018.
21. Dr. G. Ravi Chandra and Dr. K. Suresh attended a 'Workshop on Small and Wide Angle X-Ray Scattering' held at Pune during December 12-13, 2018.
22. Dr. Pramod H. Borse and Ms. S. Nirmala attended the 'Electrical and Electronic Summit (E2S – A & D)' held at Hindustan Aeronautics Limited (HAL), Hyderabad during December 18-19, 2018.
23. Dr. Y. Srinivasa Rao attended a 'Workshop on Advanced Engineering Materials' held at Vignan's Foundation for Science, Technology & Research, Hyderabad on December 28, 2018.
24. Dr. R. Subasri, Dr. D. Prabhu and Dr. Easwaramoorthi R. attended a 'Workshop on the Scientists Role in Technology Commercialization' held at New Delhi during January 16-18, 2019.
25. Mr. K. V. Phani Prabhakar attended a 'Workshop on Joining Technologies for Lightweight Vehicle Bodies' held at Mumbai on January 22, 2019.
26. Mr. Manish Tak attended the 'IMTEX 2019' held at Bengaluru during January 24-30, 2019.
27. Mr. Manish Tak, Dr. Gururaj Telsang and Ms. K. Divya attended the 'Indo-German Bilateral Workshop on Additive Manufacturing of Metal: Current Issues and Way Forward' held at CSIR-NML, Jamshedpur during February 04-06, 2019.
28. Dr. Ravi N. Bathe and Dr. Gururaj Telasang attended the 'Expert Group Meeting on Additive Manufacturing' held at the college of Engineering Pune on February 15, 2019
29. Dr. Srinivasan Anandan attended the 'Conference on Clean Buses in India: Spotlight on CNG, Electric and Hybrid Buses' held at New Delhi during February 20-21, 2019.

30. Mr. P. Santosh Kumar attended the '2nd International Conference on Changing Landscape of Science and Technology Libraries (CLSTL – 2019)' held at IIT – Gandhinagar, Gujarat during February 28 - March 02, 2019.
31. Dr. D. Prabhu and Mr. P. Laxman Mani Kanta and Mr. Ravi Gautam attended a 'Workshop on Atom Probe Tomography' held at IIT Madras, Chennai during March 08-09, 2019.
32. Mr. Sudheendra attended a 'Workshop on Preparation of EFC/SFC Proposals' held at Institute of Secretariat Training & Management (ISTM), New Delhi during March 11-13, 2019.

Panel Discussion

1. Dr. Sanjay Bhardwaj made a presentation on "IP Strategies for Open Innovation Paradigm" and participated as a panelist speaker during a technical session on 'Developing Effective IP Strategies for New Era of Shared Innovation: IP Issues in Collaborative Innovation / Partnership Model' held during "9th Edition MIPCON 2018: Managing IP Conference" organized by the Confederation of Indian Industry (CII) at Hyderabad on October 31, 2018.
2. Dr. Sanjay Bhardwaj made a presentation on "Methodology for Managing Collaborations and Technology Transfer" and participated as a panelist speaker during a technical session on 'Managing Technology and Knowledge Transfer and Spillovers' held during "World IP Forum - Conference" at New Delhi on November 16, 2018.
3. Dr. G. Padmanabham participated in the Panel discussion held during the "Health Innovation Summit' organized by IITB Alumni Association at HITEX Convention Centre, Hyderabad on November 17, 2018.
4. Dr. Sanjay Bhardwaj made a presentation on "Collaborative and Technology Transfer Strategy in the Nanotechnology Domain: Perspective of a Public-funded R & D Lab" and participated as a panelist speaker during a technical session on 'Nanotechnology Innovation for the Industry' held during "Nano Science and Technology Consortium (NSTC) Nanotech -2018" at Delhi on November 28, 2018.
5. Dr. N. Rajalakshmi participated in the panel discussion on "Stationery & Mobile Applications" held during the 7th International Hydrogen & Fuel Cell Conference (IHFC-2018) at Jodhpur during December 09-11, 2018.

Participation in Training Programmes in India

1. Dr. Kaliyan Hembram and Mr. Ravi Gautam attended a 'Hands-on-training programme on Electron Microscopy-Why, How and What' organized by CSIR-National Physical Laboratory (NPL) at New Delhi during May 22- June 01, 2018.
2. Mr. G.M. Raj Kumar and Mr. P. Sai Kishore attended the 'ASSOCHAM one day National Conclave on Goods and Service Tax (GST)' held at Hyderabad on July 04, 2018.
3. Dr. Nitin P. Wasekar attended a programme on 'Emotional Intelligence at Workplace for Scientists and Technologists' held at Centre for Organizational Development, Hyderabad during August 06-10, 2018.
4. Dr. Roy Johnson attended training programme on 'Managing Technology Value Chains for Directors & Division Heads' held at ASCI, Hyderabad during September 03 - 07, 2018.
5. Dr. Malobika Karanjai attended 'NIAS DST Training Programme for Women Scientists (under DISHA Scheme) on Science and Sustainability in India' held at IISc, Bengaluru during September 03-07, 2018.
6. Mr. Sudheendra attended a 'Workshop on Noting & Drafting' held at New Delhi during October 03-05, 2018.
7. Dr. R. Subasri attended a program on "Leadership and Organization Development for Women Scientists/ Technologists" held at Centre for Organization Development (COD), Hyderabad during October 08-12, 2018.
8. Mr. S. Arun attended the '7th Training Programme on Financial Management in Scientific Organizations' held at IIPA, New Delhi during October 29-November 02, 2018.
9. Mr. K. V. Phani Prabhakar attended a 'Training Programme on Science, Technology and Innovation Policy' held at Bengaluru during November 19–30, 2018.
10. Dr. G. Ravi Chandra and Dr. S. Sakthivel attended a 'Programme on Building and Learning Teams" held at Indian Institute of Management (IIM), Indore during December 03 - 05, 2018.
11. Mr. K. Satyanarayana Reddy attended the 'Basic Training Programme on Computers' held at CGO Complex, Hyderabad during December 10-14, 2018.
12. Dr. Neha Y. Hebalkar attended 'Programme on Integrated Scientific Project Management for Women Scientists/Technologists' held at COD, Hyderabad during January 07-11, 2019.
13. Dr. N. Ravi and Dr. S M Shariff attended the 'Programme on Emotional Intelligence at Workplace for Scientists and Technologists' held at Centre for Organization Development (COD), Hyderabad during February 18–22, 2019.

