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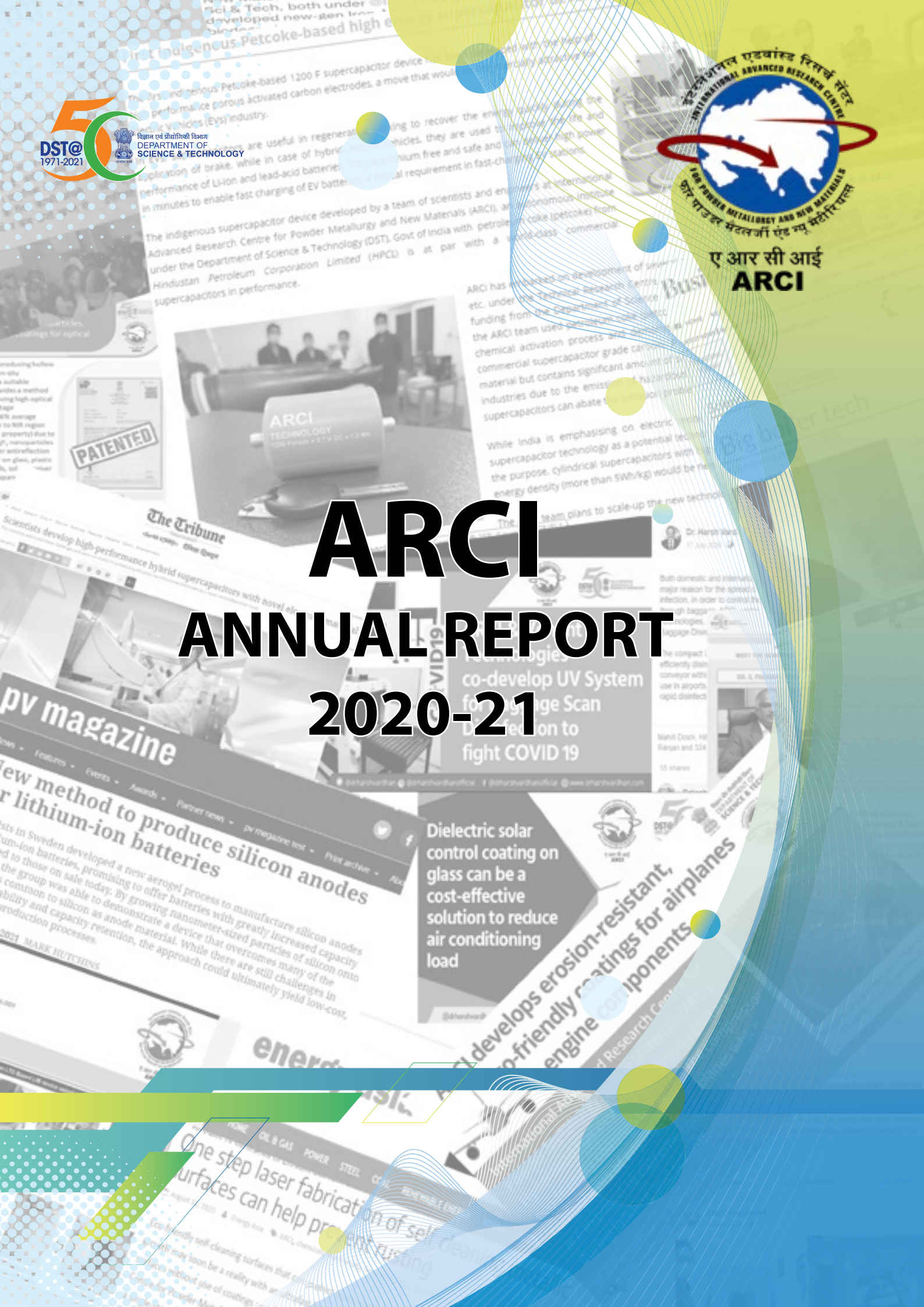
विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF SCIENCE & TECHNOLOGY

ए आर सी आई
ARCI

ARCI

ANNUAL REPORT 2020-21



ए आर सी आई
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.

CONTENTS

THRUST AREAS

Nanomaterials · Engineered Coatings · Ceramic Processing · Laser Materials Processing · Fuel Cells · Sol-gel Coatings · Solar Energy Materials · Automotive Energy Materials

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former Secretary, Technology Development Board
Department of Science & Technology, New Delhi

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Former Scientist G, DSIR and
Former CMD, National Research Development Corporation
New Delhi

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Chair Professor, Symbiosis Centre for Entrepreneurship
and Innovation, Pune

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Head, NCL Innovations & Intellectual Property Group
National Chemical Laboratory, Pune

Director's Report

It gives me great pleasure to present this report on the activities and achievements of ARCI during 2020-21. The report depicts capabilities of each Centre with achievements gained during the year. The technology development and transfer related activities and research highlights have been showcased separately for each Centre of Excellence.

The technology development and transfer activities addressing the needs of alternative energy, aerospace, conventional power, manufacturing, biomedical and automotive sectors, have been diligently pursued during the year, despite the challenges posed by COVID-19 pandemic. ARCI showed courage to get back to work and contributed in its best way towards its envisaged mandate of developing, demonstrating and transferring technologies. A number of solutions were developed and provided for effective COVID-19 disinfection. The lockdown period was productively used for developing R & D roadmaps for upscaling of technologies, publications, filing of patents, and preparing concept papers. On the lines of steps taken by the Nation on Self-Reliance, various indigenous developmental programmes have fructified this year. Intensified efforts in interacting with several industrial organizations and collaboration with other R&D and academic institutions yielded better results in the form of technology transfers, sponsored programs and new initiatives towards development of advanced materials, processes and systems to meet various application requirements.

The activities and solutions developed for combating COVID-19 included:

- Design and Fabrication of UVC based disinfection Systems for hospitals and commercial establishments. Three systems including a trolley, a cabinet and a baggage scanner have been designed, fabricated in collaboration with industry and have been successfully commercialized and deployed at hospitals, research labs, airports and several public and commercial establishments. Validation of several UVC based disinfection systems was carried out for several companies and research labs.
- Developed (at lab-scale) nanoparticle coatings on fabric using Ag-Cu-CuO based nanomaterials and the coated fabric was tested successfully for its anti-bacterial and antiviral properties.
- Multi-Purpose Disinfectant (Neutroclean) that effectively disinfects SARS-CoV-2 on cloth, plastic, wood, glass, walls, flooring, etc - developed by ARCI - Hyderabad in collaboration with Saffrongrid Limited, Hyderabad and tested at BSL-3 (Bio Safety Level 3) laboratory at ESIC Medical College & Hospital, Hyderabad.
- Sanitization Chamber for disinfecting Personal Protective Equipment (PPE)s and human body was developed by ARCI in partnership with Saffrongrid Limited, Hyderabad for product development, fabrication and assembly followed by testing at ESIC Medical College & Hospital.
- Ceramic Honeycomb Based Device for Thermal Disinfection of PPEs was Jointly developed by ARCI, Hyderabad and Sowbal Aerothermics, Hyderabad.

UVC trolley

Microbial disinfection unit

UVC Cabinet

UVC Baggage disinfection tunnel

Prototype mask showing nanoparticle coated fabric

Sanitization Chamber

Substantial translational research has been carried out during the year with focus on technology transfer to companies for various industry sectors. The achievements under the DST sponsored Technical Research Centre on "Alternative Materials and Systems" include:

- Indigenous development of Lithium Ion Battery devices. Fabrication of LFP (cathode material) and LTO (anode material) based cylindrical Lithium-ion cells (26650) using indigenously developed LFP and LTO.
- Eco-friendly, low cost and novel aqueous binder for LIB has been developed. Prototype sodium ion cell (50 mAh) indigenous electrode and electrolyte developed and fabricated.
- Efforts towards indigenous development of Lithium Ion Battery Materials: The electrochemical performance of ARCI developed LFP has been validated in coin cell and cylindrical cell configurations and know-how for production of the material is ready for transfer.
- Indigenous development of Supercapacitors had seen further progress this year. 1200F Supercapacitor using activated carbon derived from petroleum coke waste has been successfully developed. Demo-run of e-bike powered by indigenous supercapacitor developed at ARCI has been successful.
- Concerted efforts on technologies for solar applications showed encouraging results. Technology Transfer Agreements were signed with two companies: Marichin Technologies and Allox Resources for easy-to-clean coating (super-hydrophobic) sol composition and coating technique on Photo-Voltaic (PV) panels. Broad-band Antireflective Coatings with high transmittance and high weather stability through hydrothermal synthesis of nanoparticles have been developed. Perovskite solar cells (PSC) developed, exhibited a power conversion efficiency of 19 % in lab-scale (15mm x 15mm device) and 8% in prototype (50mm x 50mm) module. Commercialization Option agreement was signed with Borosil Renewables Limited for the technology demonstration at the industrial scale.
- In the area of fuel cell technology, focus continued on R&D activities from the perspective of durability, cost, accelerated stress test and other related characterization towards outreach and industrial acceptance. A technology transfer agreement was signed with LAS Engineers and Consultants Pvt. Ltd. for 'electro catalysts used in fuel cells.
- In the area of mgnetic materials for automotive applications, high coercive ferrite powders suitable for bonded magnet applications was developed by a cost-effective process which involved a smaller number of process steps when compared to conventional process. The desired particle size and distribution were achieved by suitable combination of calcination temperature and controlled milling parameters of the fluid-energy milling. The samples are currently being tested in collaboration with bonded magnet manufacturing company for validation and subsequent field trials of prototypes.

At the National Center for Development of Advanced Materials & Manufacturing Processes for Clean Coal Technologies, a first of its kind thermal spray facilities, such as Axial Plasma Spray and High Velocity Air Fuel Spray have been established. Establishment of some advanced coating technologies to economically improve the life of components, for example laser-clad coating process for life improvement of burner tip plates, has been initiated. The plan is to intensify interaction with users to identify the most critical components and provide solutions. The process for manufacture of ODS-Fe_3Al rods that exhibit good combination of strength and ductility at room temperature as well as at high temperatures has been established.

In the surface engineering activity, we continued our efforts of developing total technology including equipment of international class. During the year, two technologies viz.advanced detonation spray coating system having enhanced productivity and efficiency, and prototype model of cold spray coating system have been further refined with built in pre-set programmes for different materials. These technologies are ready for the transfer. Cathodic Arc-PVD based TiN protective

LFP/Graphite Cells and NMC/LTO Cells

Fabrication of 1200F supercapacitor

Perovskite PV module

Demonstration of the PEMFC system integrated with power condition to power AC lighting

Development and demonstration of large scale production of nano $LiFePO_4$ and Lithium Titanium Oxide powders

Technology Transfer Agreement signed with Marichin Technologies

Some typical components made using bonded magnets

Electron Beam Melting (EBM) System

Erosion resistant coatings on compressor blades

3D printed ceramics

Prototype dynamic screws for orthopedic implants

coatings were successfully developed on 510 nos of helicopter compressor blades and passed through 220 hours of in-flight testing. Wear resistant coatings, developed on minting dies, exhibited 2.5 times life enhancement.

ARCI developed antibacterial powder, exhibited >95% antibacterial activity for scrub pads being produced by a reputed collaborating company. Sol-composition was developed for fast curing, corrosion resistant, self-lubricating, adhesion promoting coating for CRCA and GI steel sheets. Coating formulation was developed for imparting anti-bacterial property by inhibiting the biofilm formation on surgical sutures for preventing surgical site infections.

In the area of Ceramic processing, a state of the art melt quenching R&D facility for the processing of speciality glass ceramics is being established. A programme to indigenously develop Solid Oxide Fuel Cell (SOFC) and Solid Oxide Electrolytic Cell (SOEC) has been conceived in consortium mode for possible commercialization. Development of 3D printing of $MgAl_2O_4$ spinel mesh for potential biomedical applications and contamination free slip casting of spinel parts are underway.

At the Centre for Nanomaterials, dispersion strengthened tungsten plates by novel PM process, Mn-Zn-Ferrite core-shell based PM-soft magnetic composites, high strength and ductile alloy of Fe_3Al with Cr, Ti, and adding nano oxide dispersoids for turbine blades were developed. A hydride-dehydride method to convert zirconium sponge to its pyrotechnic grade for thermal battery was established.

In the area of Additive Manufacturing (AM), while developing several components by AM for strategic & manufacturing sectors, certain innovation to use less powder has been put in place. Electron Beam AM has been added to the capabilities of ARCI. Indigenous development of AM grade powders is being pursued. A beginning has been made towards 3D printing of ceramics and magnetic materials.

The key to successful translational research is maintaining close interface with the relevant companies / academic institutions/other R & D labs with complementary resources/capabilities mainly for effective technology development/ field trials / commercialization, identifying needs of forging collaborations for progression to higher Technology Readiness Levels (TRLs), and providing appropriate engagement models. Formulating linkages with other required stakeholders through the multi-disciplinary working groups in the identified areas of Aerospace, Bio-medical and Sensors has started yielding results.

Performance Indicators

Parameters	2020-21
Papers in Refereed Journals	108@
Chapters in Books	17@
Papers in Conferences and Invited Lectures	143
No. of Ph.Ds. Produced	7
Foreign Patent Applications (inventions awaiting grant)	5*
Foreign Patents Granted (includes same inventions granted in multi-ple countries)	17*
Indian Patent Applications (awaiting grant)	56*
Indian Patents Granted	78*
No. of Technologies/ Designs and other IP Commercialized	23
Number of Technology Leads Awaiting Transfer	21
Research Manpower Trained (other than PhDs)	17
Technical Manpower Trained	36
B. Tech/ UG Projects Guided	16
M. Tech./ M. Sc./ M. Phil Projects Guided	19

*Cumulative figure up to the end of the financial year
@Calendar year 2020

R&D/technology Agreements, costing of technologies / projects, patent filing, prior art search, generating leads, reporting the ARCI performance parameters and periodic review of R & D projects' TRLs in terms of the IP Development Indices (IPDIs), prepared for labs like ARCI, were spear headed by our Technology Acquisition and Transfer group. Significant activities have been carried out this year towards useful technological collaborations and know-how/technology transfers.

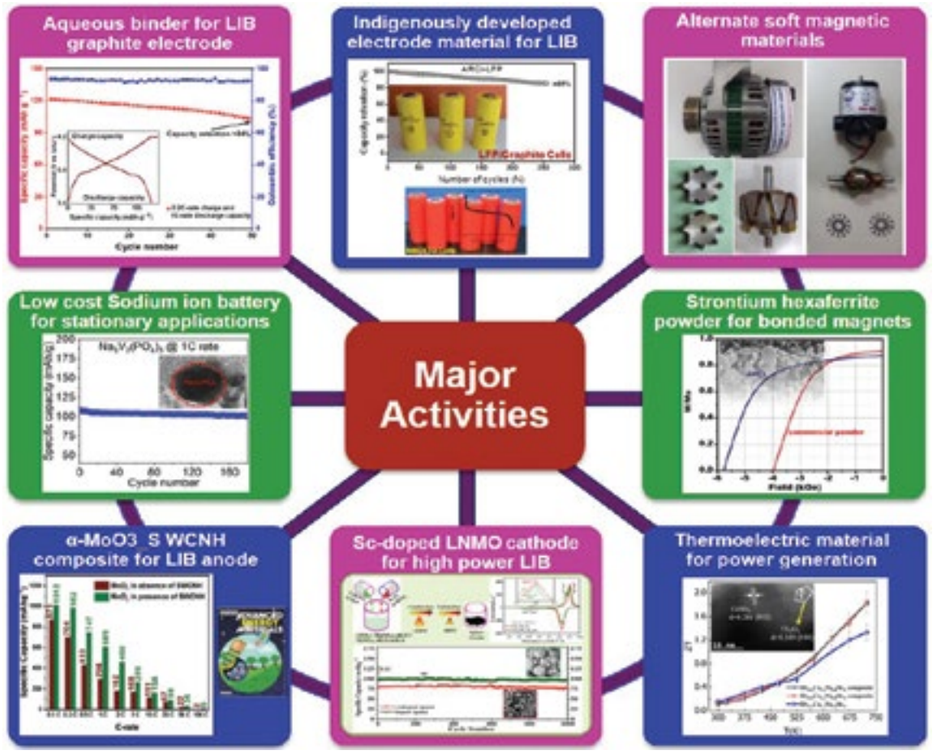
The implementation of multi-pronged strategies for maximum utilization of ARCI's research capability, activities carried out and novel initiatives being taken to its logical end have been made possible only with the continued support of each and every employee at ARCI. I am confident that the hard work, team spirit and enthusiasm of team ARCI, will help us in realizing our goals of delivering technologies and providing solutions consistent with the priorities of national missions.

(G. Padmanabham)

Technology Development/ Transfer and Research Highlights

Centre for Automotive Energy Materials

Centre of Automotive Energy Materials (CAEM) is located at IIT Madras Research Park, Chennai. The primary objective is to develop and demonstrate materials and components based processing technology to industries as well as to provide technical support. The Centre's major activities are: (i) Technology demonstration of lithium-ion battery (LIB) for electric mobility as well for stationary applications with associated materials technology demonstration; (ii) Na-ion battery for grid/off-grid storage; (iii) Soft and hard magnetic materials for motors and alternators applications; (iv) Thermoelectric materials and device fabrication for waste heat recovery; and (v) Magneto-caloric materials for magnetic refrigeration and bio-medical applications. The above activities are being executed through Technology Research Centre project on Alternative Energy Materials and Systems from the Department of Science and Technology, New Delhi, India.



Major Highlights

- *Developed fast formation protocol for lithium ion cells*
- *Lithiium ion cells (NMC532/graphite & LFP/graphite) were send to Pure EV Hyderabad & Leep e-drive Bengaluru for pre-field trials testing*
- *Lithium ion cells fabricated using indigenous $LiFePO_4$/graphite*
- *Upscaling of indigenous in-situ carbon coated NMC532 with Industry*
- *Developed new aqueous binders for graphite electrode*
- *Developed novel materials for high power LIB (Sc-doped Lithium nickel manganese spinel and α-MoO_3-SWCNH nanocomposite)*
- *Developed carbon coated $Na_3V_2(PO_4)_3$ cathode for Na-ion batteries*
- *Scaled up the melting of Fe-P alloys in collaboration with Industry*
- *Developed prototype alternator using indigenous Fe-P soft magnetic material and demonstrated better performance*
- *PV-TE hybrid system shows 6% improvement in open circuit voltage*
- *Development of skutterudite TE materials with figure-of-merit ~ 1.8*

Major Facilities

- *LIB fabrication process line and testing facilities*
- *LIB pouch cell fabrication facility*
- *Rheometer, Karl-Fischer titration and Peel tester*
- *Multichannel formation, impedance and life cycle testers*
- *LIB module/Pack tester*
- *Levitation Induction melting and Vacuum hot press*
- *Vacuum induction furnace of ~10 kg capacity*
- *Infrared spectrometer and Raman spectrometer*
- *Physical Property Measurement System (PPMS)*
- *2D-mapping of thermopower*
- *Physical vapour deposition*
- *Seebeck and resistivity measurement*
- *Thermoelectric generator testing unit*

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Technology Development / Transfer

A fast formation technique for Lithium-ion cells

Lithium ion cells are assembled in the discharged state. Formation of a lithium-ion cell is a process of performing an initial charge/discharge operation to activate the cell. During this process, a uniform solid electrolyte interphase (SEI) layer is formed at the anode, which impacts on the battery performance. Battery formation takes many hours to many days and the fastest formation process reported in literature is about 22h (Figure 1a). ARCI has developed a very fast cell formation method at room temperature by fine-tuning the SEI nucleation, growth, and stabilization processes (Figure 1b). The total time required for this process is about 6 hours, which reduces the formation time by more than 75%. The cells using the ultra-fast formation process yielded good cyclic stability and rate capability (Figure 1c-d), indicating that the formation test protocol is generic and it could be effectively used for various types of cell chemistries and cell topologies. (Indian patent filed).

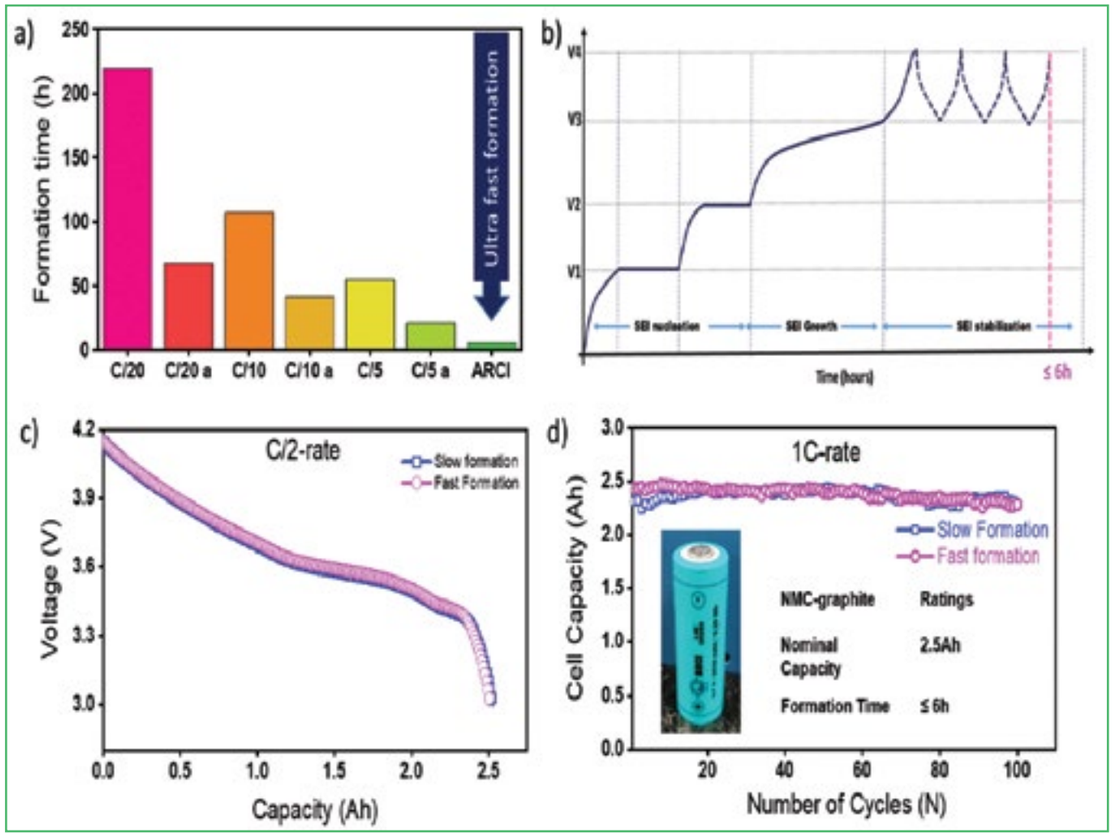


Fig. 1 Ultra-fast formation test method (a) ARCI cell formation time versus conventional cell formations time (b) Ultra-fast formation test protocol for lithium-ion cells developed by ARCI (c) Comparison of cell discharge capacity at c/2 for slow and fast formation, (d) Comparison of cycle life at 1C for slow formation and ultra-fast formation test cells

Contributors: Vallabha R. Rikka, S. R. Sahu, R. Prakash, R. Gopalan and G. Sundararajan

Fabrication of Lithium-ion cells using indigenously developed electrode materials

Lithium-ion battery active electrode materials, Lithium Iron Phosphate, $LiFePO_4$ and Lithium Titanium Oxide ($Li_4Ti_5O_{12}$) were indigenously developed at Centre for Nanomaterials, ARCI displaying encouraging results at the coin cell level. For commercialization of this technology, it is necessary to carry out a detailed study on their performance at various conditions by fabricating large Lithium-ion cells. Such a study has been undertaken at CAEM. The study includes (i) optimization of parameters to fabricate the electrodes (ii) fabrication of cells and testing them at various current rates. A few batches of cylindrical cells in the 26650 configurations were fabricated with different loading densities are fabricated in the following combination: (a) Indigenous LFP/Commercial Graphite to characterize LFP and (b) Commercial NMC/Indigenous LTO to characterize LTO materials. Preliminary results indicate that the LFP/graphite cells (5.6 Wh) and NMC/LTO cells (3.6 Wh) display a encouraging cycling stability at 1C rate and rate capability (Figure 2).

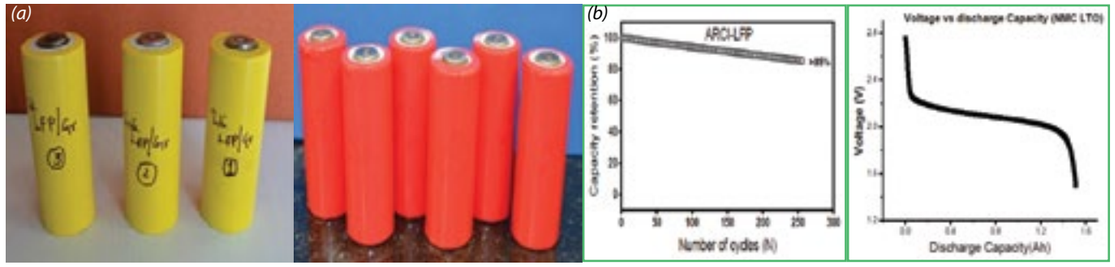


Fig. 2 (a) LFP / Graphite Cells and NMC/LTO Cells (b) LFP/graphite cells (5.6 Wh) and NMC/LTO cells (3.6 Wh) display an encouraging cycling stability at 1C rate and rate capability

Contributors: K. Shanmugam, A. Sivaraj, S. Jana, T. P. Sarangan, D. Vigneshwaran, V. V. N. Phani kumar, L. Babu, G. Vasu, Vallabha R. Rikka, S. Anandan, T. Mohan, R. Prakash and R. Gopalan

High coercive strontium ferrite powders for bonded magnet applications

ARCI has successfully developed high coercive ferrite powders suitable for bonded magnet applications by a cost-effective process involving a smaller number of process steps when compared to conventional process. The synthesized powders provide the advantage of higher resistance for demagnetization to the magnets, owing to a high coercivity of 5.7 kOe which is 40% higher than the commercial powder (Figure 3). The desired particle size and distribution were achieved by suitable combination of calcination temperature and controlled milling parameters of the fluid-energy milling (Patent Appl. No. 202111008252). The particle exhibited a compressed density of 3.3 g/cc which is within the optimal value (3.3 to 3.6 g/cc) required for bonded magnet applications. The samples are currently tested for prototype development in collaboration with bonded magnet manufacturing industry for validation and subsequent field trials.

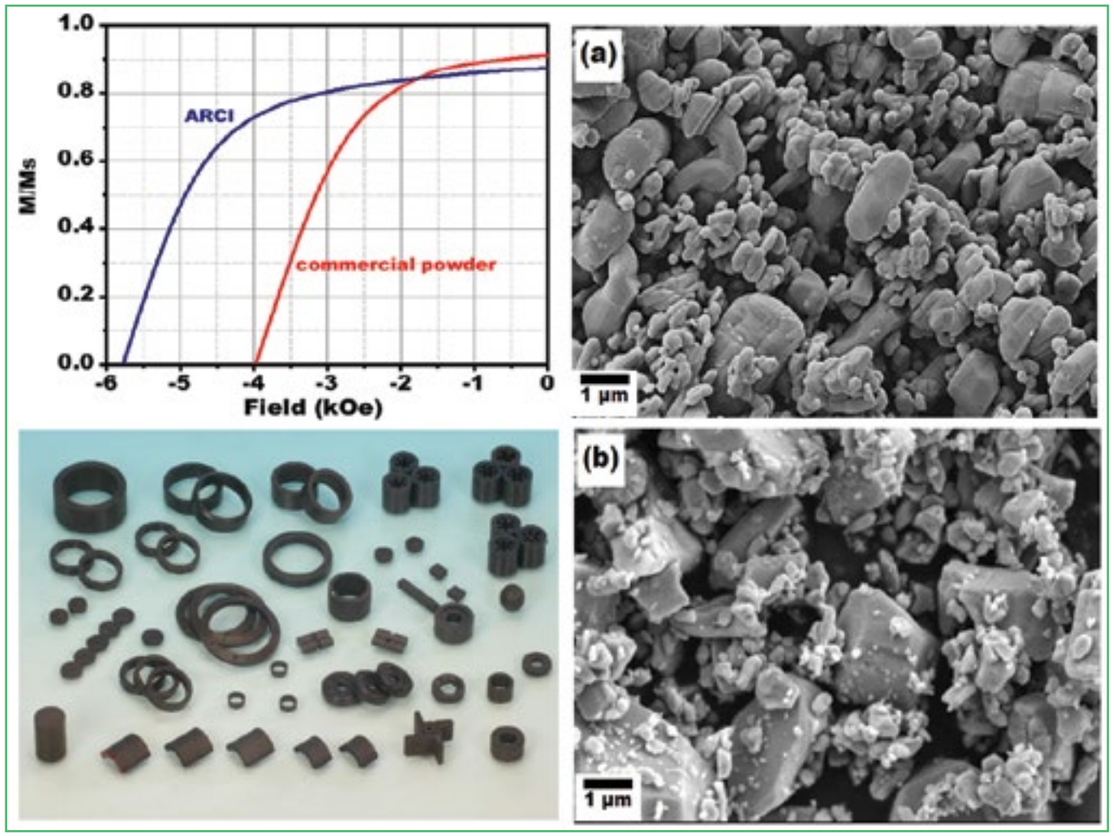


Fig. 3 Top left: Hysteresis loop showing the enhanced coercivity of the ARCI powders compared to commercial powders. Right column: SEM micrographs showing a bimodal distribution of (a) ARCI powders similar to (b) commercial powders. Bottom left: Some typical components with complex features made using bonded magnets

Contributors: D. Prabhu, M. Pavana, R. Gautam, A. R. Dilip, A. Devathai, V. Chandrasekaran, R. Gopalan

Research Highlights

α-MoO_3/single-walled carbon nanohorns composite as new conversion anode for Lithium-ion battery

α-MoO_3 is a prospective anode material for lithium-ion batteries (LIBs) due to its high theoretical capacity (1100 $mAhg^{-1}$). However, inherent poor electronic conductivity and large volume expansion during charge-discharge process of MoO_3 resulted in very low practical capacity. We have synthesized a novel composite of α-MoO_3 and single-walled carbon nanohorns (SWCNHs) by microwave hydrothermal technique. The composite shows a uniform distribution of α-$MoO_3$and SWCNHs. It displays superior electrochemical properties (1132 $mAhg^{-1}$ at 0.1C and 654 $mAhg^{-1}$ at 1C), excellent rate capability (275 $mAhg^{-1}$ at 5C) and outstanding cycle life (3000 cycles at 1C with >99 % capacity retention) without any cracking of the electrode (Figure 1). The multi-functionality of SWCNHs such as lithium storage material, electronic conductive medium and buffer against pulverization enhances the lithium storage capacity of the composite. With the advantages of a scalable method of synthesis, high capacity, excellent rate capability and long-term stability, α-MoO_3/SWCNH composite could be an exceptional anode material for high energy and high power LIB applications.