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

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
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
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

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
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
48.	Novel Ceramic Materials Having Improved Mechanical Properties and Process for their Preparation	3396/DEL/2005	19/12/2005
49.	Improved Cylindrical Magnetron Cathode and a Process for Depositing Thin Films on Surfaces using the said Cathode	21/DEL/2008	03/01/2008
50.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	1829/DEL/2008	01/08/2008
51.	An Improved Gas Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	2339/DEL/2008	13/10/2008
52.	An Improved Gas and Coolant Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	1449/DEL/2010	22/06/2010
53.	An Improved Process for Preparation of Nanosilver Coated Ceramic Candle Filter	1249/DEL/2011	28/04/2011
54.	An Improved Method for Making Sintered Polycrystalline Transparent Sub-Micron Alumina Article	1358/DEL/2011	10/05/2011
55.	An Improved Hybrid Methodology for Producing Composite Multilayered and Graded Coatings by Plasma Spraying Utilizing Powder and Solution Precursor Feedstock	2965/DEL/2011	17/10/2011
56.	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
57.	A Process and a Multi-Piston Hot Press for Producing Powder Metallurgy Component, such as Cerametallic Friction Composite	3844/DEL/2011	28/12/ 2011
58.	A Novel Process for Produced IR Transparent Polycrystalline Alumina Article and the Article so Produced	365/DEL/2012	08/02/2012
59.	A Device for and a Method of Cooling Fuel Cells	1408/DEL/2012	08/05/2012
60.	An Improved Aqueous Method for Producing Transparent Aluminium Oxy Nitride (ALON) Articles	1409/DEL/2012	08/05/2012

Sl. No.	Title of Patent	Patent Application Number	Date of filing
61.	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
62.	A Novel Method for the Synthesis of Tungsten Disulphide Nanosheets	1703/DEL/2012	04/06/2012
63.	Enhanced Thermal Management Systems for Fuel Cell Applications Using Nanofluid Coolant	1745/DEL/2012	07/06/2012
64.	Process for Producing Anti-Reflective Coatings with Scratch Resistance Property	1777/DEL/2012	11/06/2012
65.	Improved Method of Manufacturing Copper-Indium-Gallium Diselenide Thin Films by Laser Treatment	2084/DEL/2012	05/07/2012
66.	Electronically and Ionically Conducting Multi-Layer Fuel Cell Electrode and a Method for Making the Same	2198/DEL/2012	17/07/2012
67.	Fuel Cell System Equipped with Oxygen Enrichment System Using Magnet	2985/DEL/2012	25/09/2012
68.	A High Thermal Stable Selective Solar Absorber layer with Low Emissive Barrier Coating over a Substrate and a Process of Producing the Same	3312/DEL/2012	29/10/2012
69.	A Polymer Electrolyte Membrane (PEM) Cell and a Method of Producing Hydrogen from Aqueous Organic Solutions	3313/DEL/2012	29/10/2012
70.	Catalytically and Chemically Modified Carbon Nanostructures for Storage of Hydrogen	405/CHE/2013	30/01/2013
71.	An Improved Test Control System Useful For Fuel Cell Stack Monitoring and Controlling	269/DEL/2013	31/01/2013
72.	A Novel Laser Surface Modification Technique for Hardening Steel	337/DEL/2013	06/02/2013
73.	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
74.	An Improved Composition for Coating Anodizable Metal Surfaces and a Process of Coating the Same`	1310/DEL/2013	03/05/2013
75.	A Method of Preparation of Supported Platinum Nano Particle Catalyst in Tubular Flow Reactor Via Polycol Process	1571/DEL/2013	24/05/2013
76.	An Improved Composition for Antireflective Coating with Improved Mechanical Properties and a Process of Coating the Same	2330/DEL/2013	05/08/2013
77.	Process for Producing Anti-Reflective Coatings With Anti-Fogging (Super Hydrophilic), UV, Weather and Scratch Resistance Properties	2919/DEL/2013	03/10/2013
78.	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
79.	Exfoliated Graphite Separator based Electrolyzer for Hydrogen Generation	3073/DEL/2013	17/10/2013
80.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	1411/KOL/2013	13/12/2013
81.	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
82.	High Temperature Polymer Electrolyte Membrane Fuel Cells with Exfoliated Graphite based Bipolar Plates	494/DEL/2014	20/02/2014
83.	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
84.	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