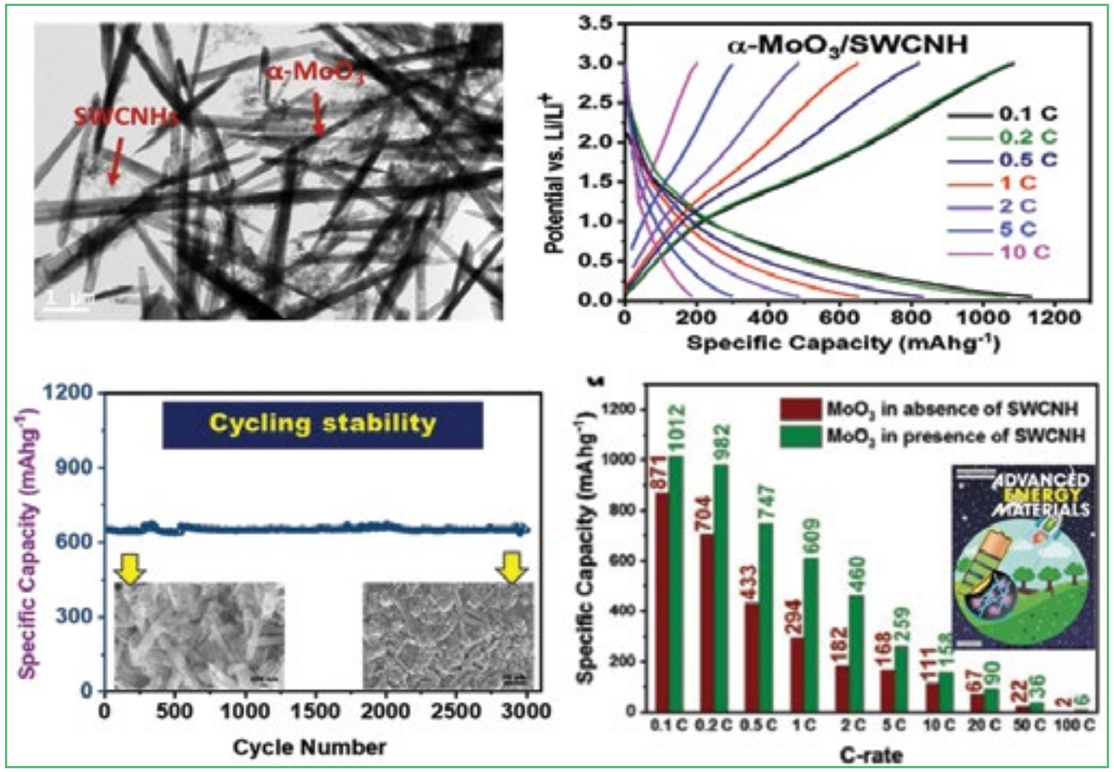


Fig. 1 TEM image, galvanostatic charge-discharge profile at different C-rates, cyclic stability at 1C rate and specific capacity of α-MoO_3 in presence and absence of SWCNHs at different C-rates

Contributors: Sumit R. Sahu, V. R. Rikka, R. Prakash and R. Gopalan

Highly-disordered Scandium-doped $LiNi_{0.5}Mn_{1.5}O_4$ spinel as potential cathode for high power Lithium-ion batteries

Highly disordered $LiNi_{0.5}Mn_{1.5}O_4$ spinel exhibited excellent charge/discharge properties as cathode in lithium ion batteries (LIBs). However, synthesis of such spinel with minimum Mn^{3+} content is a major challenge. Herein, scandium-doped cation disordered $LiNi_{0.5}Mn_{1.44}Sc_{0.06}O_4$ high voltage spinel was synthesised by solution combustion method (Figure 2). It exhibits cubic spinel system having Fd3m space group with increased Ni/Mn disorder at 16d site. The compound shows spherical aggregates with densely-packed primary particles with narrow size distribution, which facilitates high packing density and excellent electrochemical performances. It delivered a discharge capacity of 125 $mAhg^{-1}$ at 1C rate with excellent cycling stability. Even at 5C rate, it has exhibited a capacity of >100 $mAhg^{-1}$ with 98% retention after 1000 cycles. The increased Ni/Mn disorder in LNMSO decreases the charge transfer resistance and enhances the electrochemical performances. Hence, it could be a potential high-voltage cathode material for the next generation lithium ion batteries.

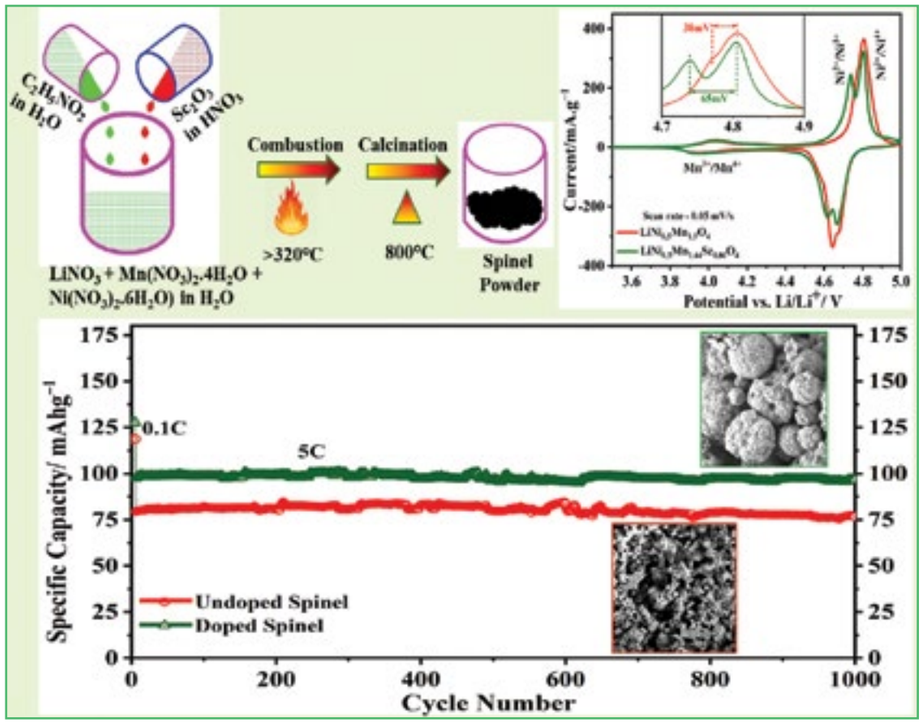


Fig. 2 Synthetic scheme, cyclic voltammetry and discharge profile of $LiNi_{0.5}Mn_{1.44}Sc_{0.06}O_4$

Contributors: S. Bhuvaneswari, U. V. Varadaraju, R. Prakash and R. Gopalan

Tamarind kernel powder based aqueous binder for graphite electrode in lithium-ion batteries

Electrode fabrication is a vital process in lithium-ion batteries (LIBs). Anode was prepared by graphite powder, conductive carbon, N-methyl-2-pyrrolidone (NMP) solvent and Polyvinyl difluoride (PVdF) binder in a dehumidified room. This process is expensive, environmentally hazardous and requires recycling of the organic solvent. Herein, we have fabricated graphite electrodes using environmentally friendly Tamarind kernel powder (TKP) polymer as aqueous binder. Graphite electrodes have been fabricated using 3, 4 and 5wt.% of TKP (i.e., C-TK3, C-TK4 and C-TK5) and 4wt.% of PVdF (C-PF4) for comparison. All the TKP samples have shown much better performance vs lithium than the PVdF sample (Fig.3a and b). A full cell of NMC532 cathode and C-TK4 anode delivered a stable discharge capacity of 122 mAh/g at 1C with a capacity retention of >84% after 50 cycles. The enhanced performance of C-TK electrode can be ascribed to (a) high surface charge stability of the slurry, (b) low swelling of the binder (c) high conductivity of the electrode and (d) branched chemical structure with more hydroxyl bonding sites. Hence, TKP could be a potential aqueous binder for the fabrication of graphite anode, and it can also be extended to other electrode chemistries.

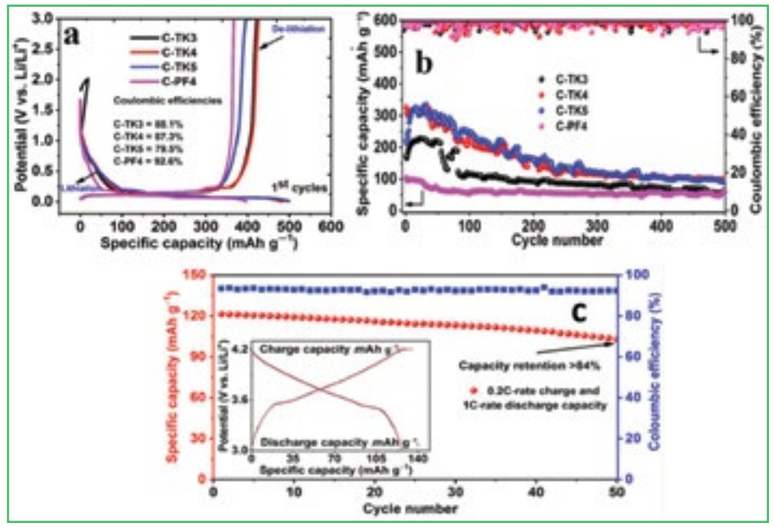


Fig. 3(a) Galvanostatic charge/discharge profile of graphite electrodes (C-TK3, C-TK4, C-TK5 and C-PF4) at 0.1C, (b) Cycling stability of the electrodes at 1C-rate for 500 cycles, (c) Cycling stability of full cell at 1C-rate for 50 cycles (Inset: Formation of cell at 0.05C-rate)

Contributors: V.V.N. Phanikumar, R. Prakash and R. Gopalan

Enhancement of electrochemical performance of $LiFePO_4$ by dry mixing with carbon black

The performance of the lithium-ion battery depends on electrode morphology that is contingent on the homogeneity and stability of the electrode slurry. By premixing of carbon black (CB) with $LiFePO_4$, the binding properties of polyvinylidene fluoride and electrostatic steric interaction of CB in N-Methyl-2-pyrrolidone is optimally utilized to stabilize the slurry and to adhere the electrode to current collector. The electrodes fabricated using premixed CB/$LiFePO_4$ slurry (BM-E) have better homogeneity in distribution of constituents and electrochemical performance compared to that of the one prepared using sequentially mixed CB/$LiFePO_4$ slurry (WB-E) (Fig.4). The strategically tuned slurry preparation method gives a higher discharge voltage of ~ 3V at 10C compared to the values of 2.4 to 2.8V of unmodified $LiFePO_4$ reported so far.

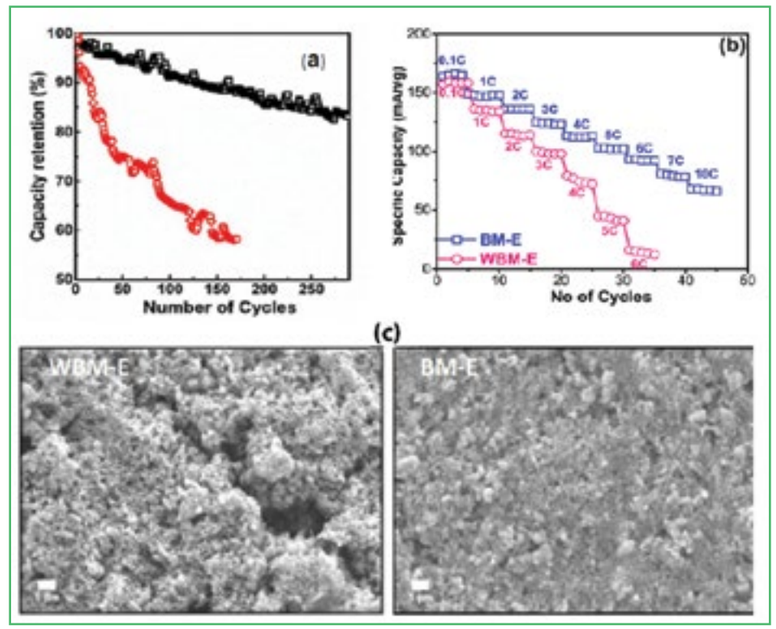


Fig. 4 (a) Cycling stability at 1 C rate of WBM-E (red circles) and BM-E (black squares) (b) Rate – capability at different C rates for WBM-E (red circles) and BM-E (black squares), ((c) Post-mortem analysis (SEM micrographs) of WBM-E and BM-E

Contributors: M. B. Sahana, K. Kumari and R. Gopalan

Sodium ion battery for sustainable energy storage applications

Sodium ion batteries (SIBs) research has been initiated to develop prototype sodium-ion cells indigenously for energy storage applications. However, a number of challenges such as lack of electrodes with high electrochemical performance, electrolyte with high sodium-ion conductivity as well as wide electrochemical stability window have to be addressed to realize the commercialization of SIB. In this regards, ARCI has put enormous efforts to develop indigenous electrode materials and electrolyte, which have shown excellent electrochemical performance. In-situ carbon coated $Na_3V_2(PO_4)_3$ and $Na_3V_2(PO_4)_2F_3$ as cathodes show 105 and 120 mAh/g when cycled at 1.0 C-rate, respectively (Indian, Japanese, Korean and European patents filed). Indigenously developed hard carbon (HC) show 300 and 230 mAh/g at 0.1 and 1C-rates, respectively. Work is ongoing with industry to jointly develop 0.5 kWh sodium ion battery module.

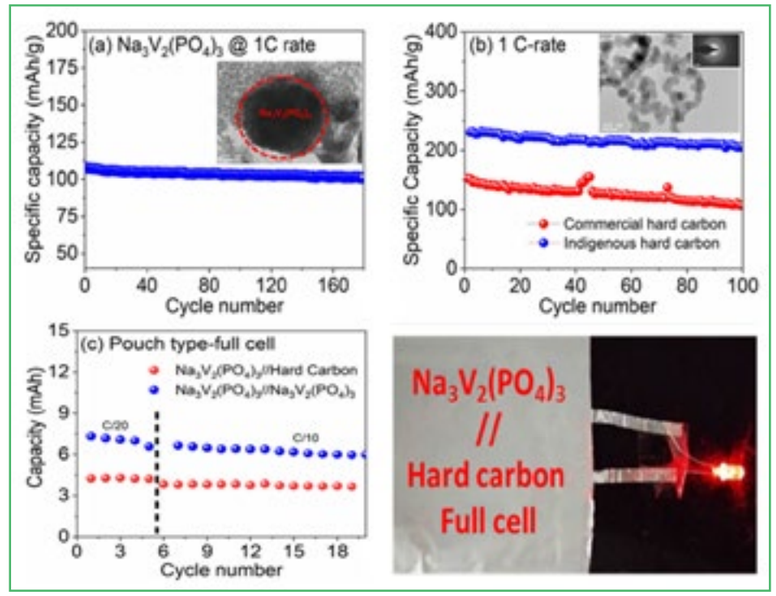


Fig. 5 Cycle performance of (a) $Na_3V_2(PO_4)_3$; (b) hard carbon in half-cell mode and (c) Full cell cycle performance comparison for $Na_3V_2(PO_4)_3$; (d) Pouch cell tested with red LED bulb.

Contributors: Bijoy K. Das, S. Sharma, Laxman M. Kanta, M. Venkatesh and R. Gopalan

Magnetic properties on jet milled Mn-Bi alloy

- Structural and magnetic properties of arc-melted and homogenized Mn-Bi alloy pulverized by jet milling at different feed rates from 0.5g/min-1.5g/min.
- With jet milling, the weight fraction of MnBi ferromagnetic phase decreases from 87% to 66% (Fig.6 (1))
- The studies show that jet milling produces uniform particle size distribution in a short span of time (Fig.6 (2))
- Magnetization measurements show that the magnetization decreases with milling and coercivity increases and reaches to 12kOe at room temperature and increases to 18 kOe at 400 K in jet milled Mn-Bi powders. (Fig. 6(3) and Fig.6 (4))
- Increase in coercivity at high temperatures suggests that these alloys can be used for high temperature applications.

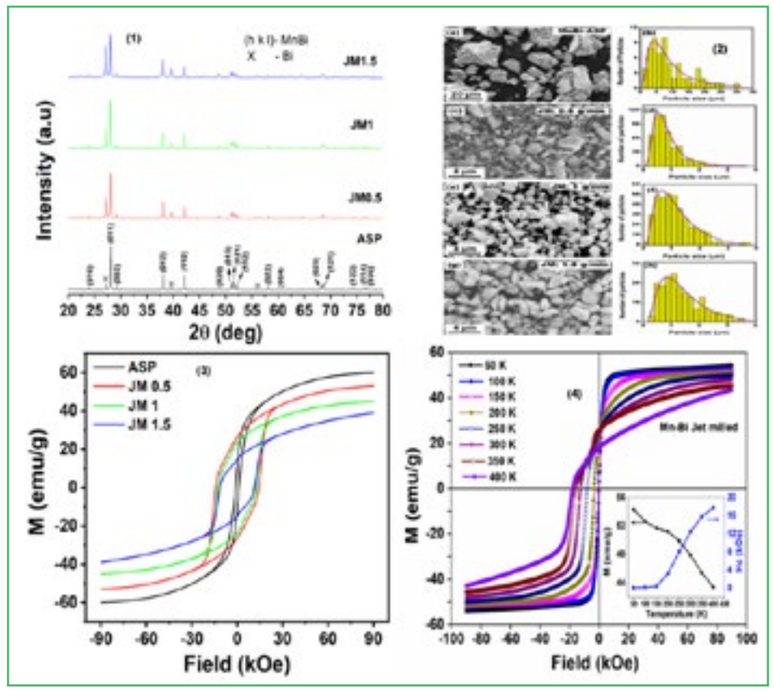


Fig. 6(1) XRD (2) SEM microstructure (3) Hysterisis loops of Mn-Bi alloy and jet milled at different feed rates (4) High temperature magnetization measurements of jet milled Mn-Bi alloy

Contributors: V.V. Ramakrishna, S. Kavita and R. Gopalan

Low-cost SbxAl1-xFe_2B_2 compound for thermoelectric power generation

Electrode fabrication is a vital process in lithium-ion batteries (LIBs). Anode was prepared by graphite powder, conductive carbon, N-methyl-2-pyrrolidone (NMP) solvent and Polyvinyl difluoride (PVdF) binder in a dehumidified room. This process is expensive, environmentally hazardous and requires recycling of the organic solvent. Herein, we have fabricated graphite electrodes using environmentally friendly Tamarind kernel powder (TKP) polymer as aqueous binder. Graphite electrodes have been fabricated using 3, 4 and 5wt.% of TKP (i.e., C-TK3, C-TK4 and C-TK5) and 4wt.% of PVdF (C-PF4) for comparison. All the TKP samples have shown much better performance vs lithium than the PVdF sample (Figure 7a and b). A full cell of NMC532 cathode and C-TK4 anode delivered a stable discharge capacity of 122 mAh/g at 1C with a capacity retention of >84% after 50 cycles. The enhanced performance of C-TK electrode can be ascribed to (a) high surface charge stability of the slurry, (b) low swelling of the binder (c) high conductivity of the electrode and (d) branched chemical structure with more hydroxyl bonding sites. Hence, TKP could be a potential aqueous binder for the fabrication of graphite anode, and it can also be extended to other electrode chemistries.

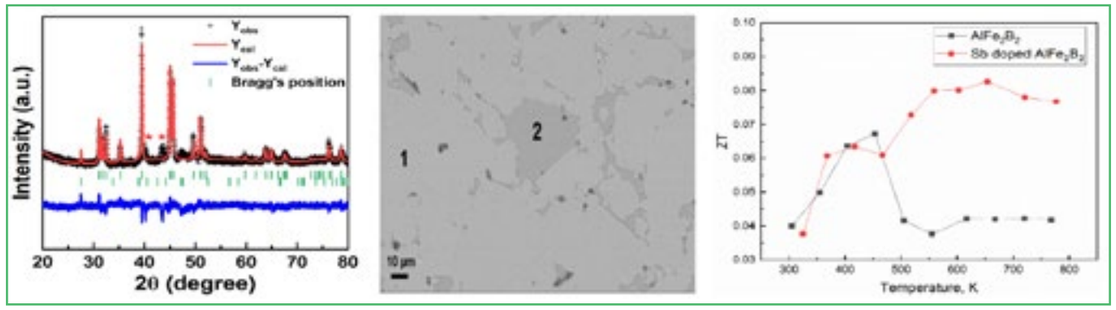


Fig. 7 XRD and SEM micrograph of the $AlFe_2B_2$ synthesized by arc melting. Variation of the figure of merit with temperature in $AlFe_2B_2$ TE compound.

Contributors: B. Prasanth, U. Goutham, D. Sivaprasaham and R. Gopalan

Centre for Solar Energy Materials

The emergence of new solar energy technologies has been a potential game-changer in the modern era of power generation. The flourishing solar energy technologies and associated R & D in the development of new technologies are boosted with India's Jawaharlal Nehru National Solar Mission (JNSM). Centre for Solar Energy Materials (CSEM) at ARCI has been established with a futuristic ideology of development and demonstration of various eco-friendly and economically viable technologies in the field of solar photovoltaic and solar thermal.

Centre's Major Achievements

Easy to Clean Coating Technology know-how agreement signed with Marichin technologies, Mumbai & Allox resources, Hyderabad

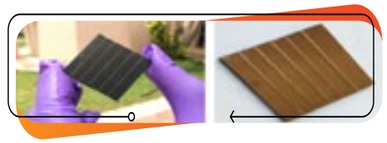
Agreement signed with Borosil for technology demonstration of AR & Easy to Clean coatings at industrial scale

Industrial projects of Anti-fouling coating on compressor blades and Thermic fluids validation by ARCI's parabolic test rig facility received from INS-Eksila & HPCL

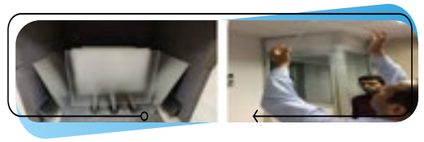
Technologies of Easy to clean coating/ Receiver tube/Smart carbon lubricants validated under standard test & field conditions

Technology Transfer & Demonstration

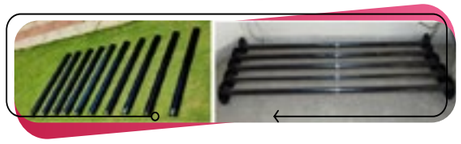
Prototype Development



Perovskite PV modules



AR coated PV glasses



High temperature stable receiver tubes (1m & 2m assemblies)

Functionalised carbon textile & easy to clean coated glasses

Facility Establishment

PV-Performance monitoring system for validation of PV Panels

Parabolic test rig for validation of solar thermal components

Large size Perovskite cells development

S. Sakthivel
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Technology Development / Transfer

Ambient temperature curable anti-soiling (easy-to-clean) coating for solar photovoltaic and other applications

Soiling loss is one of the major disconcerting phenomena for Photovoltaic Power generation. Ambient temperature curable hydrophobic coating can be a potential solution to mitigate the soiling losses (lotus effect). ARCI has developed a novel nanocomposite-based coating technology to mitigate the energy losses due to soiling. The nanocomposite coating reduces the amount of dust deposited on the panel and cleans itself by the action of water on the PV modules. The technology has been validated at various ground level and rooftop PV plants at NETRA (NTPC Ltd), Noida, Fourth Energy Partner, Hyderabad & Solar Inertia Power Pvt. Ltd, Mumbai and successfully transferred to NETRA (NTPC Ltd), Marichin technologies, Mumbai, and Allox resources LLB, Hyderabad. Recently, the technology was modified suitably and demonstrated for other applications.

Key features

- *Transparent (no loss in power output after coating)*
- *Hydrophobic property: >120º WCA*
- *High weather stability (validated by IEC 61646 STD)*
- *Good mechanical stability*
- *Easy to coat and curable at ambient condition*
- *Facile synthesis, scalable & cost-effective*

***Applications**: PV Panel, wood, textile, ceramic, metal, architecture glass, automobile windshield, etc.*

Fig. 1 Technology demonstration at rooftop PV plant (Solar Inertia Power Pvt. Ltd, Mumbai) and other applications on Architecture glass and Automobile Windshield

Contributors: S Sakthivel, R Easwaramoorthi, N Chundi, and S R Atchuta

Solar absorber tube for low and medium temperature solar thermal applications

Solar absorber tube (receiver) is one of the key components for solar water heater and concentrated solar thermal (CST) based industrial process heat applications. Currently, Indian solar water heater manufacturers and CST plant developers are importing the receiver tubes from outside India particularly from China and Europe. This has become a major challenge for the commercialization of solar thermal systems in India. In this regard, ARCI has developed a cost-efficient solar absorber coating on stainless steel by a combination of wet-chemical oxidation and sol-gel process. The receiver tubes have been validated for both the solar water heater and industrial process heat applications and demonstrated good performance in heat gain with low heat loss property on par with commercial receiver tubes. The technology was transferred to Green Energy India, Pvt. Ltd, Coimbatore, and transfer to multiple industries are being progressed.

Key features

- *High selective properties (Solar absorptance ~94%; Spectral emittance ~0.12)*
- *Low heat loss property: ~014 at 250ºC*
- *Temperature stability: <250ºC*
- *High corrosion resistance >1000 hrs withstand in salt spray test (ASTM B117)*
- *Cost-effective & Easy scalable*

***Applications**: Solar water heater, Low and medium industrial process heat, solar dryer and cooling, etc.*

Fig. 2 Images of multiple numbers of prototype solar absorber tubes developed and supplied to industries for validation for both the solar water heater and industrial process heat applications & Prototype solar water heater and parabolic trough based CST system

Contributors: S Sakthivel, S R Atchuta, V Saikrishna, M Shiva Prasad and K K Phani Kumar

Broad-band antireflective coating (BARC) for solar and optical applications

Transparent glasses utilized in energy conversion devices encounter losses majorly due to Fresnel reflections. The Fresnel reflections result in ghost images, which have proven to be the most disconcerting phenomenon for photovoltaic and other applications. These phenomena can be alleviated by development of Antireflective coatings. In this regard, ARCI has designed and developed novel Broadband Antireflective Coating (BARC) with high stability by using organic and aqueous-based nanoparticles (MgF_2/SiO_2). The cost-effectiveness and scalability of this coating to wide areas led the way forward to a potential technology. ARCI has developed BARC coatings on samples supplied by various industries and sent for validation. Recently, a commercialization Option Agreement signed with Borosil renewables limited for the technology demonstration at industrial roll-to-roll coating process followed by technology transfer.

Key features

- *High transmittance (> 96% (300-1500nm) ; >98% (380-800nm))*
- *Low temperature curable (100ºC)*
- *High weather stability (withstands >90% RH)*
- *High mechanical stability*
- *Facile synthesis, Scalable & Cost-effective*

***Applications**: Solar PV, Solar thermal, Optical, Display, etc.*

Fig. 3 BARC coated PV glass plate (1ft x 1ft); Industrial interaction with Borosil Renewables Ltd.; Coating performance validation at Borosil

Contributors: S Sakthivel, S R Atchuta, N Chundi and R Easwaramoorthi

Smart carbon nanoparticles (SCNPs) based lubricants and heat transfer fluids

Functionalized Carbon Nanoparticles developed by in-situ hydrothermal process from cost-efficient precursor sources to enhance the thermal behavior of Heat transfer fluid (HTF) and lubrication properties of the lubricant oils. A high dispersion property in a non-polar medium without agglomeration and sedimentation, uniform particle size provides enormous benefits for heat transport phenomena, which are of primary importance to solar thermal power generation and industrial heat transportation. Moreover, SCNPs act as nano bearings, which in turn have shown the reduction in Coefficient of Friction (CoF) when incorporated in the base lubricant oils. The technology has been validated through an Industry and technology transfer is being progressed. The synthesis of SCNPs is a facile, scalable, reproducible, and cost-effective process.

Key features

- *High dispersion in all type of oils without altering the base property.*
- *45-50% low coefficient of fraction compared to base Oils*
- *27-30% sp. heat capacitance enhancement in HTFs*
- *No sedimentation even after high centrifugation*
- *Thermal stability <300ºC*
- *Cost effective and easy to scale up*

***Applications**: Lubricant & Heat transfer*

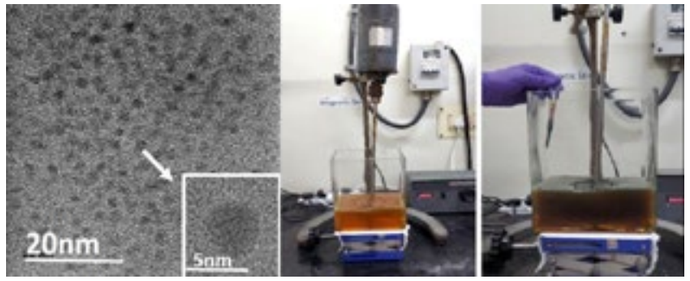


Fig. 4 TEM morphology of SCNPs & Facile preparation of SCNPs based HTFs/Lubricants

Contributors: S Sakthivel, K K Phani Kumar and S R Atchuta

Spinel nanocomposite based absorber coatings/tubes for high-temperature CST/CSP applications

The receiver tube plays a crucial role in the photo-thermal conversion of Concentrated Solar Thermal (CST) and Concentrated Solar Thermal Power generation (CSP) systems. To improve the efficiency of a CST/CSP system, a spectrally selective and high thermal stable (< 500°C) coating is required on the receiver tube. To meet these requirements, transition metal-based spinel oxides (CuNiMnOx) used to develop a high-temperature stable absorber layer with high optical absorptance (>95%) and low emittance (0.16 at 500°C). For the development of these coating, we adapted cost-effective and scalable wet chemical and nanoparticle suspension methods. Recently, multiple numbers of 1 m tubes and 2 m Prototype receiver assemblies have been successfully developed for field validation by using ARCI's parabolic test rig facility followed by technology transfer to the industrial organizations.

Key features

- *Spinel nanocomposite oxide based layers*
- *High selective properties (Abs: ~95%; Emittance: ~0.16)*
- *Thermal emissivity: 0.17 at 500°C & Thermally Stable up to 500°C under open atmosphere*
- *Cost-effective & Scalable*

***Applications**: Medium & high temperatue CST & CSP*

Fig. 5 Spectral selectivity of spinel nanocomposite based absorber coating on SS 304 substrate & images of multiple nos of 1m tubes and 2m prototype receiver assemblies developed for field validation

Contributors: S Sakthivel, M Shiva Prasad, S R Atchuta and K K Phani Kumar

Research Highlights

Fluorine based passivation material for efficient and stable perovskite solar cells

A fluorine passivation layer was proven to act as a protective blanket over the $MAPbI_3$ perovskite layer with an improvement in the water contact angle by more than 10^0 compared to the pristine film. Tauc plots (Figure 1b) of the corresponding films were measured, which also reveals the pristine $MAPbI_3$ perovskite degraded back to precursor stage (PbI_2 phase); where the bandgap changed from 1.58eV to 2.28 eV. But the fluorine passivated $MAPbI_3$ perovskite bandgap almost remains the same and the perovskite solar cells (PSC) fabricated with the fluorine passivated perovskite showed 13.8% efficiency.