Sl. No.	Title of Patent	Patent Application Number	Date of filing
85.	Method of Producing Multifunctional Self Assembled Mixed Phase Titania Spheres	3777/DEL/2014	19/12/2014
86.	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
87.	A Novel Electrochemical Method for Manufacturing CIGS Thin Film Containing Nanomesh Like Structure	426/DEL/2015	16/02/2015
88.	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
89.	Process and Apparatus for Protection of Structural Members from Wear, Corrosion and Fatigue Damage	1839/DEL/2015	22/06/ 2015
90.	A Method of Preparing of Anti Tarnishing Organic-Inorganic Hybrid Sol-Gel and Coating The Same	2049/DEL/2015	07/07/2015
91.	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
92.	Method of Producing High Performance Visible-Light-Active Photocatalytic Materials for Self-Cleaning Applications	2625/DEL/2015	25/08/ 2015
93.	Production of Graphene-Based Materials by Thermal Spray	2626/DEL/2015	25/08/ 2015
94.	Method of Preparation of High Performance ZnO Varistors and Improved Compositions	2765/DEL/2015	03/09/ 2015
95.	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
96.	A Method and an Apparatus for Preparing Nickel Tungsten based Nanocomposite Coating Deposition	201611001190	13/01/2016
97.	A Process for In-Situ Carbon Coating on Alkali Transition Metal Oxides	201611007451	03/03/2016
98.	An Improved Process for the Preparation of Stable Nano Silver Suspension having Antimicrobial Activity	201611027145	09/08/2016
99.	A Laser-based Surface Processing Apparatus and a Method to Process Metallic Materials and Components	201611034362	07/10/2016
100.	An Improved Process of Carbon - Metal Oxide Composites Prepared by Nano Casting of Wood and the Product Thereof	201611034531	07/10/2016
101.	A Method for Producing Inorganic Bonded Silica based Eco-Friendly Artificial Marble Articles and the Product Thereof	201611036479	25/10/2016
102.	Method of Producing Hollow MgF2 Nanoparticles, Anti-reflection Coating Sols and Coatings for Optical and Solar Applications	201611041804	07/12/2016
103.	A Method of Producing High Performance Lithium Titanate Anode Material for Lithium Ion Battery Applications	201711006147	21/02/2017
104.	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
105.	An Improved Gas Dynamic Cold Spray Device and Method of Coating a Substrate	201711006749	26/02/2017
106.	A Novel Equipment to Accomplish Power Metallurgy Processing Starting From the 'Raw Materials' to Finished Product	201711011552	30/03/2017
107.	An Improved Process for Preparing Durable Multifunctional Coatings on Metal/Alloy Substrates	201711020529	12/06/2017
108.	A System for Treating a Surface of Bearing Components and a Process Thereof	201711046511	23/12/2017

Sl. No.	Title of Patent	Patent Application Number	Date of filing
109.	Method of Producing Nano Structured C-TIO2 Composite Material for Visible Light Active Photocatalytic Self-Cleaning Applications	201811011478	28/03/2018
110.	An Ecofriendly Incinerator to Dispose of the Used Sanitary Napkins and Bio Medical Waste	201821021430	07/06/2018
111.	Process for Preparing Durable Solar Control Coatings on Glass Substrates	201811024034	27/06/2018
112.	Antimicrobial Aqueous based Sol-Gel Composition for Coating on Substrate and Process of Preparing the Same	201811033620	06/09/2018
113.	Laser Based Clad-Coatings for Protecting the Power Plant Components for Life Enhancement	201811039663	19/10/2018
114.	Process of Electroless Nickel/Nickel Phosphide (EN) Deposition on Graphite Substrates	201811041418	01/11/2018
115.	A Grid Independent Fuel Cell System with a Unitized (DC & AC) Power Conditioner	201911006700	20/02/2019
116.	Refurbishment of Aircraft Components using Laser Cladding	201911007994	28/02/2019
117.	Microwave Assisted Sol-Gel Process for Preparing In-Situ Carbon Coated Electrode Materials and the Product Thereof	201911008004	28/02/2019
118.	Ambient Condition Curable Transparent Super Hydrophobic Coating for Easy to Clean Applications and Method of Producing the Same	201911009429	11/03/2019

International Patents Granted and Awaiting Grant

Sl. No.	Title of Patent	Country	Patent Number / Application Number	Date of Grant	Date of filing	Indian /Family Patent Details
1.	Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	USA	US6893551B2	17/05/2005	02/08/2002	209817
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	262189
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	284812
		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	1829/DEL/2008
		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	

Sl. No.	Title of Patent	Country	Patent Number / Application Number	Date of Grant	Date of filing	Indian /Family Patent Details
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	262189; Divisional Patent of US8143550B2
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	289543
7.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	USA	US9365945B2	14/06/2016	14/06/2016	1835/DEL/2010; Divisional patent of US8486237 B2
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	2965/DEL/2011
		Canada	2784395	16/09/2014	31/07/2012	
10.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	USA	15/103343	---	10/12/2014	1411/KOL/2013; WO2015087349A1
		Australia	AU2014362928A	---	10/12/2014	
		Europe	EP3080313A1	---	10/12/2014	
11.	An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	UAE	P6000095/2018	-	11/01/2018	305898
		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	
12.	A Method of Producing High Performance Lithium Titanate Anode Material for Lithium Ion Battery Applications	Yet to decide	PCT/IN2018/050080	-	17/02/2018	201711006147
13.	An Improved Gas Dynamic Cold Spray Device and Method of Coating a Substrate	Yet to decide	PCT/IN2018/050087	---	21/02/2018	201711006749

Journal Publications

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3. P. V. Midhunlal, J. Arout Chelvane, U. M .Arjun Krishnan, D. Prabhu, R. Gopalan and N. Harish Kumar, "Near Total Magnetic Moment Compensation with High Curie Temperature in Mn2V0.5Co0.5Z (Z = Ga, Al) Heusler Alloys", Journal of Physics D: Applied Physics, Vol. 51, p 075002, 2018.
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11. K.Hembram, T.N. Rao, M. Ramakrishna, R.S. Srinivasa and A.R. Kulkarni, "A Novel Economical Grain Boundary Engineered Ultra-High Performance ZnO Varistor with Lesser Dopants", Journal of the European Ceramic Society, Vol. 38(15), p 5021-5029, 2018.
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11. P. Koteswararao, M.B. Suresh, B.N. Wani, P.V.B. Rao and L.D. Jadhav, "Synthesis, Structural and Morphological Studies of Sr2+ and Gd3+ Co-doped Ceria Electrolyte system for LT-SOFC", International Conference on Recent Advances in Materials, Mechanical and Civil Engineering, Book Series: IOP Conference Series-Materials Science and Engineering, Vol.330, Article Number: UNSP 012029, 2018 .
12. B. S. Yadav, S. R. Dhage, Amol C. Badgujar, S.R. Day and R. O. Dusane, "Molybdenum Bilayer Thin Film on Large by Cylindrical Rotating DC Magnetron Sputtering for CIGS Solar Cell Application", Proceedings of 35th European Photovoltaic Solar Energy Conference and Exhibition, Brussels, Belgium, p 866-869, 2018.
13. B.S. Yadav, S. R. Dey and S. R. Dhage, "Role of Selenium Content in Selenization of Inket Printed CIGSe2 Thin Film Solar Cell", AIP Conference Proceedings; Vol. 2082, Article 50001, 2019.
14. Sanjay Bhardwaj, S. Subbarao, T.V. Vijaya Kumar, Gadhe Padmanabham and Karuna Jain, "Research to Technology Transfer : Developing a Roadmap", Proceedings of 28th International Conference on Management of Technology (IAMOT), Mumbai. (In press)
15. L. Rama Krishna, Y. Madhavi, P.S. Babu, D. S. Rao and G. Padmanabham, "Strategies for Corrosion Protection of Non-Ferrous Metals and Alloys through Surface Engineering", Materials Today: Proceedings. (In press)

Books

1. A chapter on "Pulsed Electrochemical Deposition of $CuInSe_2$ and $Cu(In,Ga)Se_2$ Semiconductor Thin Films" authored by M. Sreekanth, B. V. Sarada, S. R. Dey and S.V. Joshi, in the book on 'Semiconductors: Growth and Characterization', (ed.) Rosalinda Inguanta and Carmelo Sunseri., Techopen, ISBN no: 978-953-51-5589-8, p 109-132, 2018.
2. A chapter on "Hole Conductor Free Perovskite Solar Cells", authored by S. Maniarasu, V. Manjunath, E. Ramasamy and V. Ganapathy, in the book on 'Perovskite Photovoltaics-Basic to Advanced Concepts and Implementation'. (ed.) S.Thomas, A.Thankappan, ISBN No.: 9780128129159, Elsevier, p 289-321, 2018.
3. A chapter on "Perovskite Solar Cell Architectures" authored by V. Manjunath, Ramya Krishna,

S. Maniarasu, E. Ramasamy, S. Sakthivel and V. Ganapathy, in the book on 'Perovskite Photovoltaics-Basic to Advanced Concepts and Implementation', (ed.) S.Thomas, A.Thankappan, ISBN No.: 9780128129159, Elsevier, p 89-121, 2018.