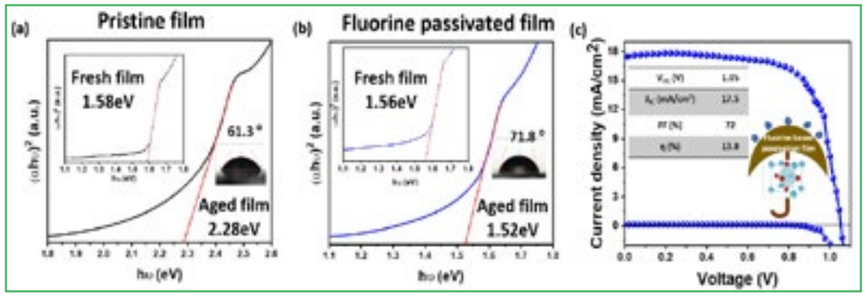


Fig. 1 Tauc plots of the $MAPbI_3$ (a) pristine and (b) film passivated with fluorine compound respectively. Insets show the water contact angle of the fresh films
(c) I-V characteristics of the fluorine passivated film with inset showing the shielding effect of the fluorine passivation layer on $MAPbI_3$

Contributors: V Ganapathy, Thulasi Raman, B Ramya Krishna and R Easwaramoorthi

Scalable and high-throughput fabrication of perovskite solar cells by bar coating

Perovskite solar cells (PSCs) are the most explored for solar energy harvesting owing to their ease of processing and high power conversion efficiency. Lab-scale PSCs with an active area of < 1 cm^2 are typically fabricated by spin coating, however, this method is not suitable for the deposition of various charge selective and absorber layers on a large-area substrate. In an effort to upscale the PSCs, a bar coating technique, which is economical and capable of large area manufacturing with high throughput and excellent uniformity, has been developed. Highly uniform and pin-hole free TiO_2 electron transport layer and $MAPbI_3$ perovskite absorber layer are deposited on 50 mm × 50 mm FTO glass substrates (Figure 2). Photoluminescence mapping indicates the formation of crystalline and defect-free perovskite absorber layers with high spatial uniformity. Proof-of-concept PSCs fabricated using such layers have exhibited a power conversion efficiency of 15.6 % with improved manufacturing reproducibility.

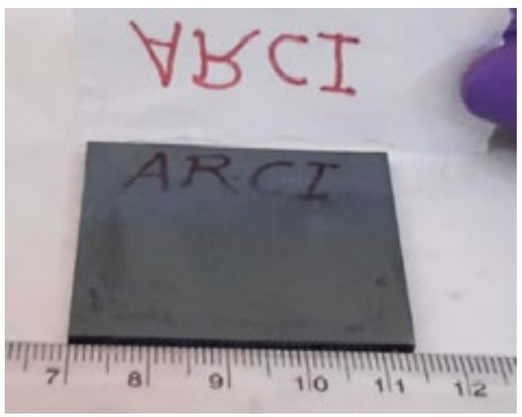


Fig. 2 Bar coated $MAPbI_3$ perovskite absorber layer with mirror like surface finish on 50 mm × 50 mm FTO glass substrate

Contributors: M Sreekanth, B Ramyakrishna and R Easwaramoorthi

Large-scale synthesis of TiO_2 sol for ambient curable electron transport layer for carbon-based perovskite solar cells

We synthesized an ambient temperature curable, large-scale, highly dispersed anatase TiO_2 sol. A large volume of 450-500mL of highly dispersed TiO_2 sol can be generated from each synthesis along with 1.5-2g of TiO_2 nanoparticles. The sol is devoid of organic binders and constitutes green solvents. The new TiO_2 sol was used as an electron transport layer for carbon-based perovskite solar cells (CPSCs) and the entire device fabrication requires ≤ 100°C. The devices exhibited comparable performance (>10%) with that of high-temperature commercial TiO_2. It can be extended for flexible PSCs.

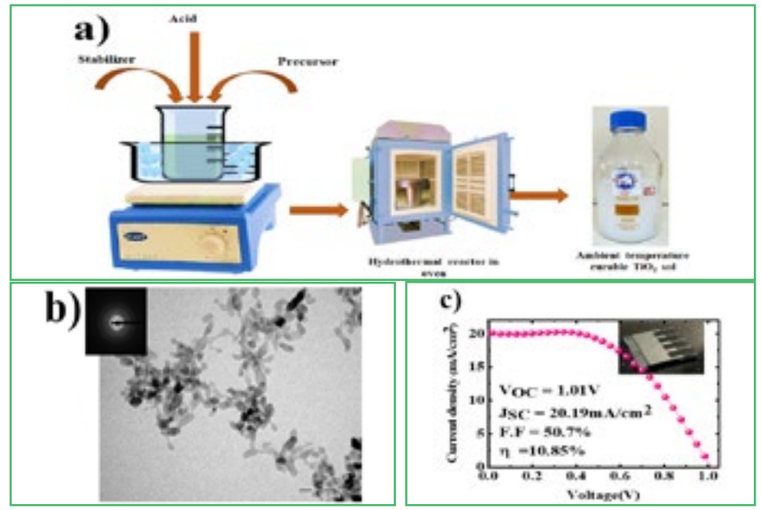


Fig. 3 (a) Schematic illustration of anatase TiO_2 sol and powder synthesis, (b) TEM image of the synthesized TiO_2 and (c) Current-voltage characterization of carbon based PSCs with TiO_2 sol (Inset showing photograph of CPSCs)

Contributors: V Ganapathy, K Reshma Dileep and R Easwaramoorthi

Flexible CIS solar cells with 7.3% efficiency by pulse electrodeposition

Flexible thin-film solar cells offer advantages for building integration applications, owing to their lightweight with simpler deployment mechanisms. Pulse electrodeposition has been effectively utilized to obtain smooth and uniform Cu/In precursor layers on flexible Mo foil substrates, which are then selenized to form chalcopyrite CIS absorbers. The fabricated CIS solar cells have exhibited an efficiency of 7.3 % (0.25 cm^2 active area) with an average efficiency of 6.6 % on 25 mm × 25 mm area devices. In addition, functioning CIS solar cells are fabricated on larger flexible foils of 50 mm × 50 mm.

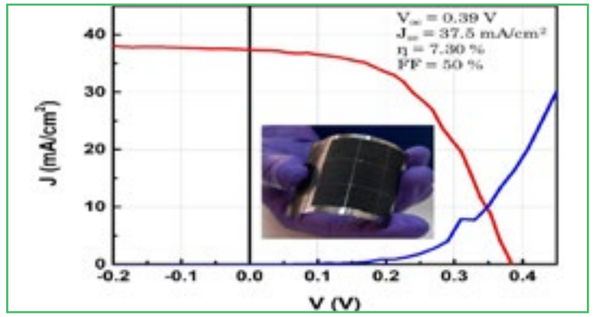


Fig. 4 J-V characteristics of pulse electrodeposited flexible CIS solar cell

Contributors: M Sreekanth, Prashant Misra and B V Sarada

Nanostructured MnO_2 by electrodeposition route for supercapacitor applications

Manganese oxide is an attractive material among the oxide materials used as electrodes in supercapacitors because of its high specific capacity, non-toxicity, earth abundance and environmental compatibility. In the present work, β-MnO_2 nanostructures have been electrodeposited on activated carbon paper as a binder and additive-free electrodes. The synthesized electrode exhibits a large electrochemical window of 1.2 V vs. Ag/AgCl with a specific capacitance of 260 F/g at 1 A/g in half cell configuration. The asymmetric device with MnO_2 as the positive electrode and commercial YP-50 carbon as negative electrode displays an active potential window of 2.2 V in aqueous Na_2SO_4 electrolyte with a capacitance of 57 F/g at 3 A/g and energy density of 38.31 Wh/kg at a power density of 3.28 kW/kg.

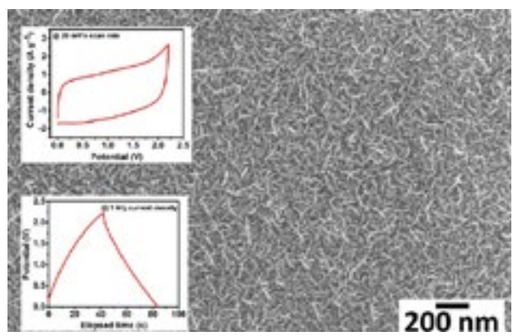


Fig. 5 FESEM image of the electrodeposited nanostructured MnO_2 electrode (Inset: CV and CD Characteristics of half-cell)

Contributors: B V Sarada, P Samhita and T Narasinga Rao

Surface functionalised carbon textile as multifunctional advanced materials for environmental remediation

Oil-water/toxic chemical separation is a field of high significance, not only for scientific research but also for practical implications aiming to resolve industrial oily wastewater and oil-spill pollution, as well as environmental protection. Therefore, the development of advanced functional materials for the efficient treatment of oil-polluted water is imperative. In this context, we have successfully developed a facile, scalable, and cost-effective preparation of flexible super-hydrophobic functionalized carbon textile used as multifunctional advanced materials for environmental remediation such as separation/ removal of contaminated oil and toxic chemicals in the water.

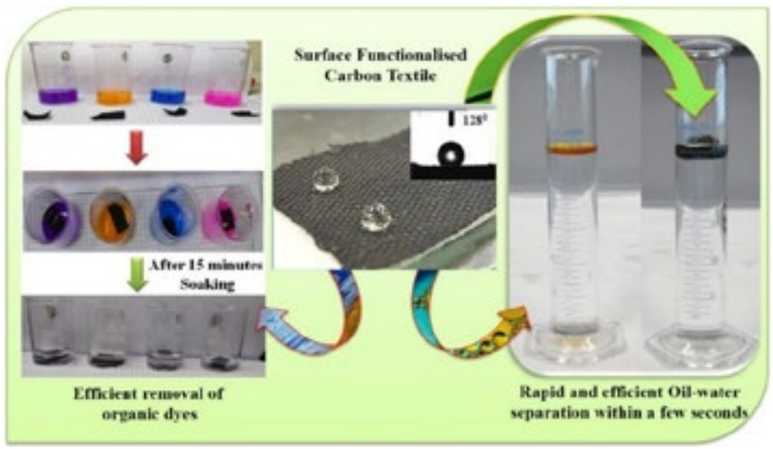


Fig. 6 Images of surface functionalized carbon textile and efficient removal of organic dyes and oils

***Contributors:** Mani Karthik, R Navaneethan, Narendra Chundi and S Sakthivel*

Magnetron sputtered Al doped ZnO thin film transparent electrode for application in solar cells and low bandgap optoelectronic devices

Aluminium doped zinc oxide (AZO) is an emergent prevalent transparent conducting oxide-based electrode material owing to its tunable optoelectronic properties, profusion in earth crust as well as non-toxicity. Optimization of oxygen flux during room temperature sputtering to obtain high quality AZO films by means of a higher figure of merit having, average electrical sheet resistance of 8.8 Ω/☐ and visible light transmittance of 78.5 %, appropriate for application in temperature-sensitive multilayer structures and photonic and electronic device. Application demonstration of room temperature sputtered AZO film on CIGS thin film solar cell has revealed a power conversion efficiency more than 11 %. An improvement in average transmission in the IR region from 78 to 85 % with a sheet resistance of 40 Ω/ ☐ is accomplished by the unique annealing technique of AZO thin film to dope Al in the AZO lattice reducing the compensating defects for its potential application in low band gap optoelectronic devices.

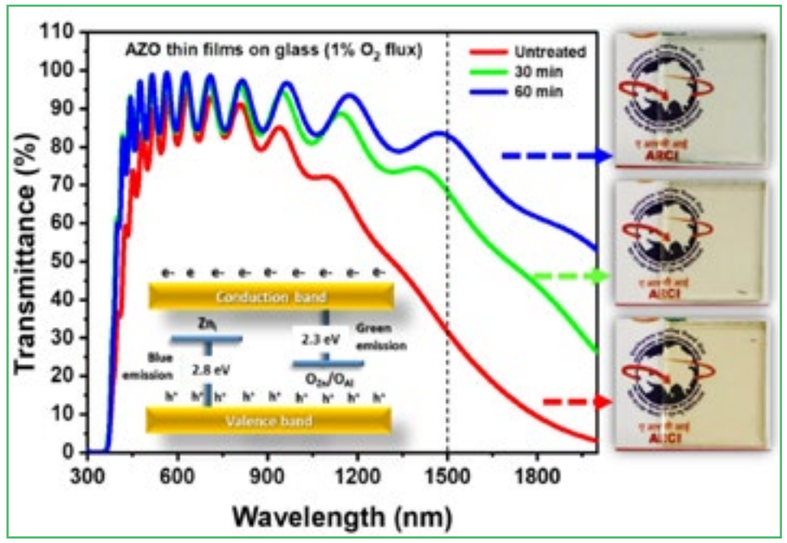
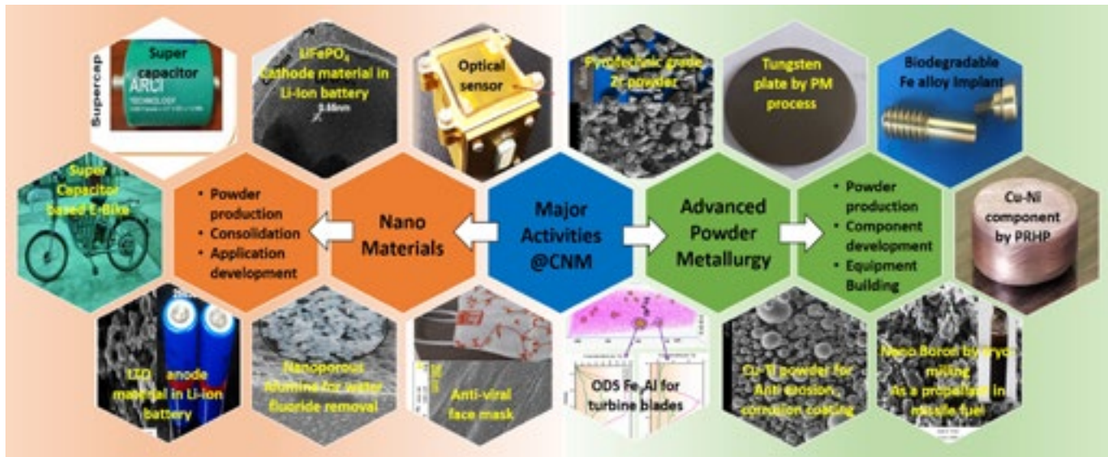


Fig. 7 Optical transmittance spectrum of sputtered AZO films on glass annealed at the different duration and representative pictures of AZO thin films on a glass

Contributors: Sanjay R Dhage, Brijesh Singh Yadav, Amol C. Badgujar and Golu Kumar Jha

Centre for Nanomaterials

Centre for Nanomaterials carries out research and technology development work in the field of nanomaterials and advanced powder metallurgy. The Centre has facilities and expertise to produce bulk volumes of powders with various compositions including the one with nanostructures, required for advanced manufacturing and state-of-the-art products. The materials being developed include powders, nanoparticles, nanosheets, suspensions, nanofibers, nanocomposites, nanoporous materials, nanostructured coatings for commercial, strategic, aerospace, and defence applications.



Thrust Areas

- *Battery and supercapacitors*
- *Nano powders*
- *Powder Metallurgy*
- *High strength steels*
- *Functional textiles*
- *Aerogels for thermal insulation*
- *Water fluoride removal*
- *Photocatalytic hydrogen production*
- *2D nano inorganic materials*
- *Nanocomposites*
- *Sensors*
- *Biomedical implants*
- *Special equipment building*
- *Magnetic materials*

Major Highlights

- *Large scale production of carbon coated nano $LiFePO_4$ and Lithium Titanium Oxide powder demonstrated as a cathode and anode material respectively in Li ion batteries*
- *Graphene-like activated porous carbon from petroleum coke for supercapacitors*
- *Nanometric gold film coatings on glass ceramic mirror segments for edge sensor in thirty meter telescope*
- *Indigenous technology "Photo Sensor for Automation and Energy Conservation"*
- *Dispersion strengthened tungsten plates by novel PM process*
- *Mn-Zn-Ferrite core-shell based powder metallurgy soft magnetic composites*
- *High strength and ductile alloy of Fe_3Al with Cr, Ti, and adding nano oxide dispersoids for turbine blades*
- *Hydride-dehydride method to convert zirconium sponge to its pyrotechnic grade for thermal battery*
- *Nano Ag-Cu/CuO for coating on a fabric for face mask for antibacterial and antiviral application*
- *Nanoporous alumina-polymer beads for quick removal of toxic fluoride from water*

Major Facilities

- *Flame spray pyrolysis equipment*
- *RF Induction plasma unit*
- *Zoz Simolyer High energy mill*
- *Inert gas Atomizer*
- *Induction melting furnace*
- *Nanospider for nanofiber production*
- *Cryo mill*
- *Spray dryer*
- *Spark plasma sintering*
- *Supercritical drying unit*
- *Progressive Reactive Hot Press*
- *Battery testing unit*
- *Various types of presses and furnaces*

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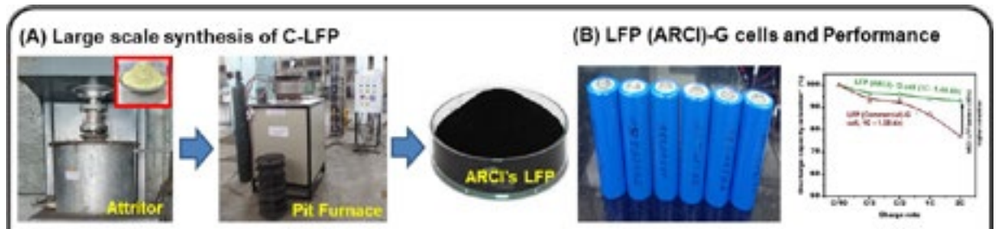
Technology Development / Transfer

Development and demonstration of large scale production of Lithium Iron Phosphate

Indigenous electrode materials technology and associated components that are essential for the manufacturing of Li-ion batteries within the country is need of the hour. ARCI has developed an innovative and low-cost attrition milling process for the synthesis of in-situ carbon modified LFP cathode for Lithium-ion batteries. In continuation with the effort to synthesize large quantities, 10 Kg C-LFP/batch has been successfully carried out in collaboration with an Indian Powder Manufacturing industrial organization (Fig.1A). The electrochemical performance of Li-ion device and coin cell derived from the large scale synthesized C-LFP exhibits capacity of 1.44Ah and 146 mAh/g at 1C current rate respectively (Fig.1B and 1C). An Indian patent is filed related to this invention. Efforts are on to improve the capacity of LFP based cell by reducing the carbon content and by increasing the tap density of synthesized C-LFP material.



(C) Benchmark

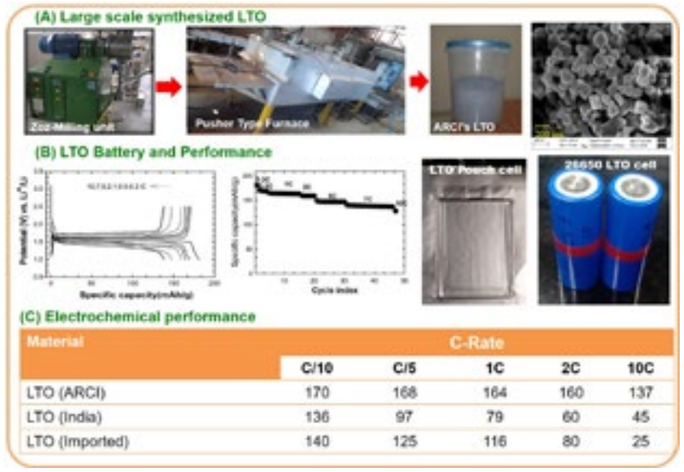
Powder Material	C-Rate				
	C/10	C/5	1C	2C	5C
ARCI's LFP	158	151	146	140	134
Commercial LFP	150	149	140	127	102

Fig. 1 Large scale synthesis of LFP by high energy attrition milling (A), photographs of LFP (ARCI)-Graphite cells and the device performance (B), and benchmarking ARCI's LFP powder with commercial LFP powder (C)

Contributors: Srinivasan Anandan, R. Vijay and T. Narasinga Rao

Large scale demonstration of nano-sized Lithium titanium oxide (LTO) material for high power Li-ion battery application

ARCI developed a simple, economical, scalable and energy efficient process for the production of LTO anode material with performance on par with commercial LTO. Subsequently, LTO based 1.5Ah 26650 cylindrical cell as well as 0.45Ah pouch cell have been fabricated and demonstrated. Further, in line with the requirement of end user, heat treatment for large quantity of milled LTO powder was carried out in continuous pusher type furnace, which is having the capacity of producing 72 Kg/day of LTO, in collaboration with an Indian Company. The resulting LTO delivers superior rate capability of 137 mAh/g at 10C with long cyclic stability. Patents, which are filed in India and USA for this invention, are granted recently. Efforts are underway for possible technology transfer to a private company.



(C) Electrochemical performance

Material	C-Rate				
	C/10	C/5	1C	2C	10C
LTO (ARCI)	170	168	164	160	137
LTO (India)	136	97	79	60	45
LTO (Imported)	140	125	116	80	25

Fig. 2 Large scale synthesis of LTO (A) performance & photographs of LTO based 26650 & Pouch cell (B) and Benchmarking of ARCI's LTO with commercial LTO materials (C)

Contributors: Srinivasan Anandan, R. Vijay and T. Narasinga Rao

Petcoke-based high energy supercapacitor and its demonstration for EV Application (In collaboration with HPCL)

ARCI has developed graphene-like activated porous carbon by a low-cost chemical activation process using petroleum coke (petcoke), which is a great value addition for the waste disposed in large quantities in oil industry. Indigenous supercap device with the specifications of 1200 F, 2.7V and 1.2Wh has been fabricated successfully, using the petcoke derived carbon. Electrochemical testing reveals that the performance of indigenous supercapacitor device is on par with the performance of commercial device (1200F). 16 numbers of 1200F indigenous supercapacitors were connected in serial to assemble the module with specifications of 75F, 43V, 19.2 Wh for E-Bicycle demonstration. A module, made from petcoke derived supercapacitor devices, has been demonstrated successfully for E-bicycle with the driving range of 1-2 km.

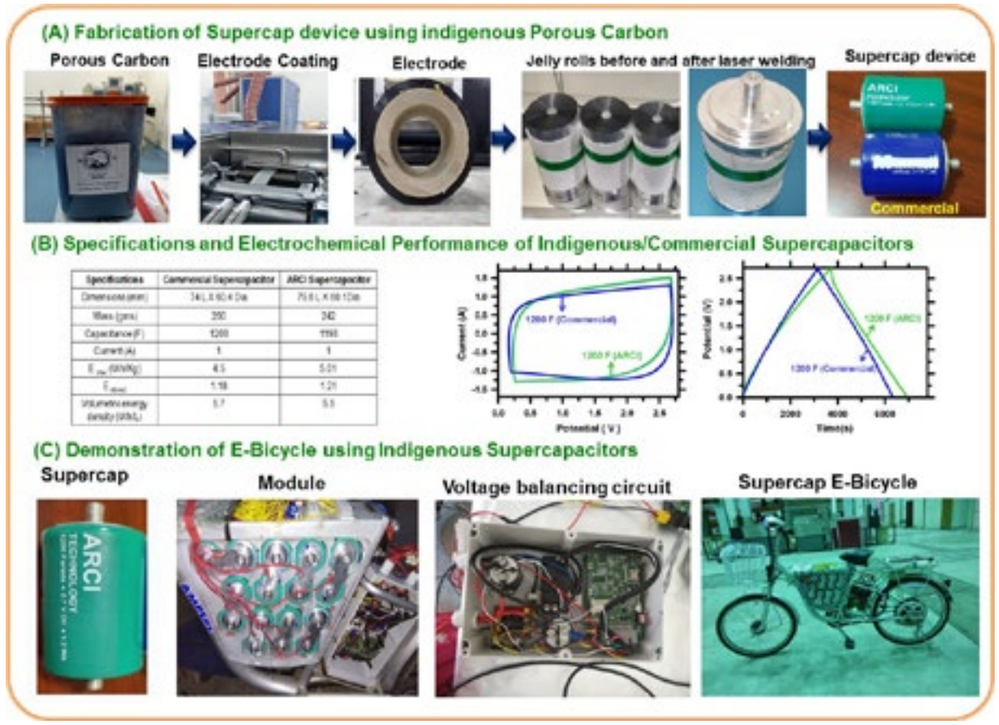


Fig. 3 Fabrication of 1200F supercapacitor using indigenous petcoke derived carbon (A), Specifications & Performance of 1200F supercapacitor (B), Assembly of module and Demonstration of E-Bicycle (C)

Contributors: Srinivasan Anandan, Katchala Nanaji, Pavan Srinivas, Ramakrishna Sahoo, R. Vijay and T. Narasinga Rao

Dispersion strengthened tungsten plates by novel powder metallurgy process

Tungsten is one of the most promising materials for use as plasma facing components due to its high melting temperature, high hot strength and hardness. Fabrication of dispersion strengthened high-dense tungsten composites was carried out using a novel powder metallurgy (PM) process involving milling-reduction-sintering. Commercial tungsten components fabricated by hot-rolling process yield anisotropic properties in the components leading to their failure. The devised PM process yields samples with homogeneous properties throughout, thereby overcoming the technical drawbacks of the commercial process. The tungsten components, fabricated by this process, exhibit fine uniform grain size of ~2.5 µm and high density (~99% of theoretical) along with hardness ≥ 500 MPa and fracture strength ≥ 1000 MPa. Possessing these room temperature properties qualifies the material for the actual applications at high temperature.

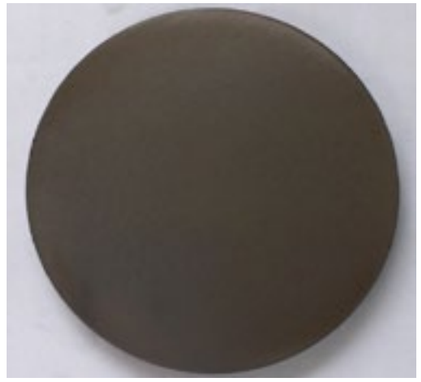


Fig. 4 High-strength, high-dense tungsten based plates of 100 mm diameter

Contributors: P. V. V. Srinivas, Dibyendu Chakraborty and R. Vijay

Indigenous transparent photo sensor technology for automation and energy conservation

A photosensor shows a response to the desired light photons (UV/Visible/IR) and transduces the electrical signal to a readable output parameter, which further activates a control device. By designing the chemistry, and by engineering the nanostructured opto-electronic thin films, a photosensor has been developed. A simple cost effective spray pyrolysis deposition (SPD) process using an indigenously sourced spray pyrolysis has been employed for obtaining the desirable nanostructures. This indigenous visible light sensor developed has the maximum sensitivity at 500nm, yields a quick response with high sensitivity. The photo sensor has been integrated to form a module that has necessary electronic controls and is depicted in Figure 5. The module has been successfully demonstrated for automatic light switching with quick response with high sensitivity. The performance of the module for continuous use and its durability are being field tested for automatic switching on and off of the street lights in ARCI depending upon the daylight conditions. The technology transfer has been initiated with a startup company based in Hyderabad.

Fig.5 Device photograph of "circuit integrated photo-sensor" fully made in ARCI; Field trial carried out for ARCI fabricated solar light switching sensor in ARCI

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

UVC disinfection technologies for combating COVID-19

The outbreak of the novel coronavirus, known as COVID-19, has caused a pandemic, causing worldwide concern. SARS-CoV-2 virus is enveloped by a fragile outer lipid envelope, making it more susceptible to disinfectants compared to non-enveloped viruses. Ultra Violet C (UVC) radiation is very well known to inactivate most of the microorganisms. Thus UVC disinfection technologies can play a major role in reducing the transmission of the virus causing COVID-19 based on existing disinfection data. Three types of UVC based Disinfection equipment are developed in collaboration with industry. A UVC disinfection trolley is developed in collaboration with the University of Hyderabad and the MEKINS Industries Limited (MIL), Hyderabad to fight against COVID-19 by a simple physical process where rapid cleaning is possible within few minutes especially in hospital settings avoiding the use of harsh chemicals. A UVC-based Cabinet (With MEKINS) for disinfecting non-critical hospital items, laboratory wear and PPEs in the research laboratories to prevent surface contamination of COVID 19. An advanced baggage disinfecting system (Kritiscan UV system) is co-developed with Vehant Technologies using a specially designed motorized conveyor to guide the baggage into the disinfection tunnel, which uses UVC light (254 nm) with appropriate irradiance to inactivate microbes & viruses in few seconds during the passage of the baggage through the tunnel.

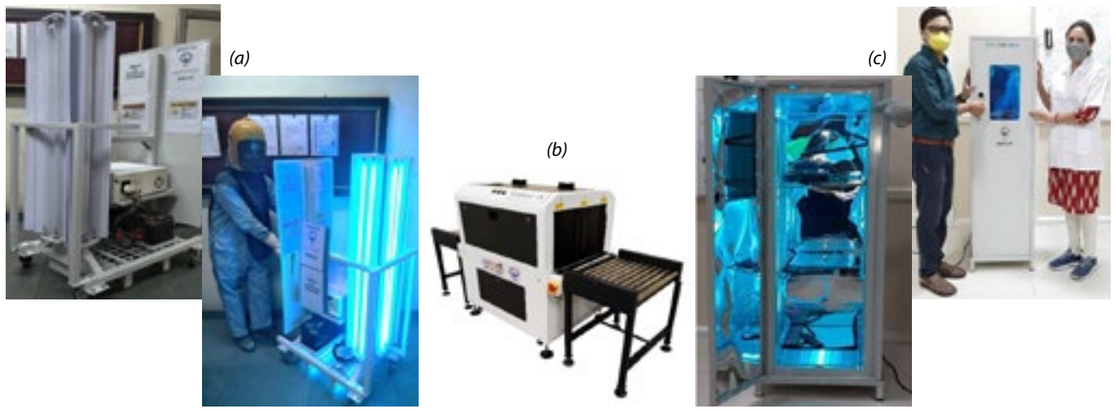


Fig. 6 Photographs of (a) UVC trolley (b) baggage disinfection tunnel and (c) UVC Cabinet

Contributors: B. V. Sarada and T. Narasinga Rao

Self-disinfecting nano-coatings on fabric for face masks for combating COVID-19

Masks are playing a major role as personal protective equipment needed to fight against the COVID-19 pandemic. Ag-Cu/CuO nanoparticles have been coated on fabrics by two different processes including nano-suspension coatings using nanopowders synthesized by FSP and electroless coating process. Very uniform coatings have been achieved on the fabric by both processes (Figure 7 (b)). The nanoparticles coated fabrics are tested for their antibacterial efficacy using ASTM E2315 (99.7% disinfection of bacteria in 30 seconds) as shown in Figure 7 (c) and anti-viral (SARS CoV-2) tested at CCMB, Hyderabad. The nanoparticles coated fabrics are found to exhibit anti-bacterial properties even after 30 washes. Prototype masks are prepared for demonstration as shown in figure 7(a).