4. A chapter on "Flexible Perovskite Solar Cells" authored by V. Manjunath, S. Maniarasu, V. Ganapathy and E. Ramasamy, in 'Perovskite Photovoltaics-basic to Advanced Concepts and Implementation' (ed.) S.Thomas, A.Thankappan, ISBN No.: 9780128129159, Elsevier, p 341-371, 2018.
5. A chapter on "The Electrochemical Conversion of Carbon Dioxide to Carbon Monoxide over Nanomaterial based Cathodic Systems: Measures to take to Apply this Laboratory Process Industrially" authored by I. Ganesh in the book on 'Applications of Nanomaterials: Advances and Key Technologies in the Micro and NanoTechnologies Series', Elsevier Book, (ed) O. Samuel, S. Thomas, N. Kalarikkal, & S. Mohan, Chapter 4, Volume III, p 83-131, 2018.
6. A chapter on "Corrosion and Wear Protection through Micro Arc Oxidation Coatings in Aluminum and its Alloys" authored by L. Rama Krishna and G. Sundararajan in the book on 'Encyclopedia of Aluminum and its Alloys', (eds.): George E. Totten, Olaf Kessler, Murat Tiryakioglu., Taylor & Francis Publishers. Chapter 25, doi:10.1201/9781351045636-140000207, 2018.
7. A chapter on "Thermal Spray Coatings: Al Alloy Protection", authored by P. Suresh Babu, D. Srinivasa Rao, L. Rama Krishna, G. Sundararajan and Aravind Agarwal in the book 'Encyclopedia of Aluminum and its Alloys', (ed.) George E. Totten, Olaf Kessler, Murat Tiryakioglu, Pubs: Taylor & Francis, Chapter 155, ISBN-9781466510807, 2018.
8. A chapter on "Polymer Electrolyte Membrane based Electrochemical Conversion of Carbon Dioxide from Aqueous Solutions" authored by P. Suresh, K. Ramya, and K. S. Dhathathreyan, in the book on 'Polymeric and Nanostructured Materials', (ed.) A.Thankappan, N.Kalarikkal, S.Thomas and A.Padinjakkara, Apple Academic Press, ISBN 9781771886444, Chapter 20, 2018.
9. A chapter on "Automotive Waste Heat Recovery by Thermoelectric Generator Technology" authored by D. Sivaprahasam, S. Harish, R. Gopalan and G.Sundararajan, in the book on "Bringing Thermoelectricity into Reality', (ed.) Patricia Aranguren ,INTECH open. UK, Vol. 1, p 163-183, 2018.
10. A chapter on "Plasma Surface Treatment: Effects on Mechanical and Corrosion Protection Properties of Hybrid Sol-Gel Coatings", authored by R. Subasri in the book on 'Encyclopedia of Aluminum and Its Alloys', (ed.) George E. Totten, Murat Tiryakioglu and Olaf Kessler, CRC Press, Taylor & Francis Group, Florida, Vol. 2, p 1922-1927, 2019. ISBN: 978-1-4665-1080-7
11. A chapter on "Economical and Highly Efficient Non-Metal Counter Electrode Materials for Stable Dye-Sensitized Solar Cells" authored by V. Ganapathy, E. Ramasamy and B. Gowreeswari in the book on 'Dye-Sensitized Solar Cell Mathematical Modeling, Optimization and Design'. (ed.) S.Thomas, A.Thankappan, ISBN No.: 9780128145418, Elsevier, p397-435, 2019.
12. A chapter on "Intercalation-based Layered Materials for Rechargeable Sodium-Ion Batteries" authored by B.K. Das and R. Gopalan, in the book on 'Layered Materials for Energy Storage and Conversion', (ed.) Dongsheng Geng, Yuan Cheng, Gang Zhang, RSC, Vol. 1, p 71-94, 2019.
13. A chapter on "Smart Nanocontainers for Anticorrosion Applications" authored by R. Subasri, Swapnil H. Adsul and S. Manasa, in the book on 'Smart Nanocontainers: Fundamentals and Emerging Applications' (ed.) Phuong Nguyen Tri, On Do-Trong and Tuan Anh Nguyen, Elsevier ISBN: 978-0-12-816770-0. (In press)
14. 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)
15. A chapter on "Nano-Configured Opto-Electric Ceramic Systems for Photo-Electrochemical Hydrogen Energy" authored by P. H. Borse, in the 'Handbook of Advanced Ceramics and Composite Applications' (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature. (In press)
16. A chapter on "Multifunctional Sol-Gel Nanocomposite Coatings for Aerospace, Energy and Strategic Applications: Challenges and Perspectives" authored by R. Subasri and K.R.C. Soma Raju in the 'Handbook of Advanced Ceramics and Composite Applications' (ed.) Y.R. Mahajan and Roy Johnson, Springer Nature. (In press)
17. A chapter on "Zinc Sulphide Ceramics for Infrared Optics" authored by Roy Johnson, Papiya Biswas, Pandu Ramavath and Yashwant R. Mahajan, in the 'Handbook of Advanced Ceramic and Composite Applications' , (ed.) Y.R. Mahajan and Roy Johnson, Springer Nature. (In press)
18. A chapter on "Processing of Infrared Transparent Magnesium Aluminate Spinel: An Overview", authored by Papiya Biswas, Roy Johnson, Yashwant R. Mahajan, Gadhe Padmanabham, in the 'Handbook of Advanced Ceramic and Composite Applications', (ed.) Y.R. Mahajan and Roy Johnson, Springer Nature. (In press)
19. A chapter on "2D-Nanolayered Tungsten and Molybdenum Disulfides: Structure, Properties,

Synthesis and Potential Strategic Applications" authored by A. Harish Kumar, A. K. Pandey, J. Joardar in the 'Handbook of Advanced Ceramics and Composites Applications' (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature (In press).

20. A chapter on "Processing of Ceramic and Cermet Coatings for Aerospace and Strategic Applications", authored by L. Rama Krishna, P. Suresh Babu, Manish Tak, D. Srinivasa Rao, G. Padmanabham and G. Sundararajan in the 'Handbook of Advanced Ceramics and Composites Applications' , (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature (In press).

Other Articles In Magazines and Newsletters

1. 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, 35-45, 2018.

Awards and Honours

1. Dr. S. Sakthivel received the '2018 Albert Nelson Marquis Lifetime Achievement Award' from the Marquis Who's Who, Berkeley Heights, New Jersey, USA during June 2018.