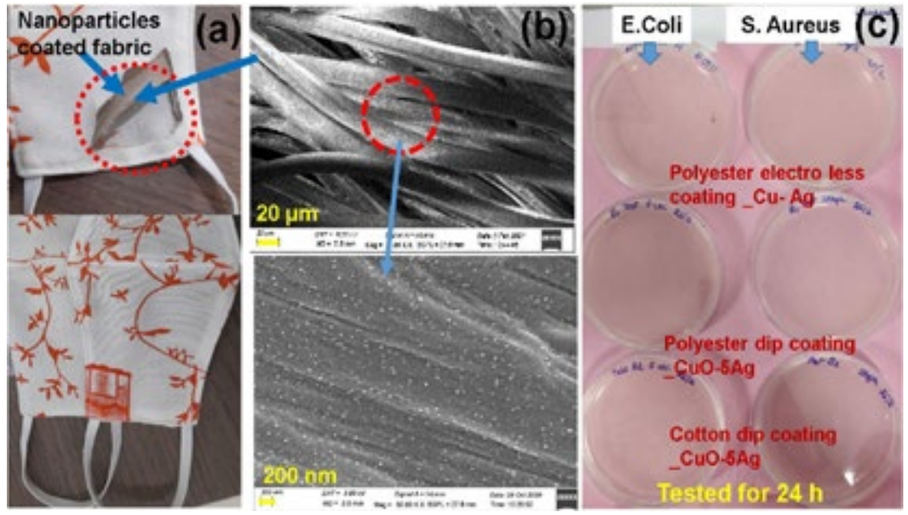


Fig. 7 (a) Prototype masks showing nanoparticle coated fabric, (b) Typical FESEM images of nanoparticle coated fabrics and (c) Antibacterial testing of nanoparticle coated fabrics using ASTM E2315

Contributors: Kaliyan Hembram, N. Sneha, B. V. Sarada and T. Narasinga Rao

Development of ODS Fe_3Al for turbine blades

Iron aluminide (Fe_3Al) has been attracting attention due to its high strength, low density, and good oxidation resistance coupled with low cost. However, Fe_3Al suffers from both insufficient strength and ductility at room temperature as well as high temperatures. ARCI is making efforts to improve these properties of Fe_3Al by alloying with Cr and Ti, and by introducing nano oxide dispersoids. The pre-alloyed atomised powder was milled with nano yttria and hot extruded. 3D reconstruction of ODS Fe_3Al APT data with concentration profiles of fine (Y-Ti-O) and coarse (Y-Ti-Al-O) dispersoids is shown in Fig. 8(a). At RT the yield strength is 1100 MPa with improved ductility of 16%. The tensile properties from RT to 700°C are compared with commercial high temperature alloys, Fig. 8(b). Lightweight with an excellent combination of strength and ductility of ODS Fe_3Al is an encouragement to produce gas turbine blades.

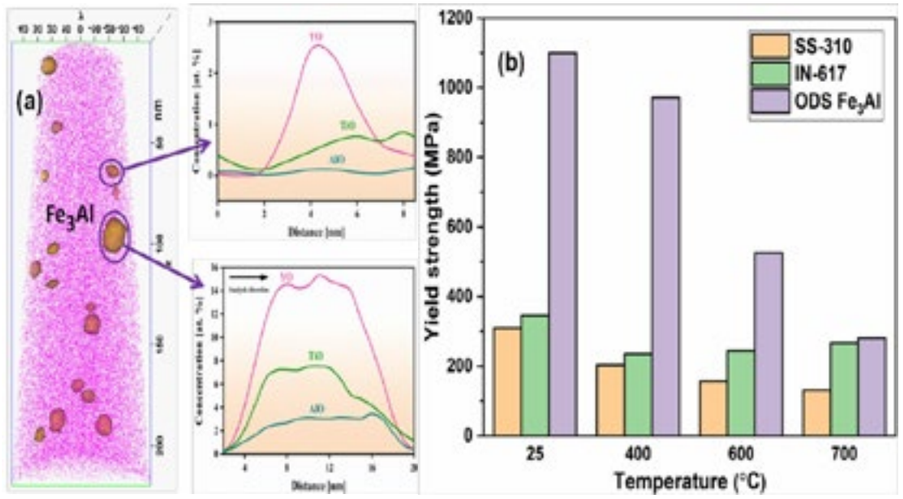


Fig. 8 ODS Fe_3Al (a) 3D reconstruction of APT data with concentration profiles of nano dispersoids, (b) Tensile properties comparison with IN-617 and SS-310 at various temperatures.

Contributors: P. Vijaya Durga, M. Nagini and R. Vijay

Research Highlights

Synthesis of pyrotechnic grade zirconium powder through hydride-dehydride method

Pyrotechnic grade zirconium powder is extensively used in making thermal batteries. ARCI has developed a synthesis of the same using hydride-dehydride (HDH) technique from the sponge. Fig. 1 shows the original zirconium sponge and the zirconium powder made from it.. HDH method offers main benefits such as simple procedure, low cost, and good controllability. A typical HDH process consists of three steps: hydrogenation, milling and dehydrogenation. A batch of 250g of powder is hydrided and milled depending upon the required particle size and distribution. This zirconium hydride powder is subsequently dehydrided under vacuum to obtain the pyrotechnic grade zirconium powder.

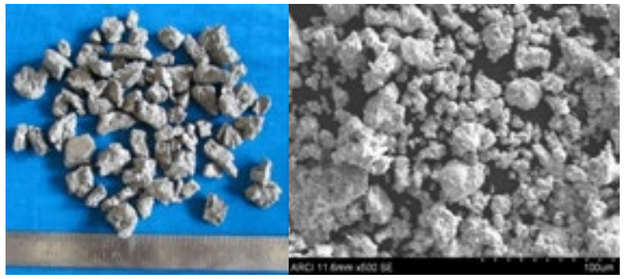


Fig. 1(a) Zirconium sponge and (b) pyrotechnic grade zirconium powder

Contributors: P. V. V. Srinivas and R. Vijay

Iron based core-shell composites for DC-AC electromagnetic applications

Mn-Zn-Ferrite core-shell based PM-soft magnetic composites for futuristic-magnetic applications were developed using reduced-Fe powder supplied by Tata Steel Ltd. (TSL) under the aegis of a sponsored collaborative research agreement of ARCI-TSL funded by TSL. Chemical-precursor based solution-technique was used to form Fe-$Mn_{0.5}Zn_{0.5}Fe_2O_4$ (Fe-MZF) powder followed by subsequent hot-consolidation/annealing to form Fe-MZF toroid-composites. Magnetic induction (B) under direct-current (DC) was found to be 1.5T@10kG, permeability-1400 and electrical-resistivity (ρ) 40 whereas at 50 Hz, the values were 1.3T, 940 and 125 respectively with core-loss 50W/kg @50Hz. Evaluated-results proved better than target-properties of ARCI-TSL with scope for BLDC motors and rotors-stators upto 1kHz application.

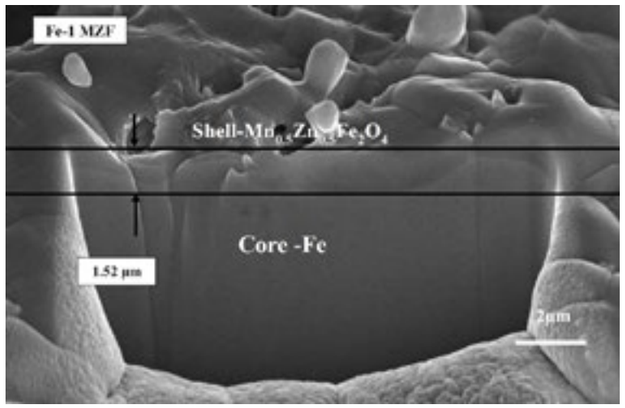


Fig. 2 Typical FESEM micrograph of Fe-MZF core-shell powder cross-section using focussed ion beam (FIB) technique depicting core and shell thickness

Contributors: Malobika Karanjai, Pramod H Borse, P. V. V. Srinivas and Hiba Aizaj

Unique process for nanometeric gold film coatings on glass ceramic mirror segments for edge sensor in thirty meter telescope (TMT)

An ambitious project of India on building Thirty Meter Telescope (TMT) requires mirrors constituted by "edge sensors" to detect, align and stabilize multiple segments of this giant telescope. Highly adherent, uniform, nanometric, pure gold film coating on the whole of the cuboidal special glass block (>50-70mm), has been developed for edge sensor fabrication. Thousands of such edge sensors are required, and thus demand the development of a durable and scalable low temperature (<100°C) coating technique for resolving the challenge of gold film deposition for edge sensor fabrication. This challenging task was achieved by a scalable & cost effective hybrid chemical route and established the feasibility of the concept in the first phase of the sponsored project from the Indian Institute of Astrophysics. This nanometric gold film coating has successfully passed the prescribed qualification tests desirable for the application in the TMT project. Based on the encouraging results in the first phase, the various issues related to technology development and scalability will be addressed in the second phase of the project.

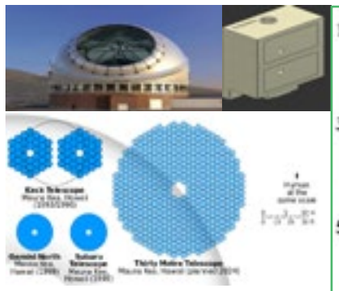


Fig. 3 TMT photograph, schematic of actual block (70x50x20mm); Schematic of 30 meter telescope made from thousands of small primary mirrors

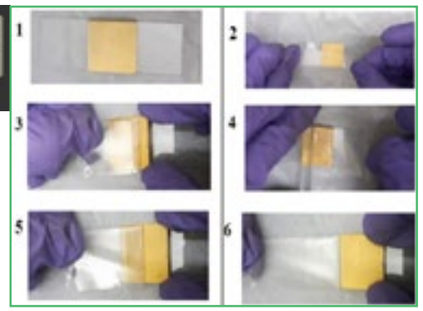


Fig. 4 Nanometric thick gold film on TMT coupon (25x25mm), passing the adhesion test from 1-6

Contributors: Pramod H. Borse, Sanjay R. Dhage, Ravi Bathe and Roy Johnson (Sensor Development Group)

Development of petroleum coke derived carbon for Lithium-ion capacitors with high energy and high power density

Though Lithium-ion capacitors (LICs) with high energy and high power are considered attractive, the design and fabrication of suitable electrode materials by a facile approach using cost-effective precursors is still a great challenge. Petroleum coke, an unavoidable industrial waste with high carbon content is utilized as a single carbon source to synthesize both high surface area activated carbon cathode and low surface area disordered carbon anode. LIC fabricated using all petroleum coke derived carbon materials exhibits a energy density of 80 Wh/kg, and a power density of 8.4 kW/kg with long cyclic stability, demonstrating that the facile approach adopted to synthesize both cathode and an anode material from a single source is an effective way for high value-added utilization of petroleum coke at the commercial level.

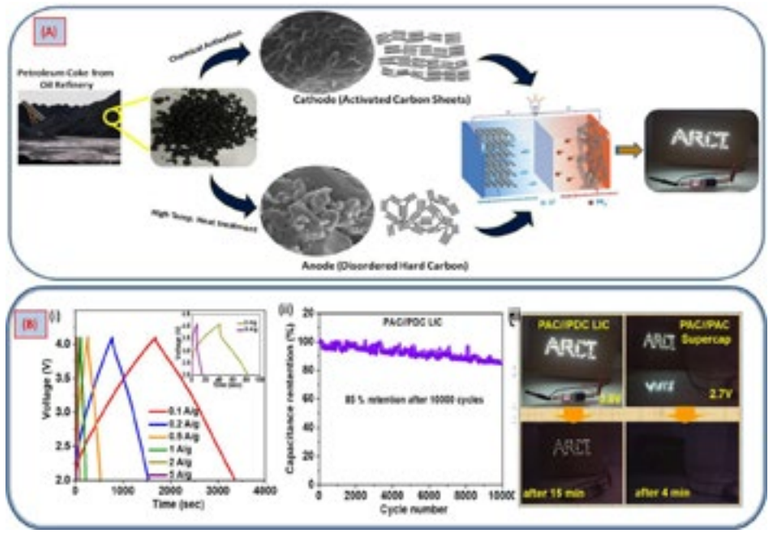


Fig. 5 (A) Schematic representation of fabrication of all Petroleum coke waste derived Li-ion capacitor, (B) Electrochemical properties of fabricated Li-ion Capacitor and its demonstration for practical usage

Contributors: Katchala Nanaji, Pavan Srinivas, Srinivasan Anandan and T. Narasinga Rao

Development of high rate cathode for Na-ion battery by Mg^{2+} doping in P2-$Na_{0.6.7}(Ni_{0.33}$-$XMn_{0.67}MgX)O_2$

Amongst various cathode materials for Na-ion battery, prismatic-type (P2) layered cathode materials have been chosen for high voltage and low air sensitivity. Recently, P2-$Na_{0.6.7}(Ni_{0.33}$-$XMn_{0.67}Mg_X)O_2$ is developed using facile co-precipitation method followed by annealing which exhibited layered structure with excellent phase purity (Figure 6 A & B). Here, Mg^{2+} has been chosen as dopant to inhibit the P2-O2 transition in the upper voltage which is responsible for the structural collapse of the compound in the subsequent charge-discharge cycles. The as-prepared Mg-doped sample (Cathode) exhibited excellent rate of 91 mA h g^{-1} discharge capacity at C/9 (1 C = 80 mA g^{-1}) exhibiting nominal voltage 3.3 V (Figure 6 C & D). Further investigation is proceeding towards improvement of specific capacity and cyclic stability with suitable Mg^{2+} concentration.

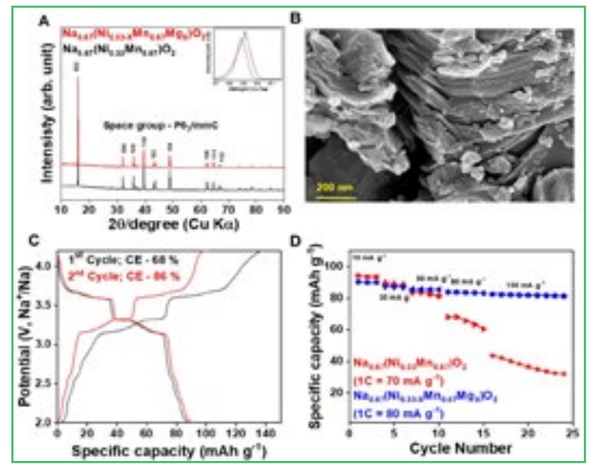


Fig. 6 (A) XRD spectra (B) FESEM image, (C) Charge-discharge curve at 10 mA g^{-1} and (D) Rate performance of P2-$Na_{0.6.7}(Ni_{0.33-X}Mn_{0.67}Mg_X)O_2$ (C rate has been calculated based on the discharge time.)

Contributors: Ramakrishna Sahoo and T. Narasinga Rao

"Point-of-use" toxic fluoride removal from water

To cater to the problem of fluoride endemic in India where more than 100 districts across the country are affected, ARCI is developing a filter for its "point-of use" fluoride removal from drinking water. Polymer cross-linked, highly nanoporous (surface area 500 m^2/g) alumina xerogel has been successfully developed which is capable of removing higher, toxic fluoride (10-20 ppm) from water to safe limits (≤ 1 ppm) in few seconds by adsorption method. Unlike other known methods, this material is being studied to use in such a way that there is minimal or no disposal, recycling or regeneration of the used material. Figure 7 shows the photograph of the alumina-polymer beads, its microstructure and the fluoride removal efficiency from the water.

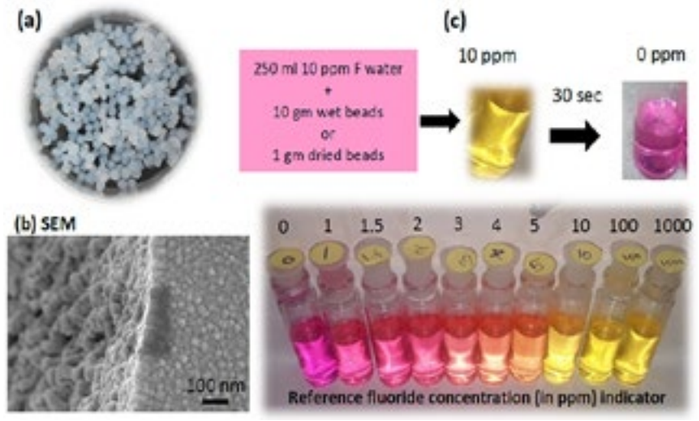


Fig. 7 (a) photograph of the alumina-polymer cross-linked beads, (b) the microstructure of the beads seen under scanning electron microscope (SEM), (c) efficiency of these beads to remove fluoride from water (below are the reference colour indicators for various fluoride concentrations in water)

Contributors: Neha Hebalkar and Shubham Sen

Next generation biodegradable Fe based alloy implants

The Fe-Mn based alloys with different compositions for biodegradable implants are being developed using a vacuum induction melting (VIM) furnace. A comparison of mechanical properties and degradation rate with commercial implant and alloys made by powder metallurgy is shown in Figure 8(a) and prototype dynamic screws in Figure 8(b). The alloys developed by VIM exhibited good mechanical properties (YS: 170 MPa, UTS: 550 MPa, E: 105 GPa and ε: 46 %) and very little magnetic susceptibility (1x $10^{-7}m^3kg^{-1}$). The mechanical properties are comparable to presently used permanent Ti and 316L metallic implants. The material showed a degradation rate in the range of 0.15± 0.02 mm/year in the simulated body fluid. These alloys are suitable for biodegradable stent and orthopedic implant applications. In vivo studies are being planned for the optimized samples. Efforts are also being made to achieve required corrosion rates and properties by alloying additions, surface engineering, and additive manufacturing.

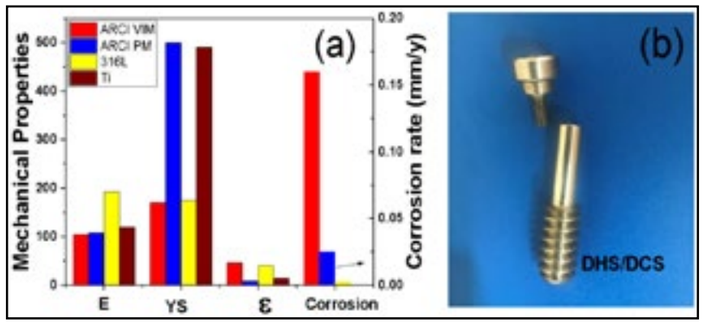


Fig. 8 (a) Comparison of mechanical and corrosion properties with commercial implants and (b) Prototype dynamic screws for orthopedic

Contributors: Kaliyan Hembram, Surya Prakash and R. Vijay

Dispersion of nano boron in hydrocarbon fuel

High-energy fuel is the requirement for more propulsion energy for volume-limited missiles and rockets. The energy content of the liquid missile fuels can be improved by adding energetic materials like boron particles into the liquid fuel to have a high volumetric heating value. The challenge in the addition of solid particles to liquid fuels is to maintain the stability of solid-liquid dispersion. The cryo-milled nano boron powder was made air-stable and dispersible in JP10 fuel by coating it with the ligand through a mechanical milling method. The ligand (Tri-octile phosphine oxide shortly called it as TOPO) coated nano boron powders with 1, 5, and 10 % concentrations have dispersion stability for a week and these dispersions of various loadings are shown in figure 9.

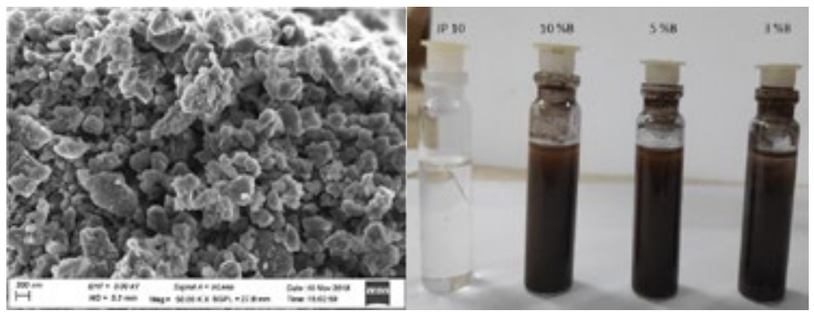


Fig. 9 (a) Cryo milled nano boron powder (b) 3 – 10 % Dispersions of nano boron particles in JP10 fuel

Contributors: S.Sudhakara Sarma, R.Vijay and T.N.Rao

Development of Cu-Ti powders through inert gas atomization

Copper-based bulk metallic glass (BMG) powders are required for the Naval Materials Research Laboratory (NMRL) for making erosion-corrosion resistance coatings on copper-based naval components. The ingots provided by NMRL were converted into spherical powders of particle size ranging from 20-60 µm with low oxygen (< 200 ppm) content using inert gas atomizer suitable for HVOF and cold spraying processes, Fig. 10(a). The ingots were melted under vacuum and atomized using high purity argon gas. This is followed by sieving / classification step to obtain the required particle size and distribution, Fig. 10(b).

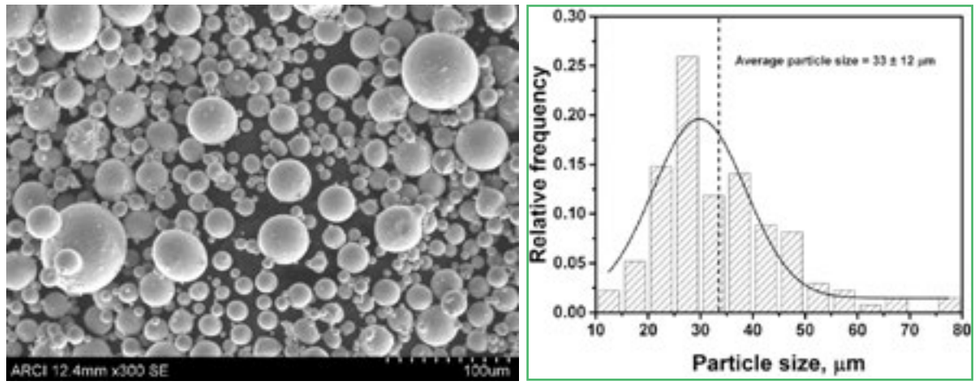


Fig. 10(a) SEM micrograph showing the Cu-Ti powder morphology and (b) particle size distribution

Contributors: S.B. Chandrasekhar, Sai Karthik and R. Vijay

In–built technology to produce 'ore-component' in indigenously developed progressive reactive hot press

Particulate materials (PM) processing in indigenously designed-developed Progressive Reactive Hot Press (PRHP) takes 'advantage' of the uniqueness of PM technology that produces high-quality products which the 'wrought-materials-technology' cannot cater-to in continuous-mode of hot-pressing of alloy/ composite powders of tailor-made powder-compositions. PRHP houses multiple PM components processed in component–shaped dies under reducing or inert atmosphere at maximum temperature/load of 1120 °C/10T/per piston. PRHP avoids duplication and addition of newer process-equipment like crushing-sizing-blending at multiple stages from ore to powder production as well as compaction-sintering/hot pressing-sizing/coining operations to obtain final PM-component. 80CuO-20 Ni processed in PRHP yield a homogenous component of Cu-Ni at 1050 C/60 MPa.

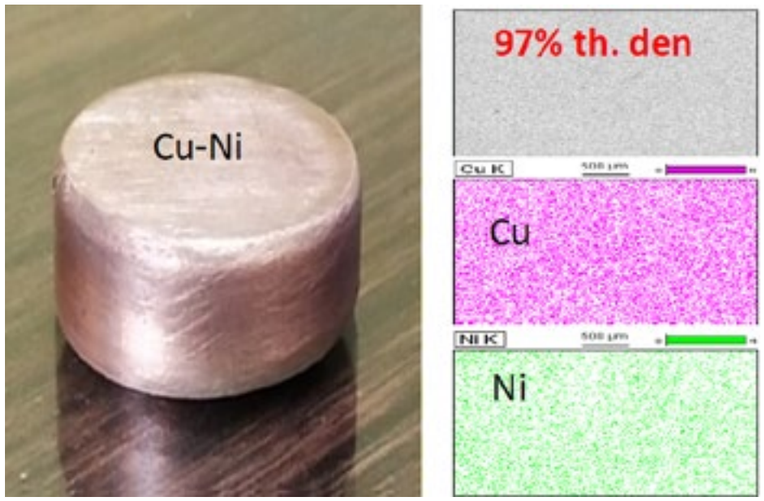


Fig. 11 Cu-Ni alloy compacts processed in PRHP under continuous mode of operation under protective hydrogen atmosphere

Contributors: Malobika Karanjai and A. Shiva Kumar

Centre for Engineered Coatings

The Centre for Engineered Coatings has been at the forefront in providing surface engineering solutions to the Indian industry, including transfer of multiple indigenous technologies and numerous application developments over the years. The recent contributions include, new coating technology development and coating solutions for a wide range of industries. In addition to application oriented R&D activities, the centre has also made significant contributions to fundamental understanding of coating deposition mechanisms. Furthermore, the centre has sustained the healthy track record of externally funded projects and has also established new state-of-the art coating facilities.

Technological accomplishments

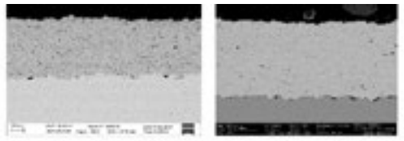
- *New Advanced Detonation Spray Coating (DSC) system has been fully developed including endurance testing and is being demonstrated to potential technology receivers.*
- *A fully automated advanced cold spray coating system including a portable version for onsite repair/refurbishment has been developed and is ready for transfer. The salient features include, air as a process gas which is highly economical, a clog free nozzle and a recipe based parameter selection for high throughput. The patent for the same has also been granted.*
- *The technology know-how for high temperature compliant glass ceramic sealants has been successfully demonstrated in the case of SiC-SS-SiO_2 for typical high temperature applications and transferred.*
- *A environmentally friendly Pulsed Electro Deposition technique for depositing various types of wear resistant coatings in automotive, textile, manufacturing sectors has been developed. This technology is considered as an alternative to the hazardous hard chrome plating and has a patent.*

Novel coatings and applications

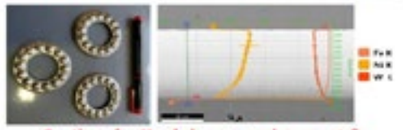
- *Development of functional DSC coatings using in-house synthesized powders and Co based alloy*
- *Development of abrasive wear resistant coatings for agricultural waste briquetting machine components to enhance the viability of green energy*
- *Successfully development and demonstration of copper coatings on building materials for anti-bacterial and anti-viral applications*
- *Development of superconductive Nb coatings using cold spray*
- *Development of wear resistant coatings for electromagnetic rail guns*
- *Development of hard chrome replacement Ni based alloy coating for wear resistance applications using pulsed current electrodeposition*

New facilities

- *A state-of-the-art Axial plasma spray coating and High velocity hybrid fuel (Air/Oxygen) thermal spray facility for depositing novel coatings with increased productivity, efficiency and performance has been established.*
- *A high temperature hot corrosion test rig was set up along with other performance evaluation rigs such as high temperature erosion, high temperature erosion-corrosion.*
- *A universal tribometer for evaluation of the tribological performance of the coatings under various modes and environments.*
- *A lab scale High Power Impulse Magnetron Sputtering (HiPIMS) facility has been established to widen application spectra and to address future demands in thin film deposition*


FeAl and Co coatings deposited at 6 Hz using ADSC


Coatings for abrasive wear resistance by CAPVD


Coatings for Hard chrome replacement & composition profile in Ni-W coatings


Ceramic sleeves and SIC-SS-SiO_2 joint

Coating and characterization facilities

- *Detonation spray*
- *Micro arc oxidation*
- *Plasma spray (APS,APPS,SPPS)*
- *HVAF, HVOF*
- *Cold spray*
- *Pulsed electrodepositon*
- *Cathodic Arc Physical Vapour Deposition*
- *Electron beam physical vapour deposition*
- *Nanoindentation*
- *Scratch testing*
- *Micro Tensile testing*
- *Tribometers*
- *Thermal cycling*
- *3D optical microscope*
- *Bending Fatigue*
- *Electrical conductivity meter*
- *Modelling & Simulation*
- *Mechanical profilometer*
- *Vacuum heat treatment*
- *Bond strength*
- *Calo tester*

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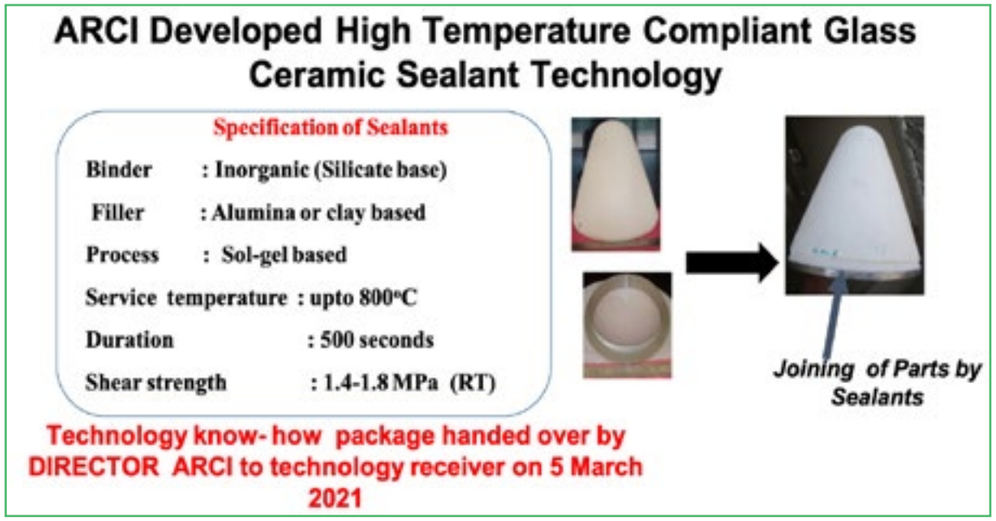
Technology Development / Transfer

Technology transfer and demonstration of high temperature compliant glass ceramic sealants

The high temperature compliant glass ceramic sealants technology has been actively pursued by ARCI. In this regard, sealing procedure and evaluation of properties have been successfully demonstrated. The synthesized in-organic binder's physical and chemical properties have accepted batch consistency. The specified room temperature shear bond strength of the joint of 1.5 MPa has been demonstrated. The acceptance criteria of the high temperature ceramic sealants for the intended application have also been confirmed by NDT and simulated tests. The salient feature of the seal is room temperature curability and has many applications in refractive and automotive industries. The process know-how documents describing the Standard Operating Parameters (SOP) for synthesizing the sealants through wet chemical processing are being handed over to the technology receiver.



Contributors: K. Murugan, Roy Johnson and B. Subramanyeswara Rao

Advanced Setonation Spray Coating (ADSC) system

An automated Advanced Detonation Spray Coating (ADSC) system with PLC controllers and various valves has been fabricated and tested. The new system is built with user-friendly programing and better control over gas flow during the coating deposition with all safety interlocks. The upgraded version can run for longer duration at higher frequencies than the previous version. Several coatings were deposited including oxides, cermets, alloys, intermetallics, etc., at higher frequencies, and the coating performance was found to be better or equal to the earlier system. The new system has been demonstrated to potential technology receivers. The technology is available for transfer to Indian industry.

Advanced DSC system in operation

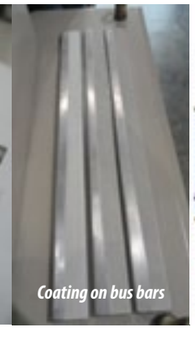
Contributors: D Srinivasa Rao, P Suresh Babu, D Sen, S Nirmala, J N Chary and N. Aruna

Development of cold spray technology and transfer related activities

Over the past decade, considerable efforts have been devoted to not only indigenize the cold spray technology but also to widen the material and application spectrum. This led to major improvements on the equipment front especially the nozzle design including the nozzle materials. Today, ARCI offers a wide material spectrum with properties comparable to expensive high pressure systems being sold globally. Significantly, our uniqueness is the use of air as the process gas and the associated operational cost savings owing to the developments on nozzle front. Patent for this technology has been granted in Russia and is awaiting for grant in India, Canada and China. Over the past decade, ARCI has made several strides and contributed significantly to the science and technology of cold spray including modelling and simulation for which it is acknowledged globally. Patents, highly cited publications in peer reviewed journals, collaboration with public and private partners for application development and significant revenue generation bear testimony to this fact.