2. Ms. S. Manasa (Dr. R. Subasri) received "Third prize" for oral presentation on "Fabrication of Self-Healing, Corrosion Protection Coatings on AA2024-T4 by Electrophoretic Deposition" at the 'National Conference on Frontiers in Corrosion Control of Materials (FCCM)-2018', held at NIT, Warangal during June 28 - 29, 2018.

3. Mr. Manish Tak received the 'IWS Young Technologist Award' for his work in development of repair and refurbishment technologies using laser cladding process from Indian Welding Society at the '8th International Welding Symposium 2018 (IWS 2K18)' at Mumbai during November 27- 29, 2018.

4. Mr. Narendra Chundi (Dr. S. Sakthivel) received the 'Best Poster Presentation Award' for the poster presentation on "Dual Functional Nanocasting for Self-cleaning and Anti-Reflecting Applications" at the '10th Bengaluru India Nano' held at Bengaluru during December 05-07, 2018.

5. Dr. Sanjay Bhardwaj received the 'Indian Institute of Chemical Engineers (IIChE)-ICI India Ltd. National Award 2018' for excellence in process or product development during the 'CHEMCON 2018 - International Conference' held at NIT, Jalandhar during December 27-30, 2018.

6. Dr. Pramod H. Borse was elected as 'Fellow of Maharashtra Academy of Science in Physical Sciences' for work in Physics from Maharashtra Academy of Sciences during induction ceremony held at the Savitribai Phule Pune University (SPPU), Pune on December 31, 2018.

7. Mr. S. Ramakrishnan received the 'Best Oral Presentation Award' at the 'National Conference on Recent Advances in Chemistry (RAC-19)' held at Anna University, Chennai during January 04-05, 2019.

8. Dr. Pramod H. Borse's affiliation of Associate Member of Institute of Physics (IOP), UK, was elevated to Member of IOP(MInstP) during January 29, 2019 for his work in Physical Sciences.

9. Dr. M. Sreekanth received the 'Best Oral Paper Presentation Award' from ACS Publications Group for presenting a paper on "CI (G) S Thin Films Solar Cells

on Flexible Substrates by Pulse Electro Deposition" at the '12th International Symposium on Advances in Electrochemical Science and Technology' held at Chennai during January 08-10, 2019.

10. Ms. Prithi J. A. received the 'Best Paper Award - Poster Presentation' from SAEST, CECRI at the 'Twelfth International Symposium on Advances in Electrochemical Science and Technology (iSaest-12) held at Chennai during January 08-10, 2019.

11. Ms. Keerthi Sanghamitra (Dr. Neha Hebalkar) received the 'Best Paper Award - Oral Presentation' at the '2nd International Conference on New Frontiers in Chemical, Energy and Environmental Engineering (INCEEE-2019)' held at NIT, Warangal during February 15-16, 2019.

12. Dr. Bijoy Kumar Das received the 'Best Poster Award' at the '2nd International Meeting on Clean Energy Materials Innovation Challenge' held at IIT, Delhi during February 21-22, 2019.

13. Dr. Mani Karthik was awarded the 'Best Scientist in Supercapacitor' by RULA Awards powered by World Research Council and United Medical Council at Trichy, Tamilnadu on February 26, 2019.

14. Dr. Sanjay Bhardwaj was elected as 'Fellow of the Institution of Engineers (India)' on February 28, 2019.

15. Mr. Vallabha Rao Rikka received 'Best Oral Presentation Award' at the '12th Research Scholars Symposium 2019" held at IIT Bombay, Mumbai on March 02, 2019.

16. Dr. A Bharathi Sankar received the 'Best Paper Award - Oral Presentation' at International Conference on Supercapacitor, Energy Storage and Applications (ICSEA-2019) held at C-MET, Thrissur during March 08-10, 2019.

17. Dr. R. Vijay was awarded the 'Fellow of Telangana Academy of Sciences in Engineering Sciences' for his work in Science and Technology by Telangana Academy of Sciences during the induction ceremony held at IICT, Hyderabad on March 15, 2019.

18. Dr. Sanjay Bhardwaj was elected as the Honorary Secretary of Indian Institute of Chemical Engineers - Hyderabad Regional Centre (IIChE – HRC) and Co-chairman of Academia – R & D – Industry Interaction Committee, IIChE – HRC for the year 2018-19.

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(as on March 31, 2019)

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

Financial Report

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Date: 26/05/2019

INDEPENDENT AUDITORS' REPORT

Basis for Opinion

We conducted our audit in accordance with the Standards on Auditing (SAs) issued by the Institute of Chartered AccouOpinion We have audited the accompanying financial statements of **International Advanced Research Centre for Powder Metallurgyand New Materials (ARCI)**, Hyderabad ("the Entity"), which comprise the Balance Sheet as at March 31, 2019, and the Incomeand 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, the accompanying financial statements give a true and fair view in conformity with the accounting principles generally accepted in India, of the financial position of the Entity as at March 31, 2019, 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). 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.