ARCI CS capability map

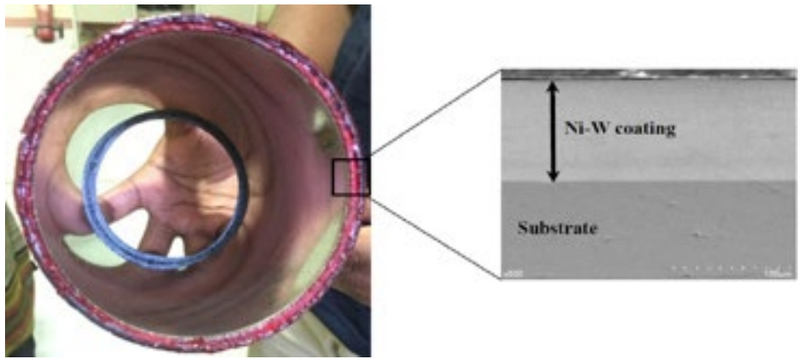

Repair work for boeing


Coating on bus bars

Contributors: Naveen Manhar Chavan, S Kumar and D. Srinivasa Rao

Industrial implementation of nanostructured Ni-W alloy as an alternative to hard chrome coatings

Across the world, the business of electroplating is worth 15 billion USD. In auto industry especially in cars, trucks, planes and bridges, several components are coated using chromium plating. In order to decrease the effluent pollution in chrome plating, particularly carcinogenic hexavalent chromium, several new processes have been explored across the world. In this regard, using the pulsed electrodeposition technique at ARCI, our research team has developed a process to deposit crack free nickel tungsten (Ni-W) alloy coatings (Figure) with high hardness, wear resistance and excellent corrosion resistance in as deposited state itself using an environmental friendly electrolyte. Unique combination of pulsed current enables crack free Ni-W coatings with less adsorbed hydrogen and impurities which is otherwise difficult using conventional electroplating techniques. The comparative properties of these coatings are presented in Table 1. The process know-how has already been transferred to a company in the electroplating domain.



Automobile engine cylinder coated (inside) with Ni-W alloy

Table 1. Comparison of Ni-W and hard chrome plated coatings

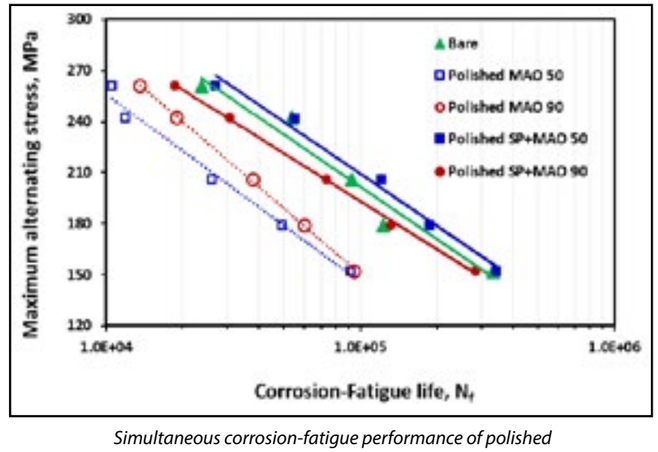
	Ni-W alloy	***Hard chrome***
Process	*Pulsed electroplating*	*Direct current electroplating*
Hardness (VHN)	*700-800 as deposited 1100-1200 heat treated @ 500°C*	*600-1100 as deposited 300-400 heat treated*
Deposition rate (μm/hr)	*35-50*	*15-20*
Wear rate (mm^3/m) $\times 10^{-5}$ @ 0.5 MPa	*2*	*5.5*
Coefficient of friction	*0.4-0.5*	*0.6*
Salt spray corrosion resistance (ASTM B117)	*Rating 9 up to 700 hrs*	*Rating 2 above 48 hrs*

Contributors: Nitin P. Wasekar and D. Srinivasa Rao

Research Highlights

Enhancing the corrosion-fatigue life of micro arc oxidation coated 6061-T6 Al alloy

Towards enhancing the life of aerospace Al alloys under plain-fatigue (PF) and corrosion-fatigue (CF) environments, a duplex treatment i.e., shot peening followed by Micro Arc Oxidation (MAO) MAO coating (SP+MAO) as proposed by ARCI in their earlier investigations is found to be effective. However, the corrosion-fatigue life of MAO coated Al alloy depends on the coating thickness and surface roughness. While functioning under multiple damaging modes, the suitable coating thickness and roughness levels have to be identified in such a way that the coated Al alloy not only exhibits higher CF life but also possess superior corrosion and wear resistances than the bare substrate. By resorting to post-polishing process, thicker MAO coatings were able to demonstrate the higher CF life (Fig. 1), which wasn't achieved in as coated condition in previous investigations. The electrochemical corrosion response studies through Electrochemical Impedance Spectroscopy (EIS) and Potentiodynamic Polarisation (PDP) have revealed the superior corrosion resistance of polished MAO coatings over bare substrate.

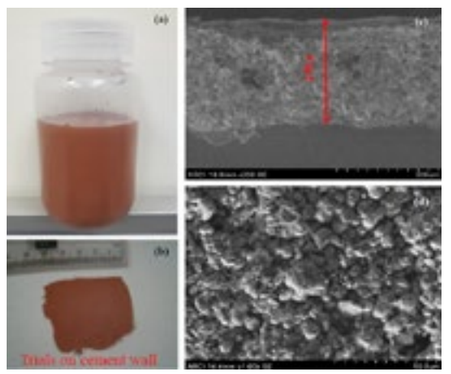


Simultaneous corrosion-fatigue performance of polished MAO coatings evaluated in 3.5 wt.% NaCl solution

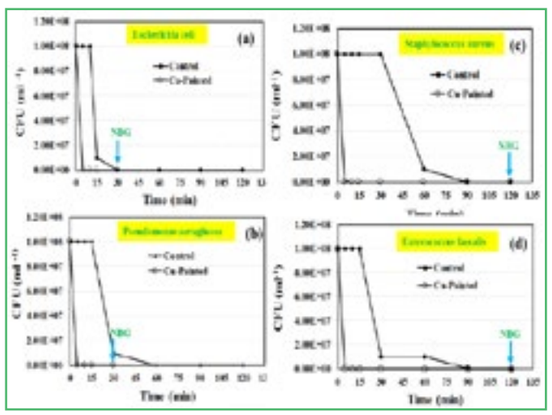
Contributors: L. Rama Krishna, Y. Madhavi and A. Jyothirmayi

Development of mineral copper paint for anti-bacterial and anti-viral applications

In the view of pandemic situation due to COVID-19, International Advanced Research Center for Powder Metallurgy and New Materials (ARCI), Hyderabad and Innomet Advanced Materials Pvt. Ltd. (IAMPL), Hyderabad collaborated to develop a self-disinfecting copper based mineral paint for hospitals to fight against COVID-19. ARCI developed a unique process to formulate a copper paint for cemented wall surface and evaluated anti-bacterial properties on gram positive and negative bacteria. The anti-viral test on the painted surface are under progress. Figure below shows the developmental activities of the copper paint. Anti-bacterial activity of gram-negative bacteria such as Escherichia coli, Pseudomonas aeruginosa and gram-positive bacteria like Staphylococcus aureus, Enterococcus faecalis was measured and the results are very encouraging. Figure shows anti-microbial activity on the above bacteria. It is interesting to note that the activity of the gram-negative bacteria rapidly comes down to less than 10 colony forming unit (CFU) per ml from the initial count of 1x108 CFU in less than 15 min exposure time. In the case of gram-positive bacteria, a reduction of less than 10 CFU was observed within 60 min exposure time. It has been noted that inactivation of gram-positive bacteria is challenging in actual practice. Further, the developed copper surface also shows no bacterial growth (NGB) after overnight aerobic incubation as seen from the data shown in the plot at 30 and 120 min exposure of gram-negative and gram-positive bacteria, respectively.



Developmental activity of copper paint. a) Inorganic copper paint formulation, b) painted on wall, c) SEM cross section analysis of the paint, d) SEM surface morphology of the paint

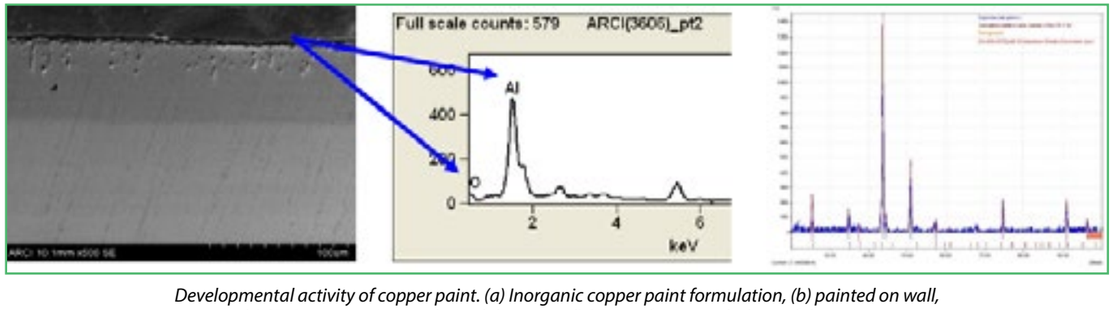


Anti-microbial activity of gram negative and positive bacteria

Contributors: K. Murugan and T. Narasinga Rao

Development of TGO layer EBPVD coating bond coat interface using NiCoCrAlY ingot through vacuum heat treatment

Vacuum annealing treatment has been carried out on EBPVD NiCoCrAlY bond coated test coupon by purging oxygen at optimum flow rate resulting in formation of thin layer (less than 1 micron) of α-Al_2O_3 oxide as observed by glazing incident angle XRD studies (Figure). Pre-grown Thermally Grown Oxide (TGO) is known to improve durability of Thermal Barrier Coating (TBC). The current method produces a two fold increase in TBC cyclic life and is effective in postponing the two major types of the oxidation-induced failure typical of TBC system with NiCoCrAlY bond coats: the gradual growth of TGO, and spontaneous failure by spallation. The stable alpha alumina scale formed on the bond coat surface prior to TBC deposition is less susceptible to separation along the TBC-TGO interface and also exhibits a lower growth rate in comparison with the TGO that develops on a similar bond coat without pre oxidation.

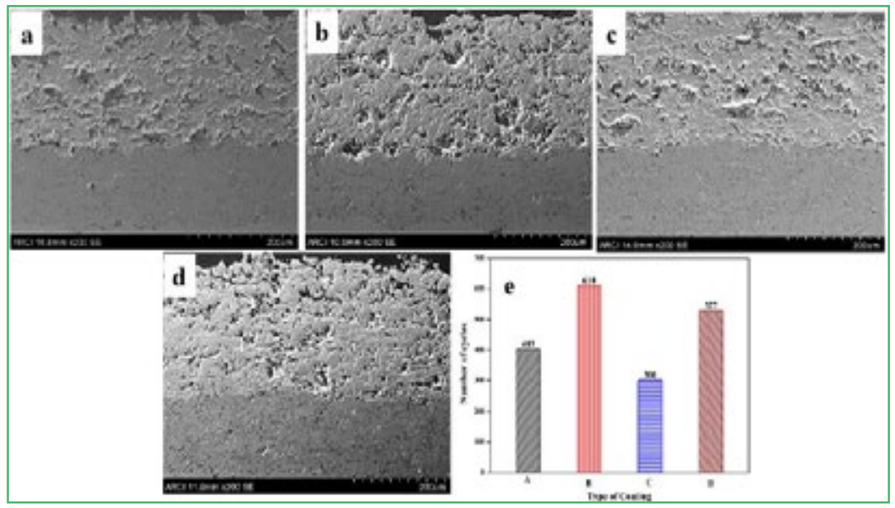


Developmental activity of copper paint. (a) Inorganic copper paint formulation, (b) painted on wall, (c) SEM cross section analysis of the paint, d) SEM surface morphology of the paint

Contributors: D Sen and D Srinivasa Rao

Role of bond coats on thermal cyclic life of Axial plasma sprayed YSZ TBCs

Plasma sprayed thermal barrier coatings (TBC) are widely used to protect gas turbine components which operate at elevated temperature and harsh environments. Spallation resistance under thermal cycling is an important indicator for qualifying the TBCs which is inherently influenced by many factors such as the top/ bond coat chemistry, coating microstructure / architecture, etc. Yttria stabilized zirconia (YSZ), the material of choice for TBCs was deposited over different bond coat materials (NiCoCrAlY, NiCoCrAlHfYSi, CoNiCrAlY, NiCoCrAlTaY) with varying functional characteristics through axial plasma spray technique. The different bond coat materials differ in terms of chemistry, but necessarily need to be dense for above applications. As shown in Figure, the bond coats were optimized to yield dense microstructure, whereas the top YSZ layer was specifically designed to form porous microstructural features over the superalloy substrates. Upon thermal cycling upto 1100°C, coatings with MCrAlY bond coats tailored with Hf-Si and Ta elements exhibited almost double cyclic life than other bond coats. The addition of such elements increases the operational temperature capability which minimizes the bond coat oxidation and thereby, reducing the thermal stresses at the interface.

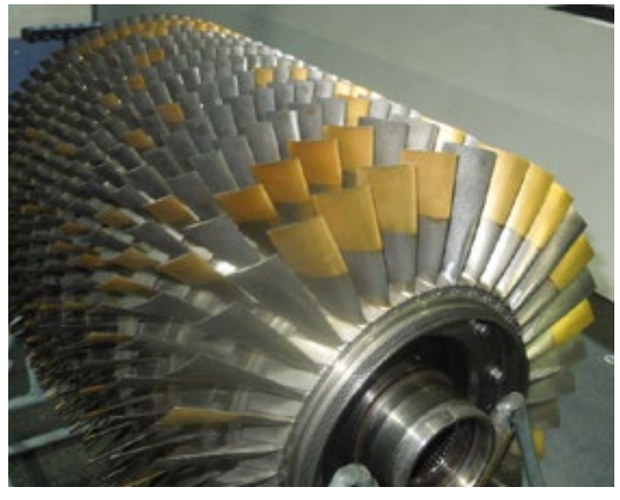


(a-d) Cross-sectional microstructure of axial plasma sprayed TBCs with diverse bond coats and (e) its thermal cyclic performance

Contributors: G. Sivakumar and K. Praveen

Technical solutions provided & highlights of ongoing programmes using PVD techniques at CEC

The Centre for Engineered Coatings (CEC) at ARCI, Hyderabad has several state of the art Physical Vapor Deposition facilities like; Cathodic Arc (CAPVD), Electron Beam Evaporation (EBPVD) and High Power Impulse Magnetron Sputtering (HiPIMS). In the last few years using the available PVD techniques, several applications were addressed by providing technical solutions and final component demonstration at the industrial scale. To highlight a few, technical solutions have been provided to Govt. of India MINT, Hyderabad and Solar Thermal Sector.



ARCI, Hyderabad developed erosion resistant coatings on compressor blades

TiN based erosion resistant coatings for compressor blades were developed and demonstrated for their real time performance and have been granted final acceptance. Similarly, TiCrN based abrasive wear resistant coatings were developed and demonstrated for the life enhancement of minting dies. The PVD coating developed by ARCI was found to enhance die life by 250% with good flowability of the minted coin. In case of renewable energy sector, for the specific case of solar thermal application, ARCI has developed PVD based high temperature & open air stable solar selective coatings and demonstrated them on 1 m length receiver tube (without any vacuum sealing). The coatings were found to be stable for 25 years at an operational temperature of 410°C.

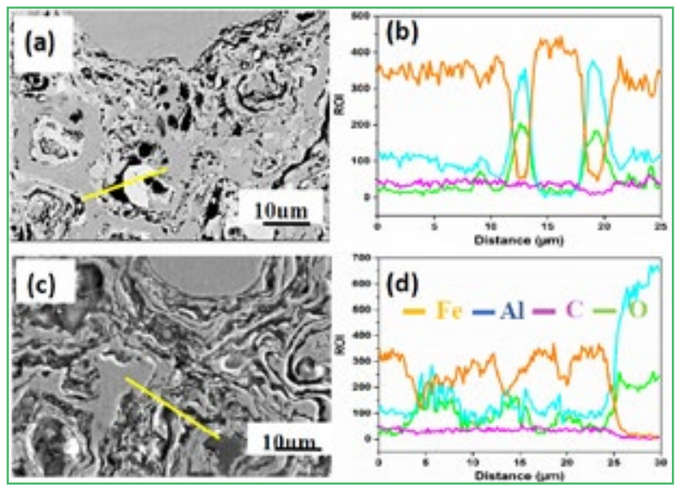
Further, in addition to the above-developed technical solutions, ARCI is also now trying to address issues related to Indian agricultural sector by developing abrasive wear resistant coatings for paddy straw briquetting machine components and other tillage tools. Similarly, a programme to develop hard and wear resistant coatings for machining tools used in machining of super alloys is also in active progress.

In addition to utilization of commercially available equipment, CEC at ARCI is also known for development of in-house industrial scale equipment to address state-of-the-art surface engineering demands. In this direction, ARCI has recently initiated the establishment of High Power Impulse Magnetron Sputtering (HiPIMS) facility and has successfully built a lab scale equipment. The established facility is now ready for depositing any metal oxide or nitride coatings. As on date, the development of coatings related to the plasma facing components are in progress. In the near future, an industrial scale facility will be established and interested users are welcome to approach us regarding the potential applications.

Contributors: Krishna Valleti, Nitin Tandekar and Pooja Miryalkar

Influence of localized compositional variation on the corrosion behavior of detonation sprayed FeAl(Cr) coatings in artifical sea water

Iron Aluminides (FeAl) have gained siginficatnt interest in the recent past to combact wear and corrosion. In this regard, FeAl in coating form is an economical option. In-house synthesized gas atomized FeAl(Cr) powder was deposited on mild steel using deotnation spray system. A dense coating with locallized compositonal variation was noticed due to the exposure of the powder to the combustion flame as illustrated by the bright and grey regions (composite structure) in the coating shown in



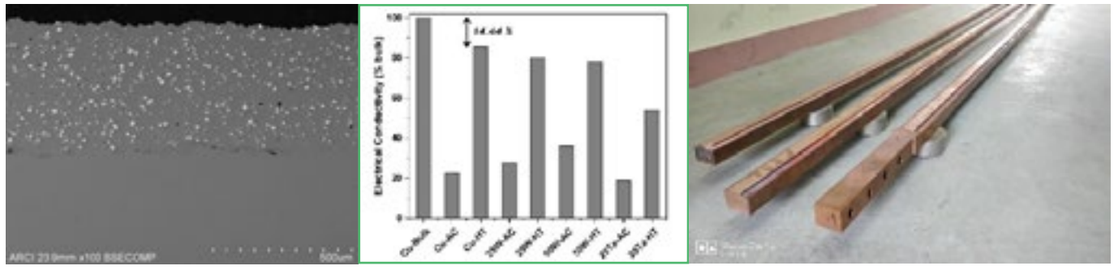
BS SEM images of detonation sprayed FeAl(Cr) coating (a) before and (c) after exposure to NaCl with EDS line scans (d and d)

Fig. (a–b). Such locallized composition variation i.e. regions depleted with Fe and richer in Al resulted in more corrosion than the regions where Al is in solid solution with Fe (Fig. (c and d). Hence to retian the Al in solid solution with Fe, process paramenters were optimised to minimize the decomposition and demonstrate superior corrosion performance.

Contributors: P Suresh Babu, D Vijaya Lakshmi, A Jyothirmai, R Vijay, L Rama Krishna and D Srinivasa Rao

Development of refractory metals and composite coating for protecting electromagnetic rail guns by cold spray technique

The objective was to develop a copper based refractory metal composite coatings for electro-magnetic rail gun application. Material optimization studies were carried out by mixing Ta, Mo and W with copper at different weight percentage and sprayed. Hardness, electrical conductivity, particulate retainment and wear studies were carried out to optimize the coatings. Extensive heat treatment studies were also carried out in order to optimize the coatings for rail applications. After optimizing the coatings using the above mentioned tests, Cu-50Mo and Cu-50W were selected as a candidates for rails. The coatings have been deposited on 4 nos. of 4 m rails and the same were heat treated using rapid heating device for improving coating cohesiveness.



Microstructure

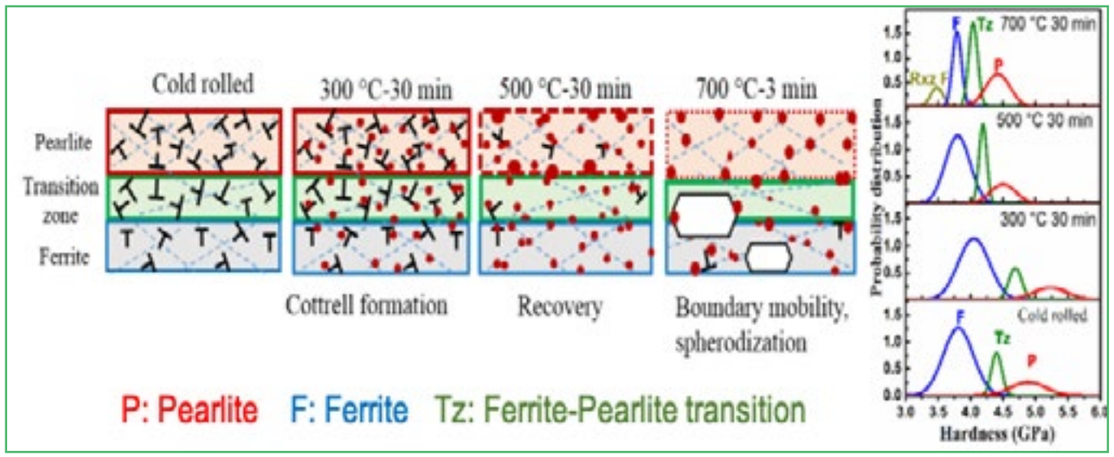
Conductivity data

4 metre long rails

Contributors: S Kumar, Naveen Manhar Chavan and D S Rao

Structure-property correlations at micrometer length scale in dual phase steel

High resolution nanoindention mapping along with scanning electron microscopy was used to establish structure-property correlations at the micrometer length scale during recovery and early recrystallization of a cold rolled high strength steel comprising of ferrite and pearlite. The NanoBlitz3D+ tool, jointly developed by ARCI and Nanomechanics Inc., was used to obtain the hardness of constituent microstructural features as a function of annealing time and temperature as shown in the figure. In addition, this work provided key insights on the role of carbon mobility and dislocation-carbon interaction during annealing as schematically shown in the figure. This work has important implications for design of next generation high strength steels.



Contributors: P. Sudharshan Phani and J. P. Gautam and S. Janakiram (University of Hyderabad)

Centre for Ceramic Processing

The Centre has been pursuing diverse programmes in the field of ceramics, focusing on emerging areas with potential demand in the country. During period of this report, the Centre has been successful in demonstrating and transferring the technology of ceramic honeycomb inserts with unique formulation and configurations for shock attenuation established for the first time for such applications. In continuation with Centre's proven capability in producing transparent ceramics with near theoretical transparency through chemical vapour deposition and hot isostatic pressing, the centre is currently establishing a state-of-the-art melt quenching R&D facility for the processing of speciality glass ceramics. During the year, the Centre has extended its expertise in the area of ceramic 3D printing and demonstrated the capability in printing spinel and zirconia formulations and complex parts with finer features for exploring biomedical applications. The Centre has also conceived , along with consortium of partners based on their capabilities, a programme to indigenously produce Solid Oxide Fuel Cell (SOFC) and Solid Oxide Electrolytic Cell (SOEC) leading to commercialisation to cater to the sustainable energy demand in the country.

Major Processing Capabilities

- *Compaction Processing*
- *Extrusion Processing*
- *Thermal Gel Casting*
- *Gel Casting*
- *Slip Casting*
- *Pressure Slip Casting*
- *Spray Drying*
- *Sol-gel Processing*
- *Combustion synthesis*
- *Melt quenching*
- *Spray Pyrolysis*
- *Isostatic Pressing*
- *Sol-gel/Slurry coatings*
- *Screen Printing*
- *Rate Controlled Sintering*

Major Facilities

- *Hot Isostatic Press*
- *Chemical Vapor Deposition*
- *HT Vac/Air Furnaces*
- *High Shear Mixer*
- *Compaction Presses*
- *Ram-Screw Extruders*
- *Ceramography*

Characterization

- *Impedance Analyzer*
- *Hot MOR*
- *Microwave NDT*
- *Rheometer*
- *Simultaneous Thermal Analyzer (STA)*
- *Dilatometer*
- *Nano-Zeta sizer*
- *Powder flow analyzer*

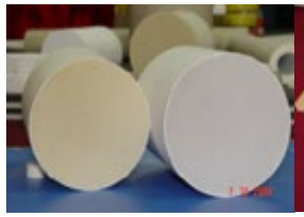
Process/Product Development

Green Dispo-Incinerator

Transparent Ceramics

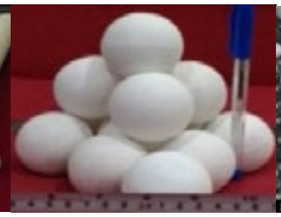
3D printed ceramics

Ceramic Foams

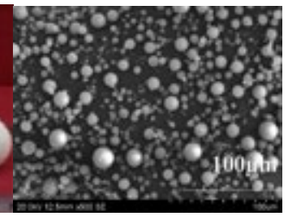


Ceramic Honeycomb

Extruded Products



Alumina Balls



Spray dried granules

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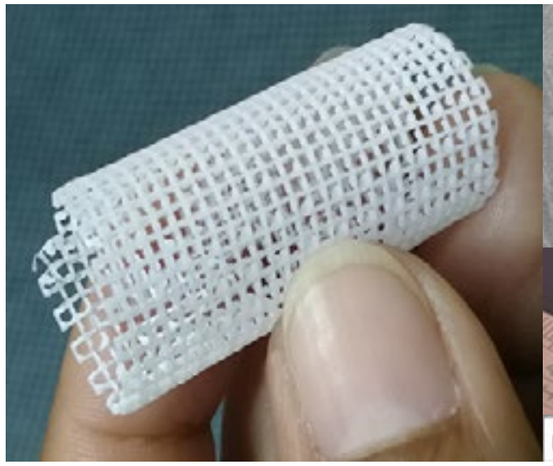
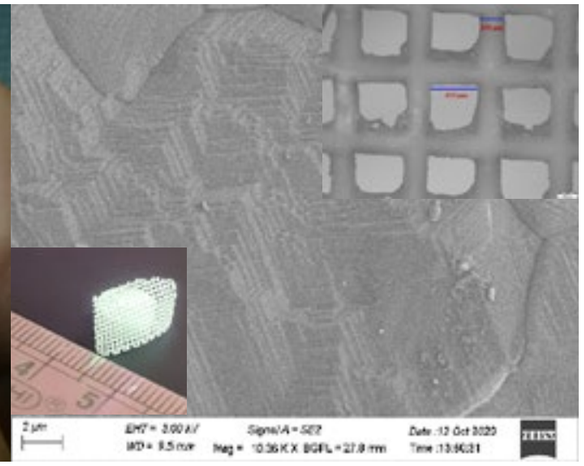
Research Highlights

3D printing of $MgAl_2O_4$ spinel mesh with finer features and hot isostatic pressing to near theoretical density

Fine mesh of spinel, with 0.25 mm rib thickness and 0.4 mm unit cell length, was 3D printed in collaboration with Baylor College of Medicine, USA. A stable colloidal dispersion of spinel in polymer-water solution was prepared and printed using a regen - HU 3D-Discovery bio-printer. Mesh samples were sintered and further Hot Isostatically pressed to a density of 3.5 g/cc. Microstructure of HIPed samples exhibited closely packed grains complementing the density with an average grain size of 10.9 µm. An elastic modulus of 238 ±15 GPa and hardness of 8GPa were measured on the HIPed samples. Current study demonstrated 3D printing of spinel mesh with finer features which can be explored as a potential prospective candidate for biomedical applications.



3D printed spinel mesh



HIPed spinel mesh and dense microstructure

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

Contamination free slip casting of spinel parts using spinel molds

Though slip casting using Plaster of Paris (PoP) is widely practiced for colloidal shaping of ceramics, $CaSO_4$ contamination originating from PoP is a major concern for processing of transparent ceramics. The contamination is generally observed in several layers from the cast surface requiring cumbersome green machining processes. In current study, $MgAl_2O_4$ spinel mold with optimum porosity of 45-50% and flexural strength of around 18 MPa was fabricated and used as a solution to avoid the contamination issues. In order to demonstrate the concept, transparent grade (S30CR) spinel specimens were cast on PoP and spinel mold and the cast was subjected to Fourier transform infrared studies. It is evident from Fig. I that the presence of peak at 1028 cm^{-1} corresponding to sulfonic group is due to PoP mold and no such peak is observed with spinel mold. Use of spinel mold offer advantages of contamination free slip casting process which in turn eliminate the green machining process and associated rejections.

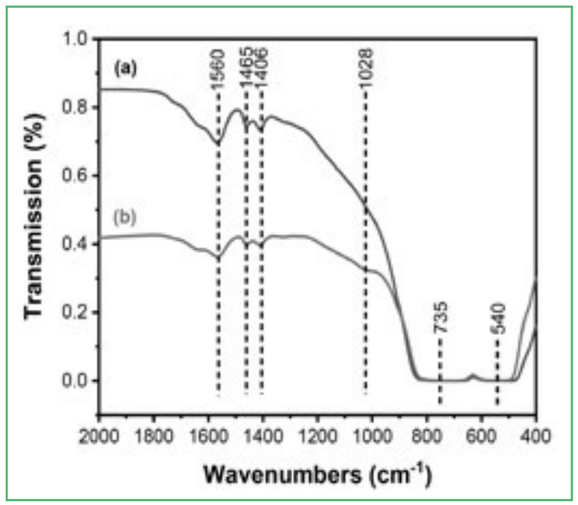


Fig. 2 FTIR transmission spectra for the spinel green body casted on the (a) spinel and (b) PoP mould substrates

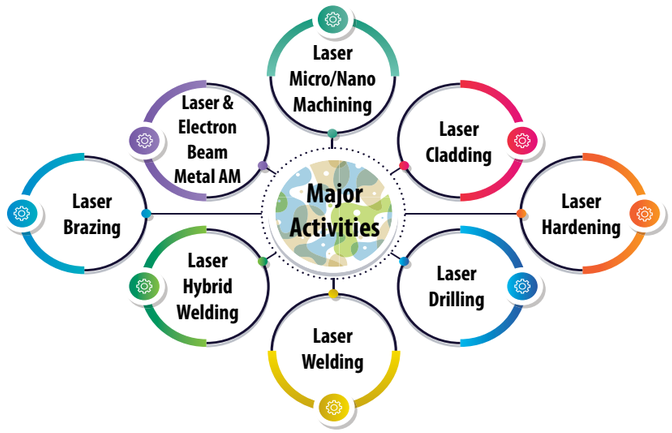
Contributors: Shiv Prakash Singh, Papiya Biswas, Y.S. Rao and Roy Johnson

Centre for Laser Processing of Materials

Centre for Laser Processing of Materials (CLPM) at ARCI is a unique R&D facility in the country based on high power industrial lasers. The Centre's main objective is to promote and provide laser based materials processing technologies for industrial application. The Centre has been conducting R&D in the areas of additive manufacturing, repair refurbishment micro processing, surface engineering, and materials joining with the help of an array of laser processing systems available at the Centre. During the year, the Centre made two major acquisitions, an Electron Beam Melting (EBM) system and one more Selective Laser Melting (SLM) system for additive manufacturing to address a wider range of applications. As in the past years, emphasis has been on development of processes and application development for various industrial sectors.