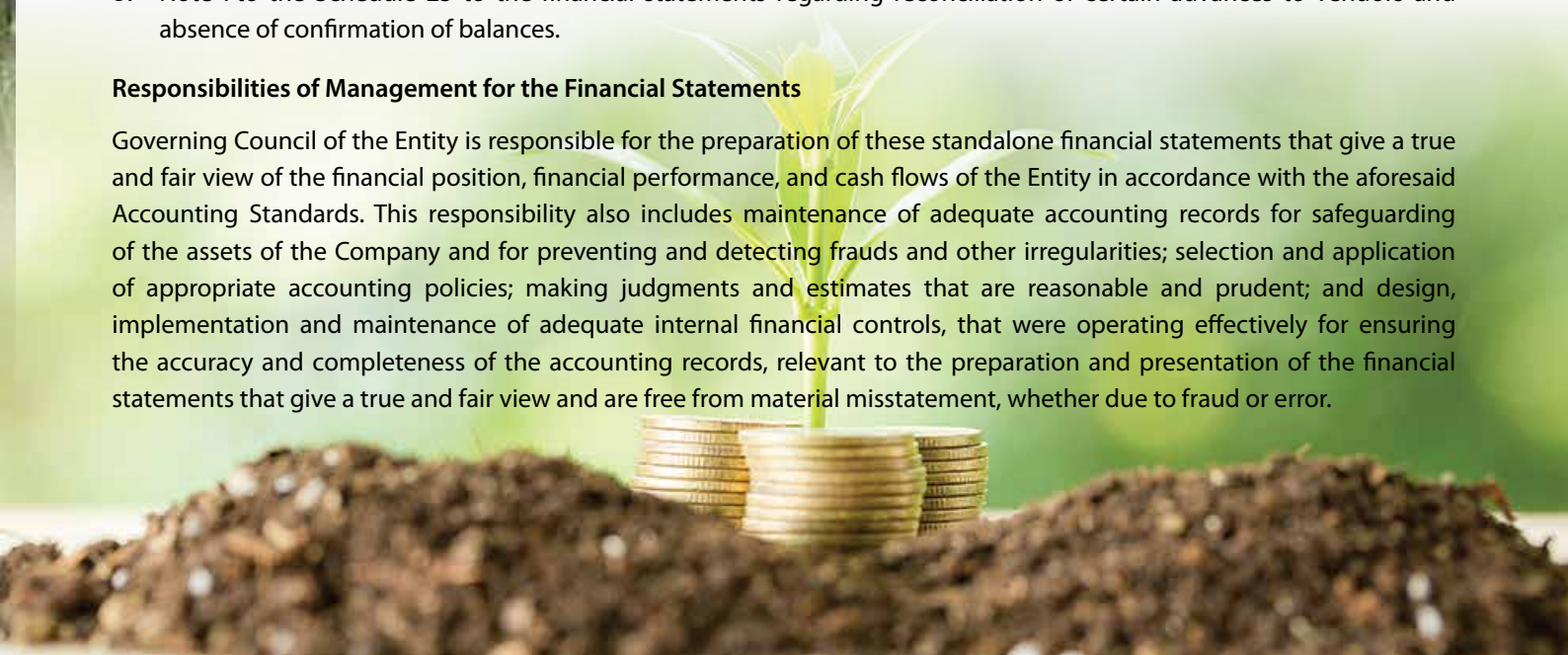
Emphasis of Matter:

We draw attention to:

1. Note 5 to the Schedule 25 to the financial statements regarding long pending items in classified under Capital Work in Progress – Rs. 29,00,42,043/-.
2. Note 6 to the Schedule 25 to the financial statements regarding certain unreconciled items appearing in the Bank Reconciliation Statements.
3. Note 7to the Schedule 25 to the financial statements regarding reconciliation of certain advances to vendors and absence of confirmation of balances.

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 aforesaid Accounting Standards. 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 managements 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 quantitative 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:

We report that:

1. 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.
2. 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.
3. The Balance Sheet, the Income and Expenditure Account and Receipts and Payments Account dealt with by this report are in agreement with books of account.
4. 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

V K Muralidhar
Partner
Membership No. 201570
UDIN:19201570AAAABJ3949

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
ARC INTERNATIONAL FUND (OPERATIONAL) BALANCE SHEET AS AT 31.03.2019

(Amount in Rs.)

GRANTS-IN-AID: FUND AND LIABILITIES	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
GRANTS-IN-AID	1	1,417,500,015.46	1,49,95,64,860.99
RESERVES AND SURPLUS	2	40,414,760.35	2,36,06,972.81
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	327,700,247.17	27,94,62,052.63
TOTAL		**1,785,615,022.98**	**1,80,26,33,886.43**
ASSETS			
FIXED ASSETS	8	1,324,928,670.93	1,25,01,28,852.73
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUND	9	0.00	0.00
INVESTMENTS - OTHERS	10	0.00	0.00
CURRENT ASSETS, LOANS, ADVANCES ETC.	11	460,686,351.55	55,25,05,033.20
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)		0	0
TOTAL		**1,785,615,022.98**	**1,80,26,33,886.43**
SIGNIFICANT ACCOUNTING POLICIES	24		
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25		

AS PER OUR REPORT OF EVEN DATE

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

V.K.Muralidhar
Partner, Membership No. 201570

G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Dr. G Padmanabham
Director

Date: 26-08-2019
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INCOME AND EXPENDITURE ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2019

(Amount in Rs.)