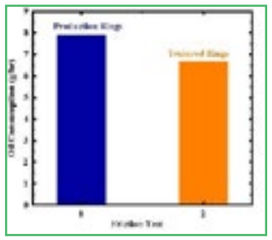
Major Processing Facilities

- *Electron beam melting (EBM) Additive Manufacturing (AM) System*
- *Metal powder bed AM system SLM 280 HL*
- *Ultrafast laser micromachining system*
- *Fiber coupled diode laser (6 and 10 kW)*
- *Slab CO_2 laser with laser arc hybrid welding system*
- *Pulsed Nd:YAG Laser*



Major Achievements

- *Established electron beam melting (EBM) AM facility*
- *Ultrafast laser surface micro texturing of piston rings and cylinder liners*
- *Development of a novel localized laser softening process*
- *Laser assisted machining for hard to machine materials*
- *Developed and demonstrated the laser clad coating for burner tip plates used in thermal power plant*
- *Development of laser and laser MIG hybrid welding process for nickel based superalloys*
- *Refurbishment of diesel engine cylinder heads and aero engine components*
- *Development and validation of AM of various components*

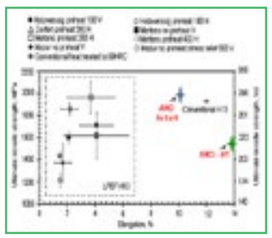


Engine test of textured piston rings

EBM Parts

Laser Cladding of Burner Tip

AM of Valve Block



AM built AISI H13 tool steel properties

EBM System

Laser assisted machining (LAM)

Laser welding of Thruster

SLM System

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Research Highlights

Establishment of electron beam melting (EBM) additive manufacturing facility

Electron Beam Melting (EBM) Additive Manufacturing works on powder bed fusion additive manufacturing principle where a high power electron beam is used to create melt pool. The facility established at ARCI is the EBM A2X system from ARCAM AM (GE Additive) make (Figure 1). The system has a build volume of 200 mm x 200 mm x 380 mm. The EBM process operates under high vacuum conditions, making it an ideal choice to process reactive materials such as Ti alloys. Higher bed temperature makes it suitable to process difficult to weld alloys; it also helps to minimize the residual stresses in the components. The EBM system is used for processing Ti alloy components for various applications (Figure 2). The unique capabilities of the EBM system make it most suitable to process C103 Niobium alloys. Considering the cost of C103 alloys, EBM AM of C103 can provide significant techno-commercial benefits.

Fig. 1 Electron Beam Melting (EBM)

Fig. 2 Electron Beam Melting (EBM) for fabrication of various parts

Contributors: Manish Tak, Ravi Bathe and G. Padmanabham

Additive manufacturing of H13 tool steel

Major progress has been made in the AM process development for AISI H13 tool steel alloy powder for advanced tooling applications. The achieved superior mechanical properties are shown in Figure 3 for both as-built and after optimized post-heat treatment, compared with properties previously reported in various AM literature of AISI H13 tool steel. Real-time demonstration of AM-built H13 tool steel core pin with efficient cooling channels resulting in enhanced service life has been carried out in collaboration with casting industry. Further, the development focused on possible high build rate, and hybrid AM was explored for metallurgical and mechanical properties. Experiments were carried out to achieve AM process parameters for higher build rate by varying layer thickness (60, 90, and 100 µm) for different alloy powders like AlSi10Mg and H13 tool steel powder.

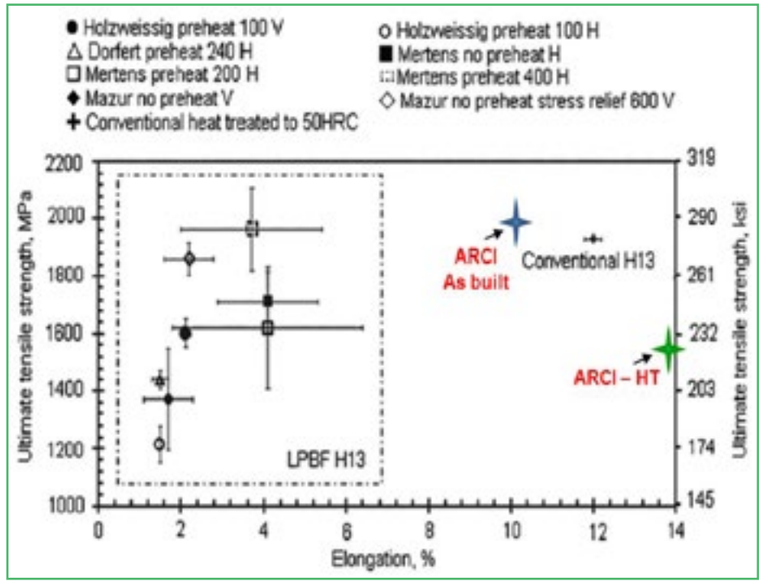


Fig. 3 Plot showing a summary of literature reported mechanical properties for SLM-AM built AISI H13 tool steel compared with corresponding properties achieved by AM of AISI H13 tool steel at ARCI AM facility

Contributors: Gururaj Telasang, DM Santhoshsarang, Ravi Bathe and G. Padmanabham

Repair and refurbishment of aero engine components using directed energy deposition additive manufacturing process

Ni-based superalloys are widely used in aero-engine components due to their high-temperature strength, excellent creep strength, superior oxidation resistance, and corrosion resistance. Despite having exceptional properties, the aero-engine components made of Ni-based superalloys are prone to damage due to extreme service conditions. Manufacturing defects during the casting or machining process are another major cause of rejection. A detailed investigation was carried out to understand the metallurgy of these materials. The as-cast superalloys, with a coarse dendritic microstructure, consist of carbides rich in Nb, W, Ti, Mo, and Cr and borides enriched with Cr and W. It also consists of γ/γ′ eutectic at interdendritic regions and finer γ′ precipitate in the γ dendrite. Additive manufacturing suitable powders were developed using inert gas atomizer available at ARCI, as shown in Figure 4. Directed energy deposition (DED) AM experiments were carried out to understand the rapidly solidified microstructure of the alloy. The rapidly solidified microstructure exhibited a fine dendritic microstructure in the melt zone with carbide precipitation at inter-dendritic regions (Figure 5). Heat affected zone revealed the dissolution of the eutectic phases near the fusion boundary.

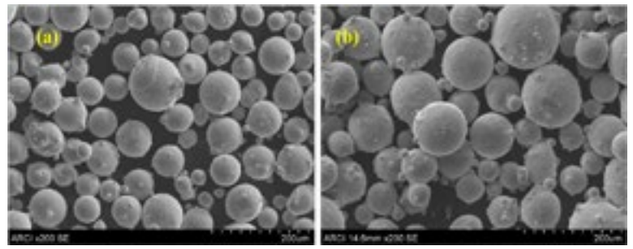


Fig. 4 ARCI developed AM powders for selected Ni based superalloys

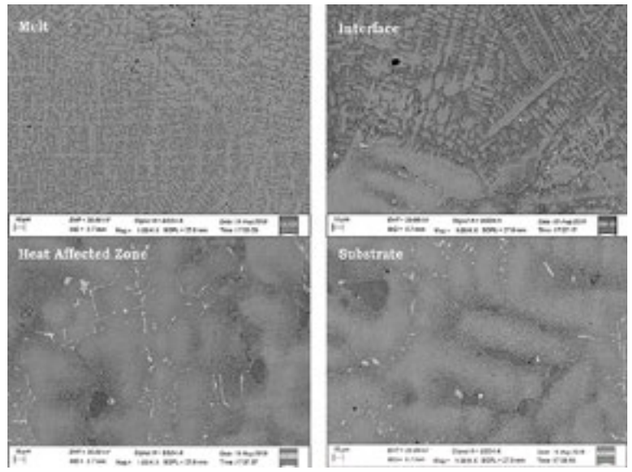


Fig. 5 FESEM micrographs at different regions (DED of Ni-based superalloy)

Contributors: Manish Tak, M. Swarna, Ravi Bathe and G. Padmanabham

Ultrafast laser surface micro-texturing of piston rings and cylinder liners

The texture surfaces were created on the automotive internal combustion engine components- piston rings and cylinder liners using 100 fs pulse duration laser. Ultrafast laser surface texturing technology developed at ARCI offers precise control over the size, shape, and density of micro-surface texture features. This technology involves creating microdimples (20-30 µm diameter and about 5-10 µm deep) having a regular pattern applied on a given surface by a pulsating laser beam (Figure 6). The created textures were tested in an engine test rig under different speeds and coolant and lubrication oil temperatures. It is observed that there is a 16% reduction in the lube oil consumption with the use of texture on the piston rings (Figure 7). The 10-hour lube oil consumption test shows that the blow by substantially reduced with textured rings.

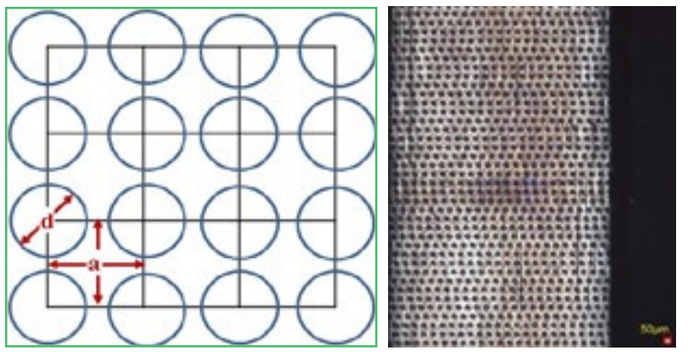


Fig. 6 (a) Schematic diagram of micro-dimples, and (b) Femtosecond laser surface textured piston ring

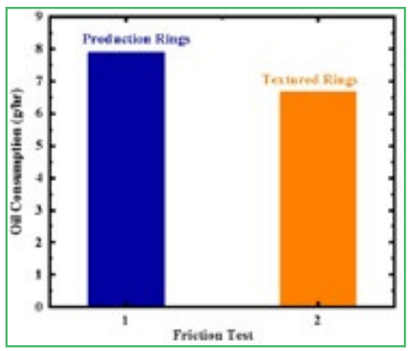


Fig. 7 Engine test of textured piston rings

Contributors: Ravi Bathe, D. Nazeer Basha and G. Padmanabham

Control and robust superhydrophobic metallic surfaces by ultrafast laser processing

Uniform distribution of well-defined, hierarchical micro-scale and nano-scale structure features was successfully generated on steel surface using 100 fs pulse duration laser. The micro patterns, either one-directional grooves or two-dimensional cross-hatched patterned surface and, over it, nano-scale laser-induced periodic structures, have been created with a laser beam that had a regular pattern (Figure 8). The surfaces prepared were robust and exhibited excellent and controllable isotropic and uni-directional superhydrophobic functionality (Figure 9). This efficient and straightforward strategy will encourage the scalability of the process both in reducing the cycle time and applying the developed hierarchical micro-scale and nano-scale structures over large areas for practical applications in the prevention of corrosion, bacterial growth, and avoidance of repeated cleaning.

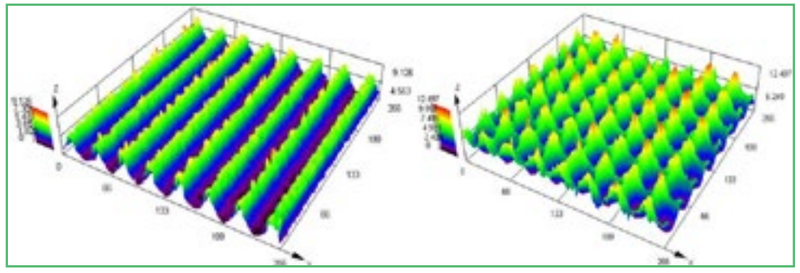


Fig. 8 3D Optical images of laser surface modified stainless steel surfaces showing microgrooves and microspikes with periodic nanostructure

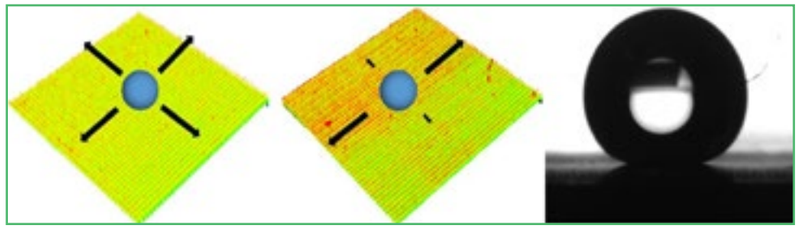


Fig. 9 The schematic diagram shows the directional superhydrophobicity on different surface features. Profile of water droplet on laser modified stainless steel surface (contact angle ~ 170 degree)

Contributors: Ravi Bathe, K. S. Srin and G. Padmanabham

Development of a novel localized laser softening process on high-strength steel sheet used in autobody and structural parts for improved formability

The method employs a laser integrated into a robotic workstation, an optical module to tailor the laser beam to a designated size and shape, and a well-designed fixturing setup (Figure 10) for laser softening of automotive or other high strength dual hard steel sheets. The developed method improves the sheet material's formability and/or manufacturability or part with minimal distortion by softening at single or multiple localized regions of interest. The method comprises tempering or modifying the rigid structure, for example, martensite in steel, into a soft structure comprising tempered martensite or ferrite or otherwise with an increase in ductility or formability of the steel sheet or part, applicable in diverse applications of the industry. Tensile (the inset of the stress-strain graph) and formability testing of softened steel exhibited a 40% reduction in strength and 25% improvement in elongation compared to untreated counterparts.

Fig. 10 A diode-laser based softening setup

Contributors: S M Shariff, P Ganesh, E Anusha, Md. Aqeel and G Padmanabham

A novel laser-based economically viable welding technology for thick-section weldments of high-temperature steel and super-alloy materials

New diode-laser-based single-pass welding process developed has shown great promise for thick section welding with butt-joint configuration. The technology involved tack-welding of filler wire with appropriate groove design under butt-configuration, process optimization (Figure 11) with appropriate shielding, and fixturing setups. The developed technology has been successfully tested with weld quality assessment for boiler steel and super-alloy materials. The figure illustrates a schematic of the setup utilized using a diode-laser integrated into the robotic workstation (the inset in the figure shows a cross-sectional weld bead profile). The developed joints (tensile test results in the inset of the figure) in case of both the materials (P91 Steel and IN-617 Ni-based alloy) exhibited 100% joint efficiency with a vast reduction in distortion (when compared with multi-pass conventional welded joint and single-pass hybrid welded joint) and thus envisaging easy adoption in the industry. The laboratory-proven technology is under testing with application on actual boiler tubes used in thermal power plants.

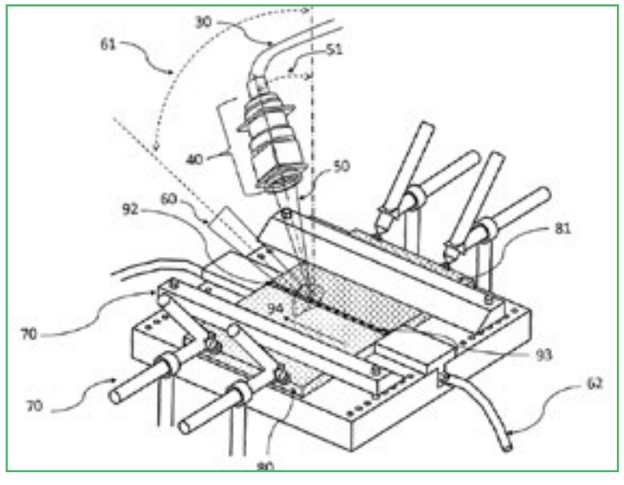


Fig. 11 A diode-laser based setup for thick-section welding

Contributors: S. M. Shariff, Md. Aqeel and G. Padmanabham

Suitability of laser hybrid welding process in joining of high strength low alloy (HSLA) steel plates

Welding experiments were carried out in spray transfer mode for 1.2 mm diameter filler wire using synergic welding. The test welds were first examined by visual inspection. Next, the metallographic examination was carried out. Process challenges like non-uniform root penetration and undercut at the top bead were addressed with an appropriate choice of joint gap and electric arc configuration, respectively. The macrostructure shown in Figure 12 consists of a fusion zone characterized by a "Y" shape configuration, two symmetrical heat-affected zones (HAZ), and base metal areas. The HAZ region adjacent to the FZ boundary (fusion line on the cross-section) is characterized by a coarse-grain structure with dominant acicular ferrite. HAZ structure in the region adjacent to the base metal (BM) is very fine-grained. The very fine-grained region reaches about more than the half-width of the entire HAZ. The structure of the fine-grained region of HAZ, similar to the base metal, is composed of ferrite with a uniform dispersion of fine carbides. The hardness contour plot shown in Figure 13 revealed that the lowest hardness was characteristic of the heat-affected zone and amounted to approximately 321 HV, which is lesser than the hardness of the base material. The resultant HAZ softening represented in blue in Figure 12 is more prominent in coarse-grained HAZ than in fine-grained HAZ and more pronounced in the neck region.

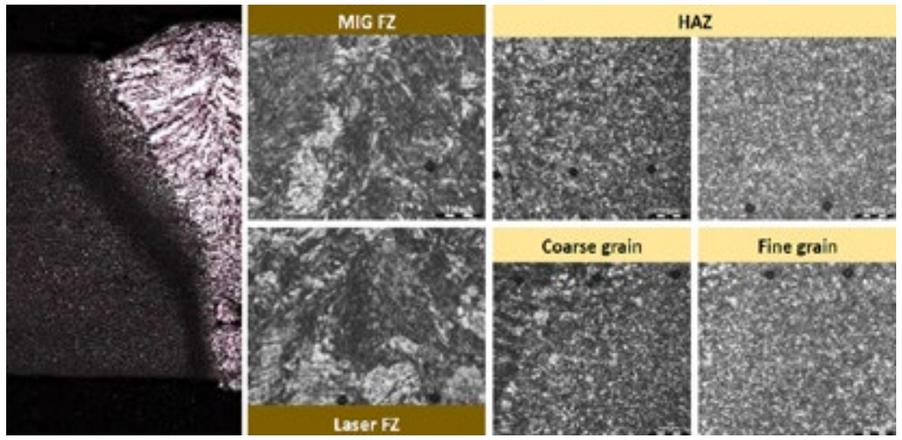


Fig. 12 Laser hybrid weld macrostructure with microstructures

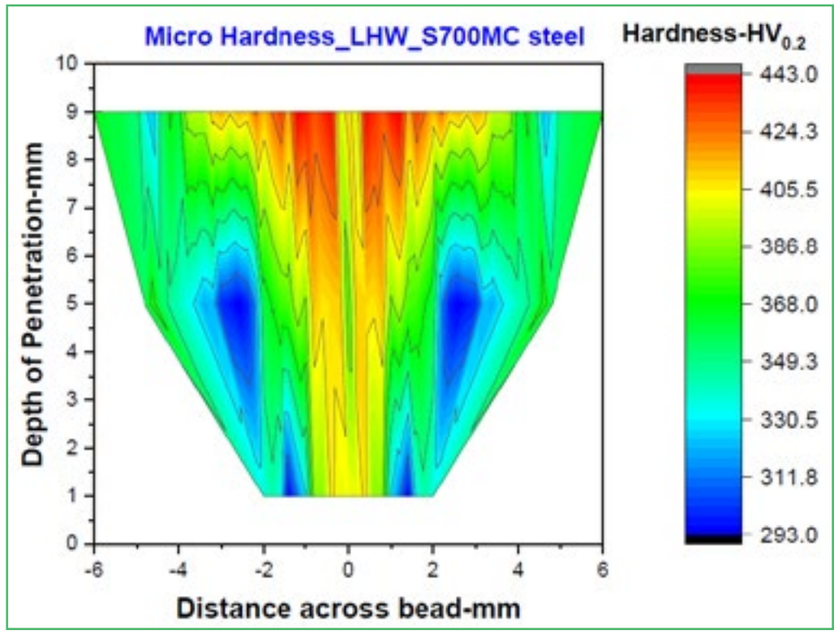


Fig. 13 Hardness contour plot

Contributors: K. V. Phani Prabhakar, E. Anburasu and G. Padmanabham

Laser-assisted machining (LAM) for Advanced Ultra Super Critical (AUSC) boiler

A Laser-assisted machining setup is established at ARCI, and systematic experimental work is carried out on IN625 material. A piezoelectric dynamometer is used to measure the cutting forces during LAM. Figure 14 shows a reduction in cutting forces while Laser-assisted machining compared to conventional machining. It is observed that various parameters such as laser power, tool-laser distance, machining parameters, the thermal conductivity of the material, size of the component, etc., play a critical role in the LAM process and by selecting the right set of parameters and conditions, cutting forces can be minimized substantially.

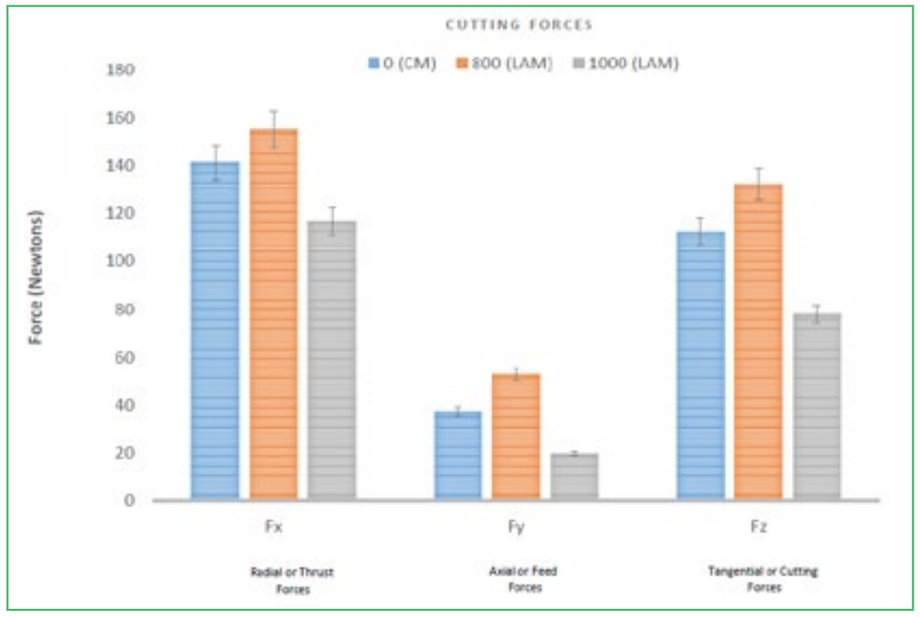


Fig. 14 Cutting forces while machining IN625: conventional machining Vs. laser-assisted machining

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

Centre for Fuel Cell Technology

The Cente for Fuel Cell Technology (CFCT) has been at the forefront of Polymer Electrolyte Membrane Fuel Cell (PEMFC) development in the country. The Centre has developed process know-how for the various components used in the fuel cell stacks and built fuel cell stacks up to 20 kW capacity. The Centre has demonstrated the application of fuel cells in decentralized power generation as power packs and range extenders in electric vehicles.

Programs

- *Design and development of Low Temperature Polymer Electrolyte Membrane (LTPEM) with high indigenous content*
- *PEM fuel cell based stationary power supply system*
- *Electrochemical Methanol Reformer (ECMR) for Hydrogen Generation*
- *Development and manufacturing of metallic bipolar plates for PEM fuel cells*
- *Development of electrically rechargeable Zinc Air battery*
- *Electrochemical synthesis of Lithium Aluminum Hydride, an advanced propellant Ingredient*

Major Processing Capabilities

- *Bulk catalyst and catalyst support synthesis*
- *Fabrication of Membrane Electrode Assembly (MEA) from small to large scale for PEMFC and PEM based electrolyzer*
- *Assembly and testing of single cell/large stacks*
- *Balance of the Plant (BoP) development for PEMFC stacks*
- *Testing and development of electrochemical methanol reformer*

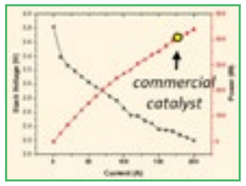
Highlights

- *Durability of developed PEMFC stacks using European standards*
- *Industry interactions for field trial /technology transfer for commercial application*
- *Technology Transfer of (Pt/FAB based) Electrocatalyst*
- *Bipolar Plate – Exfoliated Graphite*
- *Bifunctional (Oxygen evolution reaction [OER] and oxygen radiation reaction [ORR]) catalysts*
- *Successful Integration of indigenous Pt/FAB catalyst 7 EFG plate in 770 sqcm. short stack.*
- *Virtual Demonstration of the Developed System with 1 kW AC load for the Department of Atomic Energy*

Major Facilities

- *200 watts and 1 kW fuel cell test stations*
- *Glove box*
- *Battery cycler with voltage and current booster*
- *RDE and RRDE for testing of electrocatalysts*
- *Scanning vibrating electrochemical test station.*
- *X-Ray Diffraction*
- *TGA-MS*
- *Dynamic Mechanical Analyzer*
- *Porometer*
- *Gas Chromatography*

Stack developed with Pt/FAB catalyst



Polarization curve

Automated PEMFC fabrication & assembly line setup

Major demonstration of PEMFC stack

- *Bhabha Atomic Research Centre*
- *Tamil Nadu State Disaster Management Authority*
- *Neyveli Lignite Limited*
- *Indian Oil Corporation Limited*
- *Gas Authority India Limited*

I kW PEM fuel cell system

Ultrasonic Spray Coating Unit

Automated Stack Testing Unit

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Technology Development / Transfer

Fully integrated polymer electrolyte membrane fuel cell system for stationary application

Bhabha Atomic Research Centre (BARC), produces significant amount of pure hydrogen gas through electrolysis. In order to utilize the produced hydrogen, Fuel Cells from ARCI were considered as a thrust area of R & D to generate power for useful applications. A 1 kW fuel cell system developed by ARCI was deployed at BARC for demonstrating the prowess of PEMFC in stationary application. The PEMFC was integrated with appropriate power conditioners to enable plugin type AC applications.

Fig. 1 Photograph during a virtual demonstration of the PEMFC system integrated with power condition to power AC lighting

Contributors: N.Rajalakshmi, Raman Vedarajan, K.Ramya and R.Balaji

Automation of PEM fuel cell stack assembly line

The PEMFC manufacturing capability is the major gap that needs to be addressed for both cost reduction as well for implementation at many locations. While most of the current research is focused on reducing system costs and improving efficiency, less attention is being paid to the possibilities offered by mass production and economies of scale. In this context, CFCT has taken initiative on setting up an automated PEMFC assembly line. In the above process, various international/ national key players in setting up the pilot plant for automation of PEMFC stack and its components development were identified and series of discussion was carried out. As an outcome of the above process, Advanced Manufacturing Technology Development Centre (AMTDC), Chennai was identified as potential key players in setting up PEMFC stack/component assembly line at CFCT. Accordingly, MoU was signed between ARCI and AMTDC to initiate the above process. The various steps involved in automation process were identified and shared with AMTDC and its design layout is shown in figure. The various work packages were finalised and attempt towards its execution is in progress in phase wise manner. It is aimed to fabricate PEMFC stack about 100kW/year capacity using the above automated line. The establishment of this PEMFC stack assembly automation line would be first of its kind in India.

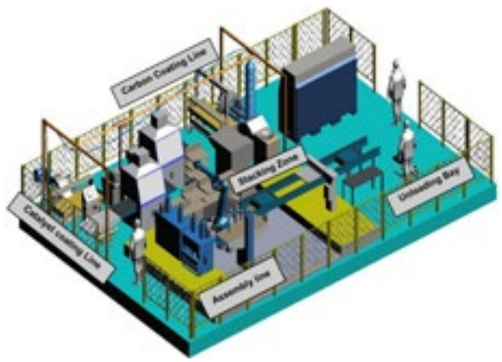


Fig. 2 Layout for the Development of Robotic PEMFC stack assembly line

Contributors: N.Rajalakshmi, Raman Vedarajan, K.Ramya and R.Balaji

Metallic flow field plates for PEM fuel cell application

ARCI is currently in the process of adopting Metallic bipolar flow field plates in PEM Fuel Cells to exploit its good volumetric benefit. However, the manufacturing of Metallic plates has numerous bottlenecks owing to the precise engineering required for the plates to be usable in a fuel cell. Among the different methods attempted for developing the flow field plates currently chemically etching a Stainless Steel (SS316L) sheet of 0.6mm to form the plates is proving adoptable. A Multicell prototype with 8-cells (Fig. 3) with flow design area of 150 cm^2/plate was tested with humidified Hydrogen/Air. Scale-up design is under progress.

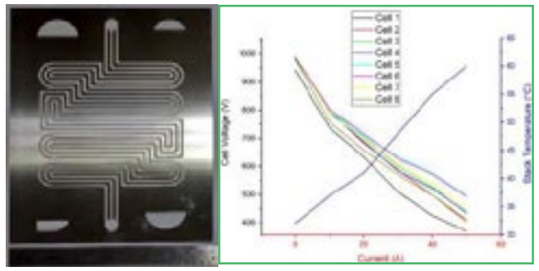


Fig. 3 Chemically etched plate and the 8 cell stack performance

Contributors: N Rajalakshmi, Raman Vedarajan, K Ramya, M Rajkumar and S Ramakrishnan

Development and demonstration of PV integrated PEM based electrochemical methanol reformer (ECMR) for hydrogen production

The successful commercialization of Fuel cell technologies requires among other things, constant hydrogen supply. Steam reformation of hydrocarbons and electrolysis of water are commonly available methods to produce hydrogen. ARCI developed a method which combines aspects of both the processes using electrolysis method to produce hydrogen from methanol – water mixture. Recently, ARCI has successfully developed, a PEM based ECMR for 2.5 Nm^3/hr hydrogen production capacity as an integrated system. Further, it is aimed to develop ECMR system based on the renewable energy especially solar energy. Accordingly, M/s. Rensol Power(P) ltd was identified as industrial partner for the joint development of renewable energy integrated Hydrogen generation system and MoU was signed. Currently the development of power supply component and its integration are underway. The proposed plan of activity is shown in the above figure.

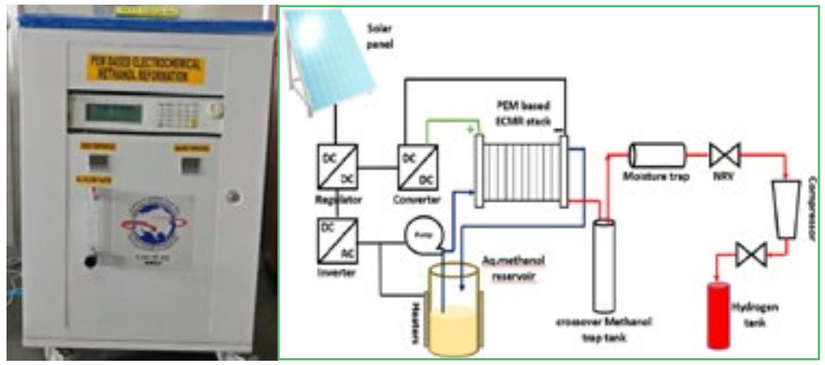


Fig. 4 Developed ECMR system with proposed plan for PV power integrated PEM based ECMR system for hydrogen production

Contributors: R. Balaji, Sriharsha, S. Yasodhar, N. Rajalakshmi and K. Ramya

Metal air battery development

Metal air batteries are being developed to store the energy produced by intermittent renewables like solar and wind. An oxygen reduction reaction catalyst that can produce high e-current density is vital for development of primary batteries. ARCI has been involved in the development of transition metal based catalysts (Co-S-C and Mn-S-C). Electrode with a current density of 50mA/cm^2 at ~1V has been developed with C-S-Co catalysts. In the rechargeable battery development, a 100Wh electrochemical cell has been assembled. The cell is to be tested for performance and cyclability. Apart from this, aluminium air cell development is undertaken with view to increase the electrochemical capacity and decrease the parasitic reaction of self-corrosion by providing suitable coatings.