	SCHEDULE		CURRENT YEAR		PREVIOUS YEAR
INCOME					
Income from Sales/Services	12		0.00		0.00
Grants/Subsidies	13		426,055,000.00		36,48,67,000.00
Fees/Subscriptions	14		437,639.15		0.00
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		26,791,130.99		2,15,28,647.00
Other Income	18		19,523,759.99		5,13,30,636.00
Increase/(decrease) in stock of finished goods and work-in-progress	19		0.00		0.00
TOTAL (A)			**472,807,530.13**		**43,77,26,283.00**
EXPENDITURE					
Establishment Expenses	20		321,025,846.60		37,02,63,732.03
Other Expenses	21		170,501,432.01		15,93,14,262.89
Expenditure on Grants/Subsidies	22		0.00		0.00
Interest	23		8,026,234.00		0.00
Depreciation (Net Total at the year-end: corresponding to Schedule 8)			161,338,863.05		14,06,78,911.85
TOTAL (B)			**660,892,375.66**		**67,02,56,906.77**
Balance being excess of Income over Expenditure (A-B) Transfer to Special Reserve [specify each] Transfer to/from General Reserve			-188,084,845.53		-23,25,30,623.77
BALANCE being Excess of Expenditure over Income - Transfer to Grants-in-Aid			**-188,084,845.53**		**-23,25,30,623.77**
SIGNIFICANT ACCOUNTING POLICIES	24				
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25				

AS PER OUR REPORT OF EVEN DATE

G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Dr. G Padmanabham
Director

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

V.K.Muralidhar
Partner, Membership No. 201570

Date: 26-08-2019
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 Rules, 1962.
   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 to the A/c 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

V.K.Muralidhar
Partner, Membership No. 201570

G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Dr. G Padmanabham
Director

Date: 26-08-2019
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:42,60,55,000/ towards revenue and Rs: 10,60,20,000/- as capital grant-in-aid under Plan (Previous year Rs. 36,48,67,000/ and Rs. 16,77,90,000/- 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. 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

V.K.Muralidhar
Partner, Membership No. 201570

G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Dr. G Padmanabham
Director

Date: 26-08-2019
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
RECEIPTS AND PAYMENT ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2019

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
I. **Opening Balances**			I. **Expenses**		
a. Cash in hand	30,559.00	50,504.00	a. Establishment expenses	300,475,401.74	300,595,733.00
b. Bank Balances			b. Other expenses	139,595,046.46	155,809,196.39
i) In Current accounts		0.00			
ii) In Deposit accounts	0.00	0.00	**Total: Expenses**	**440,070,448.20**	**456,404,929.39**
iii) Savings accounts	57,343,711.47	6,207,895.86			
Total: Opening Balances	**57,374,270.47**	**71,258,399.86**			
II. **Grants Received**			II. **Payments made against various projects**		
a. From Government of India	532,075,000.00	532,657,000.00			
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	**532,075,000.00**	**532,657,000.00**	**Total: Payments made Against Projects**	**0.00**	**0.00**
III. **Income on Investments From**	0.00	0.00	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)			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	7,833,724.00	6,781,668.00	a. Purchase of fixed assets	103,500,843.64	124,008,039.00
b. Interest from sponsored projects	0.00	0.00	b. Expenditure on capital work-in progress	0.00	0.00
c. Loans, Advances to staff etc.	192,510.00	0.00			
Total: Interest Received	**8,026,234.00**	**6,781,668.00**	**Total: Expenditure on Fixed Assets & Capital WIP**	**103,500,843.64**	**124,008,039.00**
V. **Other Income**	27,604,797.15	13,365,893.00	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
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	0.00	309,245.00	a. Advance for Festival-Staff	0.00	66,600.00
b) Sales of Fixed Assets	2,390,090.44	0.00	b. Advance to Staff-HBA	3,750,000.00	14,82,400.00
c) 7th CPC Contribution - TDT Funds	0.00	43,221,831.00	c. Return of EMD & security deposits	0.00	6,30,000.00
d) TDT Fund Contribution for Manpower Usages	1,703,697.00	157,294.00	d. Institutional grants	0.00	1,32,000.00
			e. Deposit: Gratuity to LIC	1,301,427.00	9,20,278.00
e) TDT Fund Contribution for Equipment Usages	5,335,433.00	889,739.00	f. Deposit: EL Encashment to LIC	7,837,071.00	2,74,72,773.00
			g. Advances to Delhi Cell	0.00	1,00,000.00
f) Employees Group Insurance Scheme-LIC	0.00	58,049.00	i. TDS receivables	300.00	0.00
g) TDS Refund	0.00	207,341.00	j. Advance to Staff-Vehicle	0.00	24,000.00
			k. Advance to Staff-Computer	0.00	2,80,970.00
			l. Deposit: Gases	0.00	10,200.00
Total : Any Other Receipts	**9,429,220.44**	**4,48,43,499.00**	**Total : Other Payments**	**12,888,798.00**	**3,11,19,221.00**
			VIII. **Closing Balances**		
			a) Cash in hand	25,800.00	30,559.00
			b) Bank balances		
			i) In Current accounts	0.00	0.00
			ii) In Deposit accounts	70,000,000.00	0.00
			iii) In Savings accounts	8,023,632.22	57,343,711.47
			Total : Closing Balances	**78,049,432.22**	**57,374,270.47**
TOTAL	**634,509,522.06**	**668,906,459.86**	**TOTAL**	**66,89,06,459.86**	**58,79,59,027.01**

AS PER OUR REPORT OF EVEN DATE

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

V.K.Muralidhar
Partner, Membership No. 201570

G.RAVI SHANKAR
Senior Finance & Adminstartive Officer

Dr. G Padmanabham
Director

Date: 26-08-2019
Place: Hyderabad

OUR COLLABORATORS

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ARCI

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