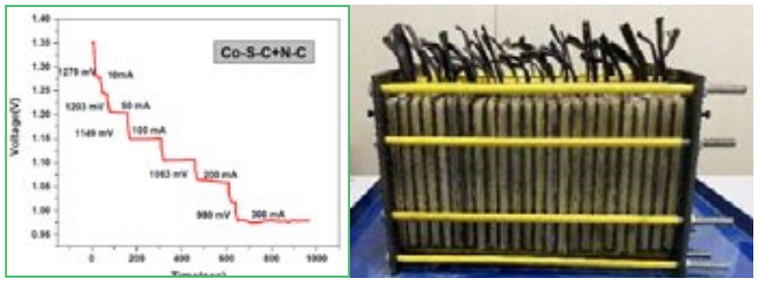


Fig. 5 Performance of Co-S-C catalyst and 100 Wh metal air cell

Contributors: K.Ramya, N.Rajalakshmi, Imran Karajagi and A.B.Aravind

Energy storage platform on batteries

In an attempt to reduce the cost of a fuel cell stack, alkaline fuel cell that uses a membrane electrolyte is being developed. The use of anion exchange membrane in an alkaline fuel cell eliminates the formation of crystals of alkaline carbonates that block the gas diffusion electrodes and helps in operation under solvent free conditions and leak proof in addition to the advantage of use of less/ no noble metal based electrocatalysts. The Centre is involved in the development of low cost, low metal loading transition metal based catalysts like Fe-N-C

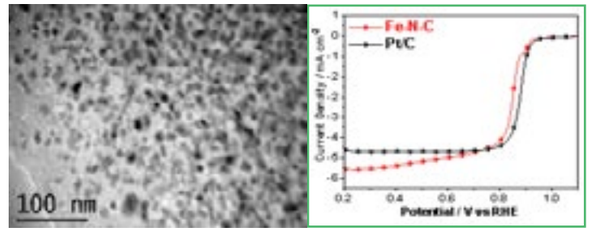
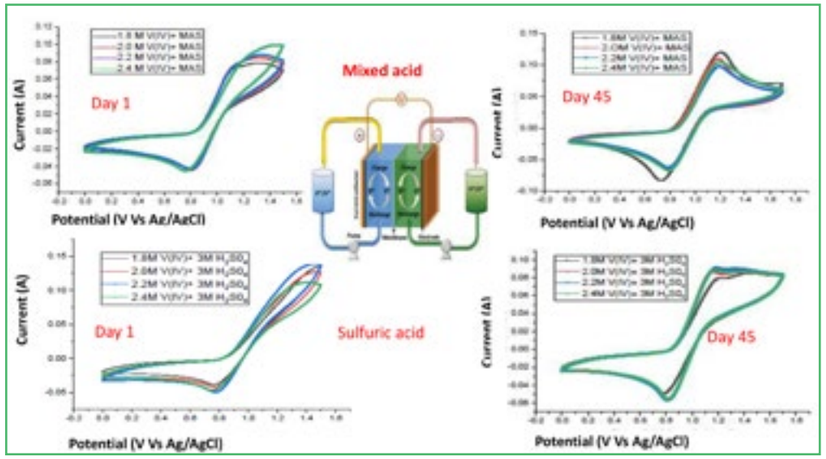


Fig. 6 TEM image of Fe-N-C catalyst and its LSV curve comparison with Pt/C and cycling characteristics in VRB half cell in mixed electrolyte

for Oxygen reduction reaction apart from development of catalysts for hydrogen evolution reaction and polymer electrolyte membranes. Vanadim Redox Batteries (VRBs) that offer long cycle life, flexibility in design, low capital cost and fast response time are also being developed with mixed electrolyte streams to enhance mass transport and reduce ohmic resistance.



Contributors: N.Rajalakshmi, K.Ramya, R.Balaji and Imran Karajagi

Research Highlights

Fuel cell developments at ARCI

ARCI has already developed and demonstrated PEMFC stacks and systems for disaster management, strategic applications etc. The Centre is in the process of developing advanced indigenous PEMFC stacks of different capacities. Computational fluid dynamics analysis is being used for the numerical investigation of reactant flow and flow distribution for 50 cells stack. Simultaneously, the indigenous component in membrane electrode development is being addressed via taguchi methods the parameters being, low loading and optimal utilization of catalyst ink. The developed electrodes are being activated and tested for durable cycle life.

U-type and Z-type flow distribution analysis *Active area 25 cm²* *Active area 770 cm²*

Fig. 1 TEM image of Fe-N-C catalyst and its LSV curve comparison with Pt/C and cycling characteristics in VRB half cell in mixed electrolyte

Contributors: N.Rajalakshmi, Raman Vedarajan, K. HariGopi, S. Yasodhar, V. Tarun Kumar, J.Prithi, R.Manoj Kumar, J. Sasikumar and R. Lingheswaran

Screening of recycled membrane with crystallinity as a fundamental property

Recycling of the precious components like proton exchange membrane and catalyst after their life, has been speculated to increase the commercial viability of PEMFC. Further, most of the research work on recycling have focused mainly on the procedure to extract the membrane and no correlation on understanding the condition of the membrane for reusability or recyclability has been reported to date. At ARCI, we have developed a relationship between the structural properties of the recycled membrane to the overall electrochemical performance. The change in crystallinity of the used membrane was quantitatively analyzed and extrapolated in predicting the possible second-life application.

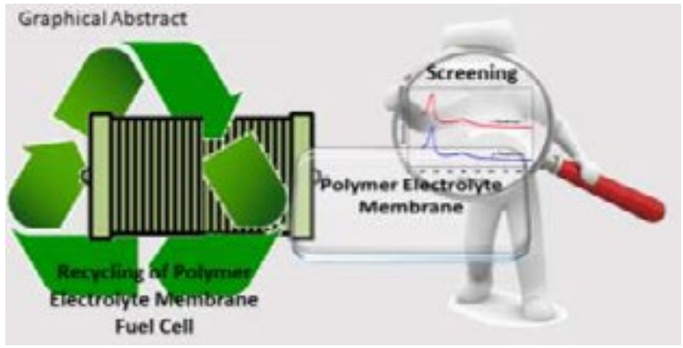


Fig. 2 Schematic representation of recycling polymer electrolyte membrane and analyzing its properties for second-life

Contributors: Raman Vedarajan, N. Rajalakshmi, P. Sreeraj and Abha Bharathi

Superhydrophobic catalytic support for efficient water management in PEMFC

Electrocatalysts used in a Polymer Electrolyte Membrane fuel cells (PEMFC) play an important role both in the performance as well as the cost of the device. Formation of water during the operation of PEMFC, floods the system at different conditions. Fluorination of carbon support leads to increased hydrophobicity of the electrocatalyst. This helps in avoiding flooding issues due to hydrophilic groups. ARCI, has developed a cost effective and superhydrophobic electrocatalyst exhibiting a smart water management property while retaining the efficiency of the PEMFC device.

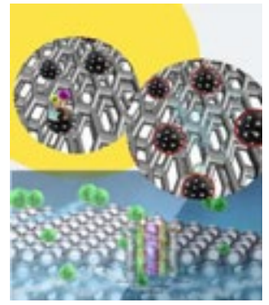


Fig. 3 Schematic representation showing the higher water rejection capability of the ARCI prepared electrocatalyst compared to conventional electrocatalyst

Contributors: Raman Vedarajan, N.Rajalakshmi, J. Prithi and P.Sreeraj

Corrosion aspects and coating of metallic bipolar plates for PEM Fuel cells and electrolyzer application

Metallic bipolar plates (BPP) or flow field plates in a Polymer Electrolyte Membrane based Fuel Cell or Electrolyzer provides advantages over graphite. However, BPPs made of SS and Ti are prone to corrosion due to the presence of the agressive acidic environment (pH 2-3) and operating temperature (80° C), which degrades the performance of the fuel cell. Hence, metallic BPPs needs a suitable coating which are cost effective as well robust. ARCI has been working on identifying and scaling up different coating techniques such as conductive polymer coating on Ti, modified conductive polymer coating on 316L SS, patterned Pt deposition on Ti-6Al-4V and chromium nitriding over SS.

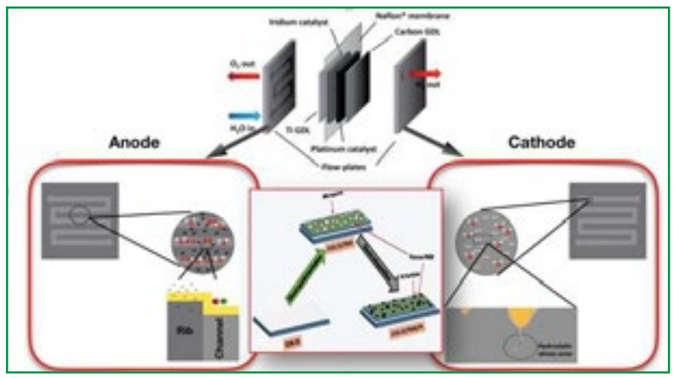


Fig. 4 Schematic representation showing patterned Pt deposition and conductive polymer coating on metallic plates

Contributors: Raman Vedarajan, N.Rajalakshmi, K.Sriram and V. Sri Harsha

Centre for Non-oxide Ceramics

Developing Innovative Processing Techniques for Technology Oriented Product Development, Materials Synthesis and Fabrication, Characterization and Testing,Prototype Development, Technology Transfer

Uni-axial hydraulic press

Vacuum sintering furnace

Processing expertise

- *Advanced colloidal forming*
- *Spray-freeze drying*
- *Pressureless sintering*
- *CVD coating*
- *Porous ceramics*
- *Extrusion processing*
- *Fused Deposition Modelling (FDM) 3D printing*

Major facilities

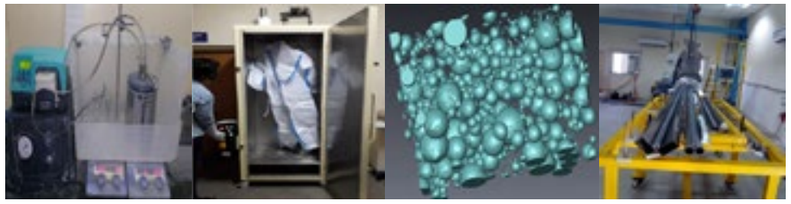
- *High-tonnage hydraulic press*
- *Cold isostatic press*
- *High-temperature sintering furnace*
- *Conventional and ultrasonic machining facilities*
- *Extrusion press*

Cold isostatic press

Vacuum hot-press

Centre for Non-Oxide Ceramics (CNOC) has been pursuing R&D in the area of various non-oxide ceramics and allied materials for niche applications. The Centre is equipped with state-of-the-art facilities for development and upscaling of ceramic parts. In recent years, 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 this reporting period, the Centre was engaged in producing complex shape components through cold isostatic pressing by designing of innovative assemblies of mould/mandrel and flexible rubber bags. Current focus of Centre's activities are 3D printed advanced ceramics through fused deposition modelling (FDM) for structural applications and glass-based sealants for solid oxide fuel cell (SOFC) applications. In addition, Centre's ongoing R&D activities include the development of various non-oxide-based ready-to-press (RTP) granules, wear and impact resistance parts, nitride-based ceramics for transparent windows, carbon nano-fibre (CNF) and carbon nano-tube (CNT) reinforced SiC composites etc. Centre in collaboration with M/s. Sowbal Aerothermics has taken initiatives for the development of honeycomb-based air heating for efficient microbial disinfection system and demonstrated for bacterial disinfection.

Ultrasonic machining system | *Polished CVD SiC blank* | *SiC cold finger ADITYA-L1* | *5-axis CNC machine*



Freeze granulator | *Microbial disinfection unit* | *3D tomography of SiC foam* | *Extrusion press*

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Research Highlights

3D printing of complex shape light-weight SiC ceramics through fused deposition modelling

Forming of ceramics through fused deposition modelling (FDM) has several advantages compared to other 3D printing techniques including simplicity of the process, easy to upscale and low cost. FDM of ceramics utilizes composite filaments of ceramic particles (up to 60 vol.%) in thermoplastic binders. The process involves layer by layer extrusion of the filaments through a nozzle above the softening point of filament followed by solidification that allows 3D shape formation. Then the parts undergo de-binding and sintering. Recently, ARCI has carried out a feasibility study on FDM 3D printing of SiC ceramics in collaboration with M/s SiCeram, GmbH by using SiC-based filament feedstock. The study demonstrated 3D printing of SiC specimens and complex shape light-weight SiC prototypes. Subsequently, 3D printed SiC parts were subjected to post processing including binder removal and sintering that achieved higher than 98% relative density. Detailed study showed that the properties of FDM 3D printed SiC are comparable with the parts processed through normal dry pressing and sintering with an additional advantage of complex shape processing.

Fig. 1 FDM 3D printed light-weight SiC prototype
Size: 75 mm (D) × 15 mm (H)

Contributors: D C Jana, B P Saha and Roy Johnson

Fabrication of hybrid SiC composite tubes reinforced with carbon nano and long fiber

Carbon fiber (short and long) reinforced SiC composites with improved mechanical and fracture properties are candidate materials for use in high temperature and harsh environments. Boron nitride coated continuous carbon fiber (BN-Cf) reinforced SiC based hybrid composite tubes (BN-Cf/SiC-CNFs) are fabricated by a unique process. Process involves systematic laying of the long carbon fiber in the matrix of spray granulated SiC powder containing premixed carbon nanofiber (CNFs). Hybrid composites with long fibers were cold isostaticaly pressed (CIPed) and further sintered to obtain hybrid SiC composite tubes as shown in Fig. 2(a). Density and mechanical properties of the base matrix and tubes are shown in Table I. Higher fracture toughness observed can be attributed to the bridging and pull out of the fiber [Fig. 2(b)] and also synergistic contribution of specially laid long fibers in nanofibers containing SiC matrix.

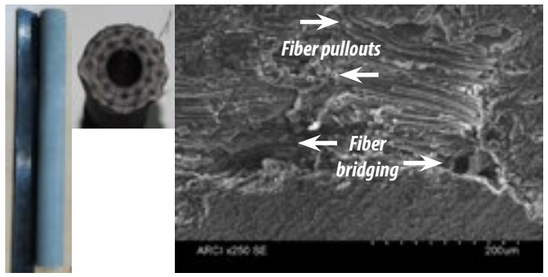


Fig. 2 (a) Sintered SiC hybrid composite tubes showing fibre arrangement in the cross section (b) Microstructure showing bridging and pull out of the fiber

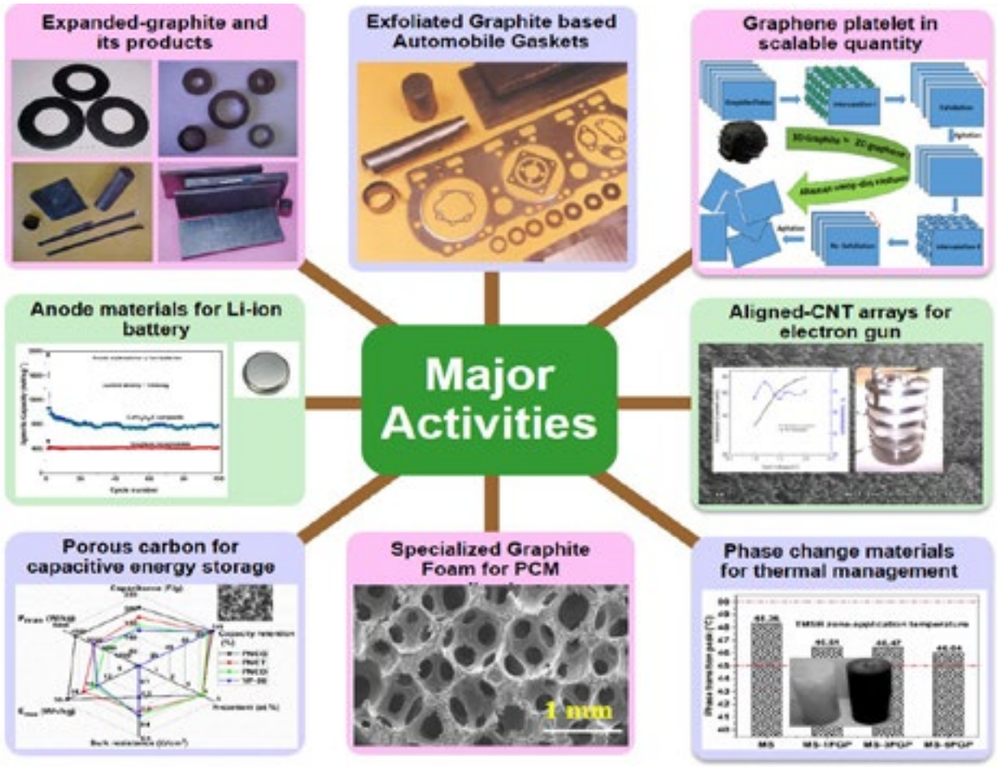
Table 1 Density and mechanical properties

Sample	Relative density (%)	Vickers hardness (GPa)	Indentation fracture toughness (MPa m1/2)
SiC-CNFs matrix	98.6	24.89 ± 0.82	4.86 ± 12
Cf/SiC-CNFs hybrid composite tube	96.4	22.68 ± 2.17	5.26 ± 0.74

Contributors: Shaik Mubina and Bhaskar Prasad Saha

Centre for Carbon Materials

The Centre for Carbon Materials (CCM) intensively works on application oriented Research and Development activities to develop and demonstrate the processing of advanced materials component based technologies to Indian industries. The major acctivities of CCM are: (i) Technology demonstration to develop expanded graphite in bulk quantity and to develop various products therefrom; (ii) Corrosive resistance graphite-based bipolar plate development; (iii) Graphene production in scalable quantity for functional composites; (iv) Phase change materials for battery thermal management; (v) Additives for lubrication, (vi) Oil-water separation and (vii) High performance electrode materials for battery and supercapacitor applications. The research towards better scientific understanding of various materials and products are being executed through various characterization-mediated underlying mechanisms.



Major Highlights

- *Upscaling expanded graphite production in scalable quantity*
- *Developed specialized seal, tape, board and gasket*
- *Developed graphite based bipolar plate*
- *Designing a chemical reactor for continuous chemical treatment*
- *Process for graphene platelet production in bulk quantity*
- *Highly-aligned carbon nanotube arrays for field emission*
- *Developed graphene based Li-ion anode with exceptional capacity*
- *Developed novel composite materials (transition metal oxide) for high power LIB*
- *Developed porous carbon with high specific capacitance*
- *Developed nanoadditives for lubrication*
- *Developed eutectic composites for battery thermal management*
- *Developed composites for thermal interface materials*

Major Facilities

- *Laser flash thermal conductivity set-up*
- *Simultaneous thermogravimetry (STA))*
- *Rheometer and planetary ball mill*
- *Thermo-mechanical analyzer*
- *Electrochemical work station*
- *UV-Vis spectrometer*
- *Zeta potential set-up*
- *Source meter*
- *Arc discharge set-up*
- *Chemical vapor deposition set-up*
- *High shear mixer*
- *Four ball tester*
- *High pressure and high temperature autoclave*

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Technology Development

Development of process to produce expanded graphite

Expanded graphite obtained from natural graphite intercalation compound by customized thermal treatment process has application in several areas such as sealing material, oil absorbing material, fire retardant, high-power battery, electrode, military material, etc. The industrial significance of expanded graphite is prominently affected by the initial expansion temperature and the expansion volume; which in turn closely relates to the preparation process of intercalation and the chemical reagents. A unique process was developed at laboratory scale and scaled to prototype demonstration, wherein natural graphite flakes were chemically intercalated and thermally treated to produce Exfoliated Graphite Powder. Using the Exfoliated Graphite Powder developed at ARCI, various industrial products including Graphite Bipolar Plate for Fuel Cell applications, Automotive Gasket sheets, graphite Tapes etc were developed. Technology of Exfoliated Graphite powder and development of various products was transferred to M/s Falcon Graphite Industries, Hyderabad. Recently, the process parameters and technology were modified for its suitability for different grades and types of graphite raw material to target various important applications.

Fig. 1 SEM Micrograph of exfoliated graphite exhibiting worm structure

Key features

- *A unique design of reactor for graphite intercalation process.*
- *Exclusive thermal treatment process for exfoliated graphite.*
- *Process to obtain expandable Graphite with expansion ratio of more than 150 -200.*
- *Prototype demonstration of full process for 2.5 kg/batch.*
- *Easily scalable and cost effective process.*

***Applications**: Bipolar Plate for Fuel Cell, Cylinder Head Gaskets Sheets for Automotive Applications, Graphite Tapes for electrical contact in metallizing Industries, custom design seals for specific applications.*

Contributor: P. K. Jain

Research Highlights

Nanocarbon/N-doped carbon hybrids for carbon/carbon supercapacitor

In automotive sector, electric vehicles have drawn huge interest to attain zero-emission. High-performance electrode materials for supercapacitor are insightful focus to find suitability. To design an unique electrode material based on multimaterial-coupled hybrids, porous material consisting of nitrogen-enriched carbon (NC) coated on few-layered graphene platelets (FGP), nitrogen-incorporated tubular carbon (NTC) and deoxygenated graphene oxide (DGO) are developed for carbon/carbon supercapacitor. The porous carbon loaded with FGP (PNCG), NTC (PNCT), DGO (PNCD) and YP-50 exhibited a specific capacitance of 188, 147, 121, and 114 F/g (at 0.5 A/g) and capacity retention of 97, 93, 90 and 96 % (for 1000 cycles), respectively. PNCG//PNCG (28.17 Wh/kg & 4160 W/kg) exhibited superior capacitive energy storage in comparison toYP-50 (16.32 Wh/kg and 2977 W/kg) using compressed graphite foil based current collector.

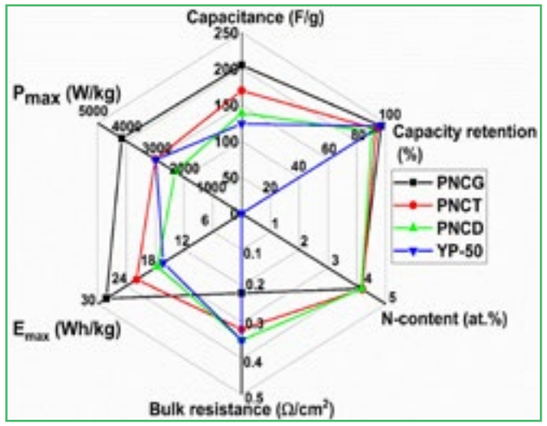
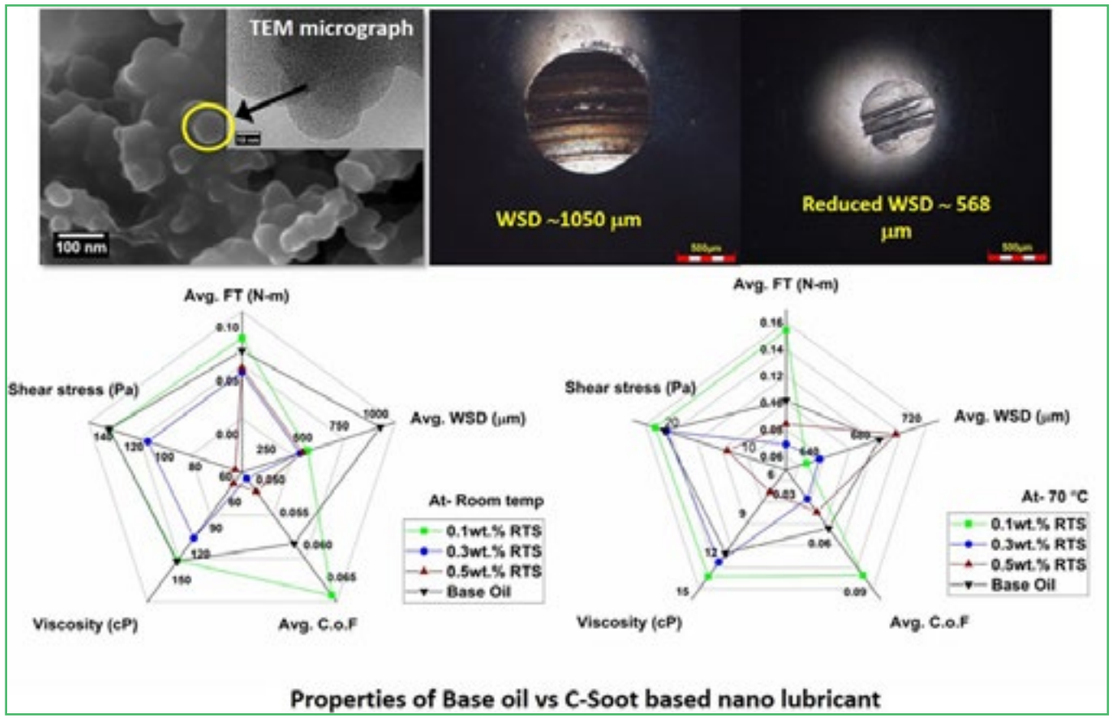


Fig. 2 A radar plot depicting the physicochemical and electrochemical properties of PNCG, PNCT, PNCD and YP-50

Contributors: Balaji Padya, Ravi Kali and P.K. Jain

Rubber waste derived carbon soot as friction and wear reducing additive in lubricating oil

Carbon soot particles are soft, flocculent and amorphous in nature, have a smooth surface, graphitic layers arranged to give them a solid internal structure with an average elastic modulus of 16.5 GPa and a hardness of 1.2 GPa making these particles ideal for tribological applications. Carbon soot particles (50-100 nm) with sphere-like morphology were synthesized from the decomposition of waste rubber which exhibited heliocentric-like arrangement of graphitic layers. The soot particles displayed excellent oxidation resistance over 500°C in air and when dispersed in lubricating oil acted as viscosity index modifying additive at optimized concentration and also reduced the shear stress generated in the oil. Tribological properties of soot dispersed oil samples outperformed the pure oil showing lower values of wear and friction coefficient (C.o.F). Significant reduction in C.o.F are seen both at room temperature (~16%) and 70°C (~32%) after addition of optimized concentration of soot particles. 56% reduction in wear scar was observed for the 0.3 wt.% of soot particles in pure oil at room temperature.



Properties of Base oil vs C-Soot based nano lubricant

Contributors: Ravi Kiran and P.K. Jain

Concentric-shelled disordered carbon for sodium ion storage: A step forward in recycling solid waste to value-added carbon

Graphite is extensively applied as the negative electrode in commercial LIBs. It works based on the reversible intercalation reaction of Li ions by forming graphite-intercalation compounds (GICs) and its low charge/discharge potential with long cycle life. However, it displays poor electrochemical performance in Sodium-Io Batteries (SIBs) because of the larger ion size (Na^+) in comparison with Li^+, and sodium GICs are thermodynamically unstable as compared to other alkali graphite-intercalation compounds. We report, a cost-effective strategy to generate nanoscaled concentric-shelled disordered carbon (CSC) from discarded bicycle's rubber tube via burning in a controlled atmosphere. CSC is used as an anode material in SIBs and it exhibited reversible specific capacity of 150 mA h g^{-1} at a current density of 100 mA g^{-1} after 100 electrochemical cycles. This study proposes that recycling of discarded bicycle's rubber tube is sources for the emergence of high-performance nanocarbon, which can boost the capacity of SIBs.

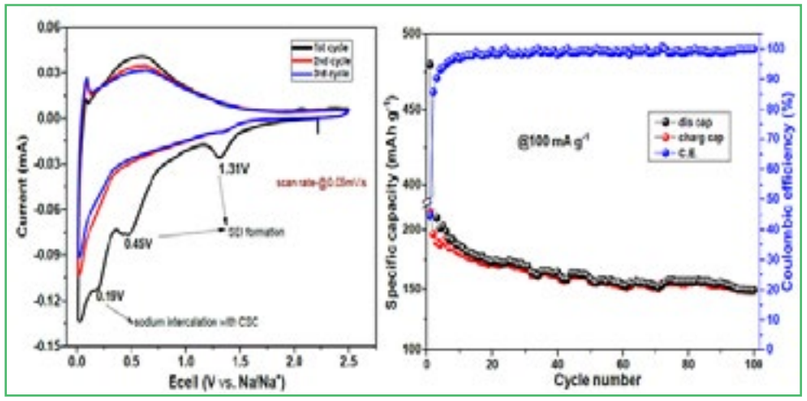


Fig. 3 Cyclic voltammetry and cyclic stability of concentric-shelled disordered carbon (CSC)

Contributors: Ravi Kali

Novel metal free carbon-based polymeric semiconductor for photocatalytic studies

Novel graphitic-carbon nitride (g-C_3N_4) photocatalyst was synthesized by thermal-pyrolysis of melamine between 500-700 °C in ambient atmosphere. It consists of layered morphology with periodic array of C-N aromatic architecture as shown in the figure. g-C_3N_4 possess a moderate bandgap of 2.7 eV corresponding to an optical wavelength of 460nm which makes it active under visible light. The XRD diffractogram confirms two significant peaks at around 13° and 27° associated with the intra-planar and inter-planar distances respectively. The photocatalytic degradation of organic dyes is one of the major studies done using g-C_3N_4. Typically, within 30 minutes, almost complete degradation of RhB dye was observed. This material has potential applications in several other fields like energy, environmental remediation, etc. g-C_3N_4 based hybrid materials involving carbon nanomaterials and other potential photocatalytic material can create a new branch of research in material science.

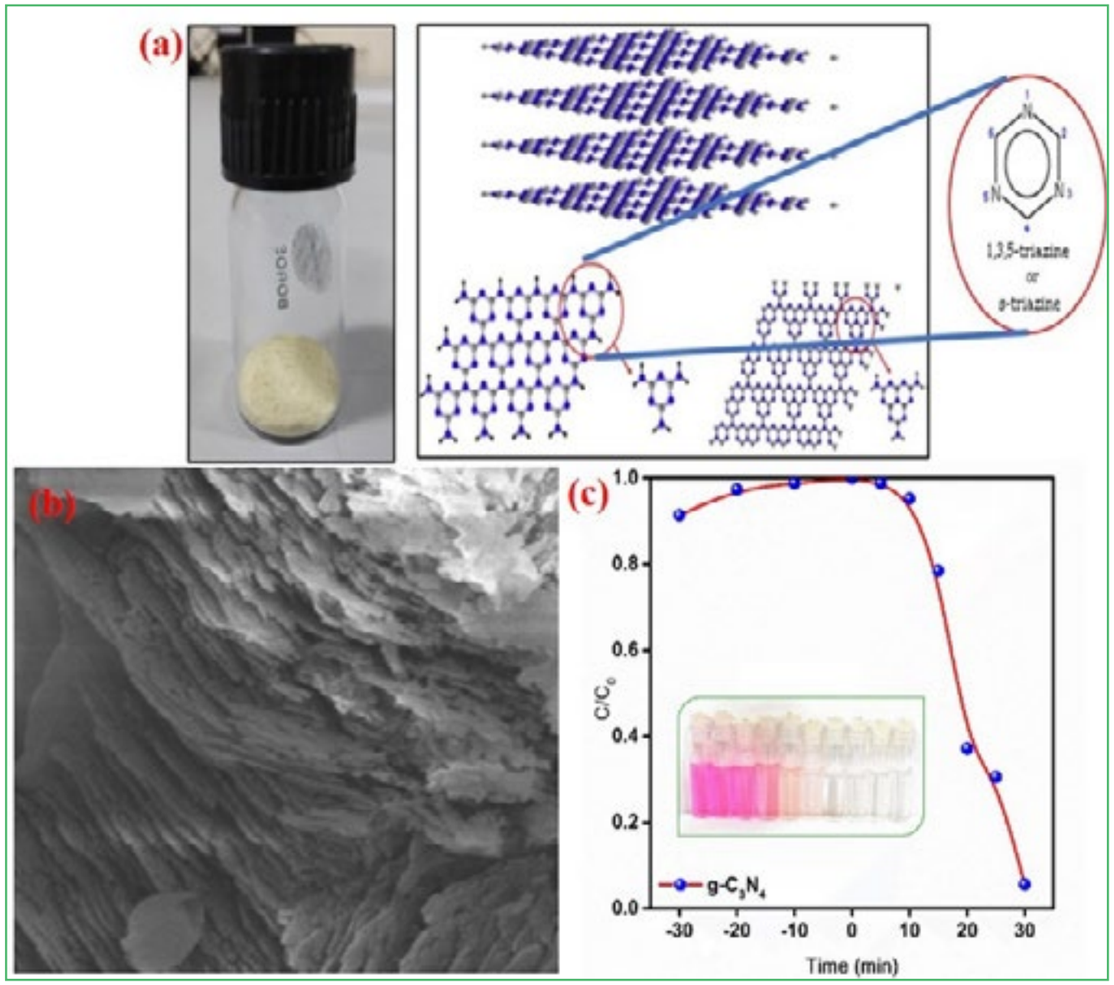


Fig. 4 (a) Image of synthesized g-C_3N_4 and layered structure of g-C_3N_4 consisting of periodic C-N heterocyclic array, (b) FE-SEM morphology of g-C_3N_4 and (c) dye degradation studies using g-C_3N_4, gradual photodegradation of RhB

Contributors: V.P. Madhurima and P.K. Jain

Centre for Sol-gel Coatings

Sol-gel processing is a wet chemical based synthesis route, where the sol is generated as a result of hydrolysis and poly-condensation of fully hydrolysable or organically modified metal-organic precursors. The sol can be used to deposit coatings on various substrates followed by thermal or radiation curing to obtain a functional coating.

Highlights

Hybrid nanocomposite multi-functional coatings developed/ demonstrated so far:

- *Eco-friendly self-healing corrosion resistant coatings for Al/Mg alloys/steels*
- *Self-lubricating, adhesion promoting, corrosion protective coatings on GI and steel sheets*
- *Anti-bacterial biofilm inhibiting coatings on glass, metal, plastics and fibres*
- *Scratch and abrasion resistant coatings on plastics*
- *Decorative nanocomposite coatings on glass and ceramics*
- *Easy to clean, hydrophobic coatings on glass, metal and plastics*
- *Anti-reflection coatings on glass and plastics*
- *Solar control coatings for glass*
- *Solar selective coatings for SS and Al substrates*
- *Flame retardant coatings on fabrics*

Self-healing corrosion resistant coatings

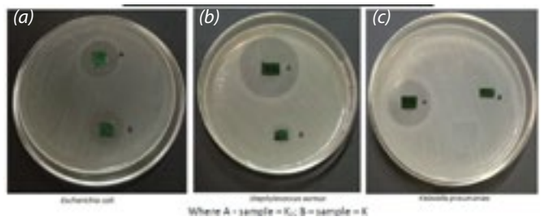
Hard Coatings on Plastics

SS showing difference in hydrophobic behavior

Decorative coatings

Achievements during the year

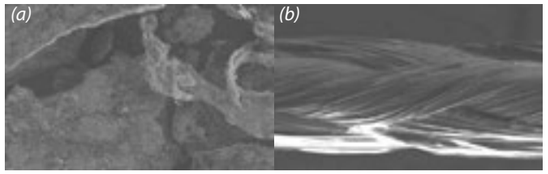
- *Sol composition developed for fast curing, corrosion resistant, self-lubricating, adhesion promoting coating for CRCA and GI steel sheets*
- *Sol-gel based product developed for imparting anti-bacterial (AB) property to abrasive pads made of non-woven nylon fabric*



Sol-gel coated products exhibit excellent zone of inhibition against different bacteria (a) Escherichia Coli, (b) Staphylococcus aureus and (c) Klebsiella pneumoniae. A & B are different AB powders

- *Coating formulation developed for imparting anti-bacterial property by inhibiting the biofilm formation on surgical sutures for preventing surgical site infections*

Process/product development



Sol-gel based (a) AB nano composite powder (b) Biofilm inhibiting coating on surgical suture

Sol-gel AB nano composite powder and abrasives loaded formulation deposited on scrub pad

Major facilities available

- *Process facilities: Pilot plant for 10, 20 and 100 litres reactors*
- *Cleaning and pre-treatment facilities for substrates: Plasma treatment*
- *Coating deposition: Automated flat spray and dip coaters*
- *Curing & densification: UV, IR, LED curing units and drying ovens*
- *Characterization and testing: Contact angle, Weather resistance, Spectroscopic Ellipsometer, Taber abraser, UV–Visible–NIR spectrophotometer, Electrochemical workstation and Scanning Kelvin probe*

Plasma pre-treatment

Dip Coater

Scanning Kelvin probe

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Technology Development / Transfer

Antibacterial coatings on nonwoven abrasive pads

Scrub pads made of abrasive-loaded nonwoven nylon fabrics are used for domestic and industrial applications. Under service conditions, they experience a moist environment, thereby becoming breeding grounds for the rapid growth of bacteria and spread to other surfaces. Due to increasing concern of antibiotic resistance, it is essential to make these surfaces antibacterial. For this purpose, environment friendly nanocomposite antibacterial powders were developed, homogenized with formulation, and loaded with abrasives. This modified formulation when applied, the scrub pads exhibits antibacterial properties with > 95% log reduction of bacterial strains, *E.coli, S. aureus and K. pneumonia*.

Antibacterial coated Scrub pad generated in the scrub pad production line at CUMI, Chennai

Contributors: R. Subasri, KRC Soma Raju, DS Reddy, K Srinivasa Rao and Roy Johnson (ARCI, Hyderabad); Xavier Kennedy and Ayath Basha (Carborundum Universal Limited, Chennai)

Research Highlights

Release mechanism of corrosion inhibitors from nanocontainers of self-healing corrosion protection coatings

Self-healing coatings contain corrosion inhibitors loaded into nanocontainers, which are released in response to an external trigger like change in local pH in the event of coating damage, thereby providing prolonged corrosion protection. Three different corrosion inhibitors, Ce^{3+}/Zr^{4+}, 8-Hydroxyquinoline (HQ) and Mercaptobenzothiazole (MBT) were evaluated for their release from halloysite nanotube containers at different pH values of corrosive medium and further validated with different kinetic models (Korsmeyer-Peppas, Higuchi, Hixson-Crowell, etc.) used to study the drug release. The investigations revealed the ideal pH conditions suitable for release of specific corrosion inhibitor. This information could be useful in designing the self-healing coatings.

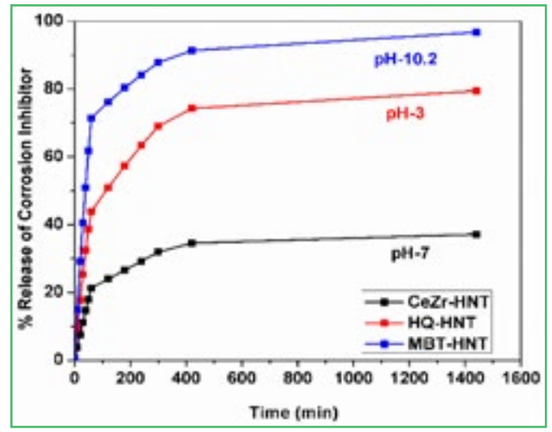


Fig. 2 % Release of different corrosion inhibitors (data for pH conditions where maximum release occurred only are presented)

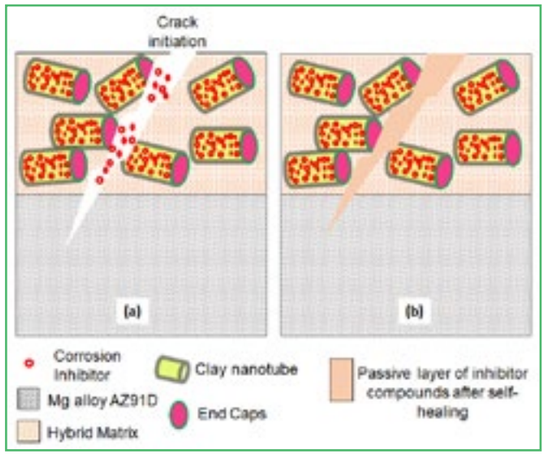


Fig. 1 Self-healing mechanism of inhibitor loaded halloysite nanotubes

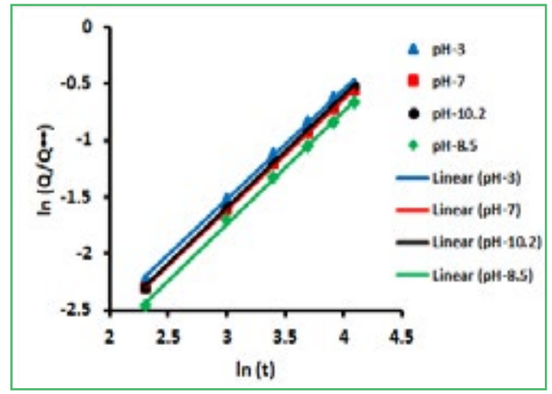


Fig. 3 Release rate fit of Ce^{3+}-Zr^{4+} using Korsmeyer-Peppas model

Contributors: Swapnil H. Adsul and R. Subasri

Duplex coating for improved corrosion protection of Mg alloys

Mg alloys are extensively used in automotive, aerospace and biomedical applications due to their low densities and high strength-to-weight ratios. However, they are prone to corrosion when exposed to extreme atmospheric conditions. Anodization is one of the conventionally employed corrosion protection techniques. However, anodized layer alone is not sufficient to offer corrosion protection for longer durations due to its porous surface morphology. Ambient curable hybrid sol-gel nanocomposite coatings with embedded corrosion inhibitors were used as sealant over the anodized layer and this duplex layer was found to provide enhanced corrosion protection with self-healing properties.

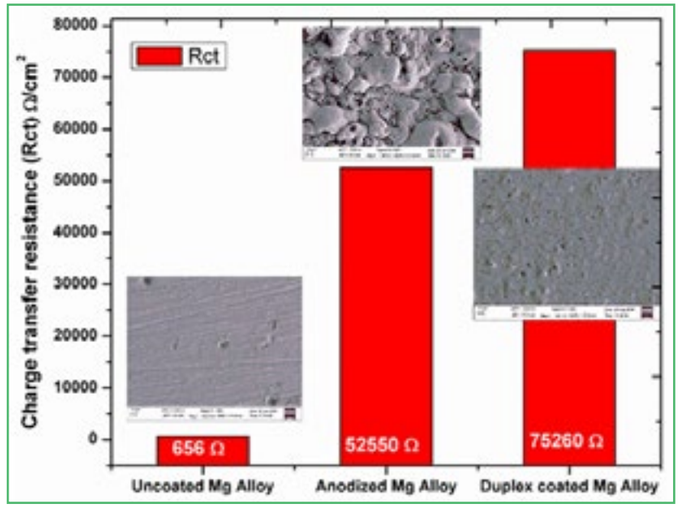


Fig. 4 Charge transfer resistance and corresponding SEM images of uncoated, anodized and duplex coated Mg alloy AZ31

Contributors: K Pradeep Premkumar and R Subasri

Biofilm inhibiting nanocomposite coatings on sutures to prevent surgical site infections

Engineering the surfaces of surgical sutures with low surface free energy coatings is the key solution to prevent bacterial colonization/infections and combat antimicrobial resistance (AMR). Two different hydrophobic nanocomposite coating compositions named IH and HC were deposited on nylon, silk, polyglactin 910 surgical sutures, which was followed by biofilm inhibition testing using ATCC and clinical isolates of bacterial strains of Staphylococcus aureus, Pseudomonas aeruginosa, Acinetobacter baumanii, Enterococcus faecalis and Eschericia coli in some cases. Biofilm inhibition for the sol-gel coatings was found to be better than commercially available Triclosan coated sutures in most cases, as shown in Fig. 5.

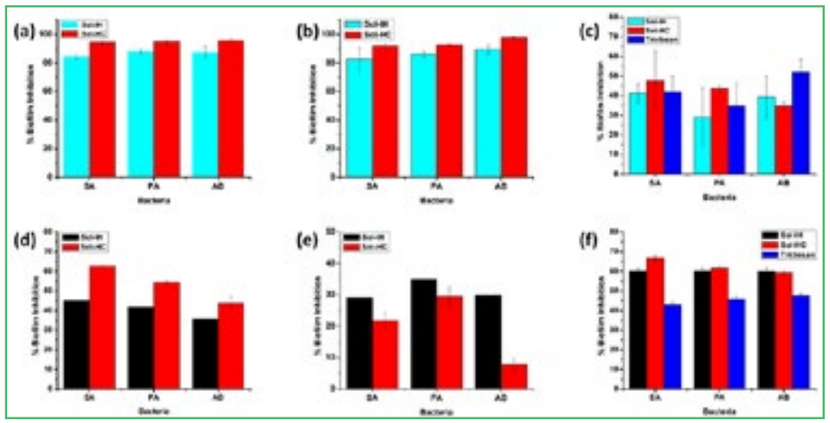


Fig. 5 Percentage biofilm inhibition of on (a) coated silk suture against ATCC (b) coated Nylon suture against ATCC bacterial strain (c) coated Polyglactin 910 against ATCC bacterial strain compared with commercially available triclosan coated suture (d) coated silk suture against clinical isolate bacteria (e) coated nylon suture against Clinical isolate bacteria (f) coated Polyglactin 910 suture against clinical isolate bacteria compared with commercially available triclosan coated suture

Contributors: Ramay Patra, K.R.C. Soma Raju, R. Subasri (ARCI, Hyderabad); Susmita Chaudhuri, Debrupa Sarkar (THSTI, Faridabad); Prashant Garg, B. Bhaskar (LVPEI, Hyderabad)

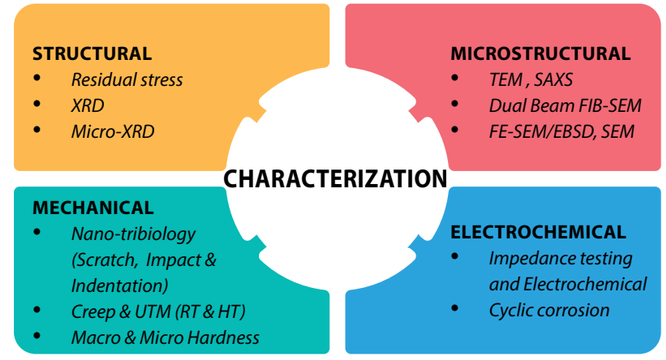
Centre for Materials Characterization and Testing

Objectives

- *To offer a range of solutions for internal characterization needs and conduct basic research to support ARCI's technology development programmes*
- *To carry out multi-scale, multi-property characterization for R&D laboratories, industries and academic Institutions in project mode*

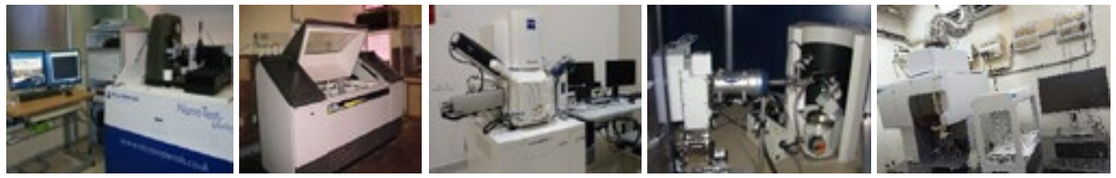
Highlights

- *Experienced team to perform Microstructural, Structural, Chemical and Mechanical characterization*
- *State-of-the-art characterization tools to probe different types of materials in the crystalline and amorphous states, covering all length scales (bulk, coatings and nanomaterials)*
- *Facilities in the Centre are available for use by academic institutions and industry*



Major Equipment

TEM | SAXS | UTM | Residual Stress | Dual Beam | High Flux Powder X-ray Diffraction



Nano-Test | Cyclic Corrosion Chamber | FESEM | Micro X-ray Diffraction | ICP-OES

Characterization Facilities

Microscopy

- *Transmission electron microscopy*
- *Field Emission SEM with EBSD*
- *Dual beam FIB-SEM*
- *Conventional SEM*
- *Optical microscopy*

X-ray Techniques

- *Small angle X-ray scattering*
- *High flux X-ray diffraction*
- *Micro-diffraction*
- *Residual stress*

Mechanical Testing

- *Nano-tribology*
- *Creep testing*
- *Tensile and compression testing*
- *Micro/Nano Indentation testing*

Chemical/ Electrochemical

- *ICP-OES*
- *Electrochemical analysis*
- *Cyclic corrosion testing facility*

Specimen Preparation

- *Metallography*
- *Vibratory polishing*
- *PIPS*
- *Twin-jet electropolishing*
- *Dimple and disc grinders*
- *Ultrasonic and mechanical disc punches for TEM specimens*

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Research Highlights

Indentation creep of PVD coatings for machining applications

To enhance the performance of physical vapour deposited coatings such as TiN, TiAlN and TiAlCN, a nanocrystalline-TiAlN/a-Si_3N_4 (NC) coating has been deposited. Recently, a new laboratory technique, cyclic nanoimpact testing, performed using nanoindentation, has been developed to simulate interrupted milling conditions employed in the cutting tool industry. The depth vs. time data from nanoindentation can be fitted as:

Y = a*(X-b)^c

where X is the time, Y is the depth, and a, b and c are the constants. c = m/2 and m = 1/n. m is the strain rate sensitivity and n is the stress exponent.

Fig. 1 shows a representative depth vs. time curve along with the fit parameters. Using the analysis developed by us, the machining performance order of the coatings has been determined to be TiN>TiN/NC>NC.

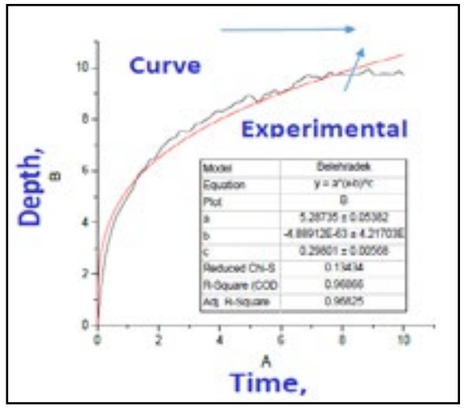

Fig. 1 Experimental and curve-fitted data of depth-time curve of TiN/NC multilayer coating obtained from nanoindentation

Contributors: N. Ravi and P. Suresh Babu

Structural stability of metal halide perovskites by in-situ non-ambient X-ray diffraction

Metal halide perovskites exhibit exceptional optoelectronic properties and solution processability. The poor structural stability of metal halide perovskites at elevated temperature (> 60ºC) and moisture (> 50 % RH) is one of the major factors limiting the commercial potential of perovskite solar cells (PSCs). Herein, in-situ non-ambient X-ray diffraction has been used to study the influence of temperature and moisture on the structural stability of Methylammonium lead iodide ($MAPbI_3$), which is the baseline material in R&D of PSCs. A combination of elevated temperature and high RH accelerate the degradation of $MAPbI_3$ into PbI_2 through hydrated intermediate perovskite phase. The intrinsic stability of perovskite absorber can be notably improved by fine turning the precursor stoichiometry, perovskite layer deposition and post-annealing, as evident from the non-ambient XRD analysis.

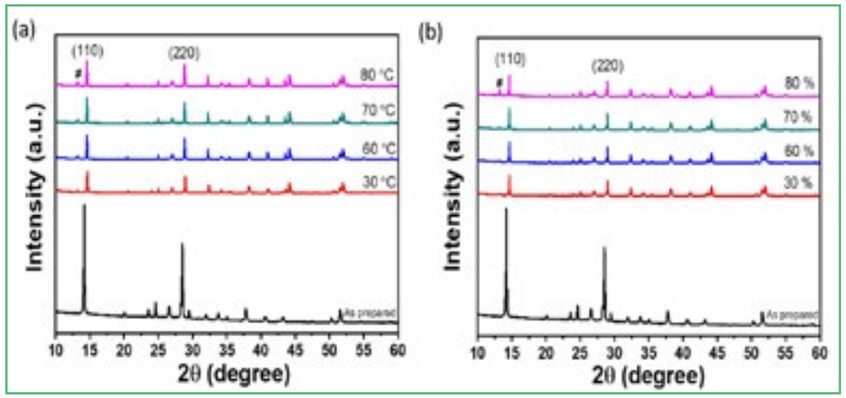

Fig. 2 In-situ XRD patterns of the $MAPbI_3$ perovskite film exposed to (a) varying temperature at 70% RH (b) Varying moisture at constant temperature of 30 ºC. # - hydrated phase of $MAPbI_3$

Contributors: K. Suresh and R. Easwaramoorthi

Microstructural study of additively manufactured Inconel 718

Inconel 718 (IN718) is one of the prominent aerospace alloys and owing to low (Al+Ti) content, it has also gained prominence as the most amenable alloy for additive manufacturing. In-house synthesized IN718 powder was processed using laser-based powder bed additive manufacturing technique in order to study the effect of solution treatment on precipitation and to compare the precipitate evolution to that in Wrought IN718. As-build alloy along with the wrought alloy from which the powder is synthesized, were subjected to homogenization and double aging treatment. Three different solutionizing treatments, at 980, 1030 and 1080°C were carried out in order to study the effect of the same. In addition to the solutionized samples, the as-processed alloy was also subjected to aging. Transmission electron microscopy observations were carried out on all aged samples and the presence of both γ" and γ' precipitates in the matrix was seen. In the case of direct aged and 980°C solutionization of aged samples, the presence of a secondary matrix phases such as laves and delta was observed. It is known that both these phases consume Nb required for formation of γ", which is a prime strengthening phase. As the high temperature performance of the alloy depends on the size and volume fraction of the γ" precipitates, quantitative microstructural analysis of all aged samples was carried out using small angle x-ray scattering. The results are shown in the chart below. It can be observed that solutionization at 1080°C and 1030°C resulted in volume fraction similar to that of found in wrought IN718, thus confirming that AM processed IN718 responds similar to that of wrought IN718 with respect to precipitation evolution.

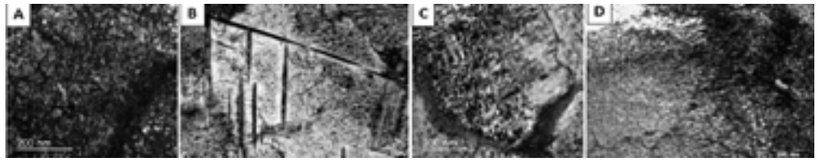

Fig. 3 Bright field images of additive manufactured IN718 after A) 980°C Direct aged, B) 980°C solutionized and aged, C) 1030°C solutionized and aged, and D) 1080°C solutionized and aged

Sample	γ"			Total V_f
	Size (nm)	ND(X10^{17})	$V_f(\gamma")$	$V_f(\gamma")+V_f(\gamma')$
Direct Aged	6.4	1.9	2.3	4.1
980° C Solutionized+Aged	6.3	1.7	1.8	3.3
1030° C Solutionized+Aged	6.9	5.9	4.9	11.5
1080° C Solutionized+Aged	7.5	6.8	4.4	9.8
Wrought IN718 -980° C Solutionized+Aged	7.2	2.3	1.7	6.4
Wrought IN718-1030° C Solutionized+Aged	8.0	3.7	2	6.7
Wrought IN718-1080° C Solutionized+Aged	6.7	5.0	4.4	13.3

Table 1: Size and volume fraction of γ" in aged AM-IN718 and wrought-IN718 solution treated at different temperatures

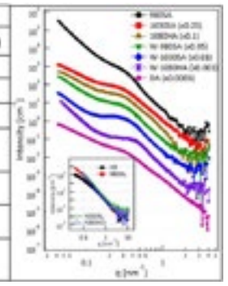

Fig. 4 SAXS curves of AM-IN718 and wrought-IN718 in solution treated and aged condition

Contributors: M. Ramakrishna and K. Suresh

Microstructure and property correlation in laser clad Inconel 625

Laser cladding of Inconel, as compared to other coating techniques, has several advantages such as control of crystallographic texture and strong metallurgical bonding at the clad–substrate interface. Inconel 625 powder was deposited onto carbon steel using a diode laser with laser power varied from 800 W to 2400 W in 200 W increments. There was a gradual increase in dilution (2 to 40%) with laser power with a corresponding decrease in hardness. The grain size increased (Figure 5) with laser power up to 1600 W. Crystallographic texture had a greater effect on the hardness of the coatings as compared to the grain size.

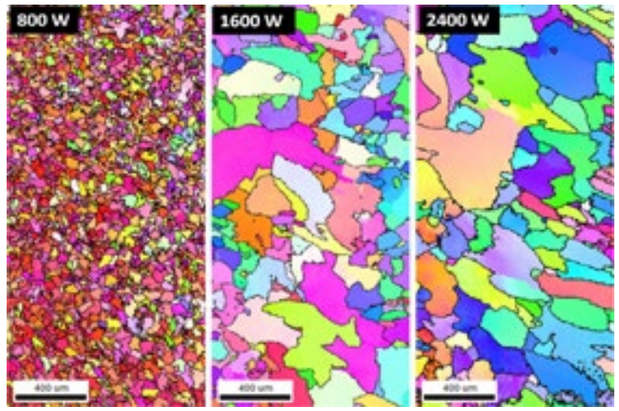

Fig. 5 Inverse pole figure (IPF) maps of laser clad Inconel 625 with increasing laser power (the laser power used in mentioned in the inset)

Contributors: L. Venkatesh and Manish Tak

Corrosion behaviour of ODS iron aluminides in a chloride containing solution

Oxide dispersion strengthened (ODS) Fe_3Al is expected to provide improved ductility, creep resistance and fracture toughness by the beneficial action of stable nano-sized dispersoids. In this study, the important influence of alloying elements on the passivation behaviour in ODS Fe_3Al has been explored. Cyclic polarization (CP) studies were carried out on ODS-Fe_3Al alloy in 3.5 % NaCl solution for different exposure times of 1, 72, 120, 166 and 240 h. The CP curves in Fig. 6 show a positive hysteresis loop, which is indicative of pitting corrosion. The corrosion increases up to 72 hours, of exposure to NaCl solution, after which the formation of a passive layer prevents further corrosion.

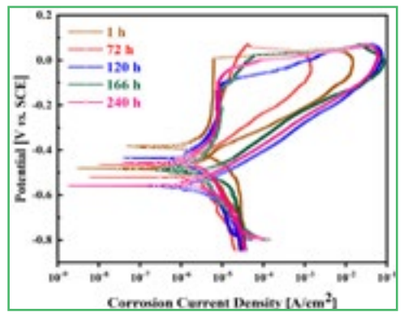

Fig. 6 Cyclic polarization curves of ODS–Fe_3Al alloy

Contributors: A. Jyothirmayi, R.Vijay, P.Vijaya Durga and M.Nagini

Centre for Technology Acquisition and Transfer

Achievements at a glance

- R & D /Technology Agreements signed : 28
- Confidential Agreements signed : 29
- Costing for technologies / projects : 42
- Patents filed / granted : 13 / 23
- Prior art search and related reports : 28
- Leads generated : 60 +
- Performance reporting to government agencies/ stakeholders : 45 +
- Competitive Intelligence performed : 12

Intellectual Property Development Indices (IPDI) based Collaborative and Technology Transfer Models { ICTTMs}

- Implemented at ARCI from 2014-2015
- Key role in significant growth (more than double) of collaborations / technology transfers for 2016-21 vs. 2011-2016
- Taking care of advanced materials sector, lab to industry technology transfers
- Attempting to maximize impact of available R & D capability by value addition from IPDI 1 to 10
- Imparting flexibility in forward progression on Readiness Levels, based on assessment at milestones
- Enhancing the trust between stakeholders, when negotiations include the present and target IPDI levels

I C T T Ms

Salient features of ICTTMs and role of the centre

IPDI	1	2	3	4	5
Activities →	*Basic Concepts and understanding of underlying scientific principles*	*Shortlisting Possible Applications*	*Research to prove technical feasibility for targeted applications*	*Coupon level testing in simulated conditions*	*Check repeatability/ consistency at coupon level*
IP Chain Milestones →	*Exploratory Studies*		*Laboratory Testing*		
Role of CTAT →	• *Competitive intelligence* • *Identification of possible collaborators* • *Selecting appropriate engagement models (decision variables include IPDIs, collaborators, IP ownership & licensing methodology, deliverables, milestones, financials etc.)* • *Preparing/ negotiating/ finalizing contractual agreements* • *Patent analysis and filing* • *Costing of technology-derived products / technologies / projects*				

IPDI	6	7	8	9	10
Activities →	*Prototype testing in real-life conditions*	*Check repeatability/ consistency in real-life conditions*	*Reassessing feasibility {IP, competition, technology, commercial, impact on SHE (safety, health and environment)}*	*Initiate technology transfer*	*Support in stabilizing production*
IP Chain Milestones →	*Field Demonstration*		*Technology Transfer*		
Role of CTAT →	• *Activities mentioned from IPDI 1 to 5 above* • *Preparing status report on ongoing R&D projects and using them for IP/ technology marketing efforts* • *Feasibility assessment* • *Costing of technology-derived products/ technologies /projects*		• *Activities mentioned from IPDI 1 to 8* • *Receivables management (collection of technology transfer fees/ royalties) even beyond IPDI 10*		

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Contributing towards mutually rewarding technological partnerships (Agreements signed during the year)

Technology Demonstration / Transfer Agreements

Sl. No.	Purpose	Month/Year of Signing
1	Human Disinfection System for COVID -19	April, 2020
2	UVC based Disinfection System for COVID -19	May, 2020
3	Easy-to-clean coating (super hydrophobic) sol composition and coating technique on PV panels	May, 2020
4	Photocatalyst-assisted copper-based mineral (self-disinfecting) paint	May, 2020
5	UVC based tunnel baggage disinfection system for airports, railway stations, bus stations and hotels, commercial and private complexes for disinfection of baggage to fight COVID-19	June, 2020
6	UVC based disinfection cabinet for hospitals, research and academic institutes, commercial complexes and disinfection of domestic articles to fight against COVID-19	June, 2020
7	Production of hypochlorous acid solution and its qualification for surface disinfection	July, 2020
8	Production of transparent photo sensors	July, 2020
9	Disinfection system for currency notes based on UVC radiation to fight against COVID-19	August, 2020
10	Design, development and integration of capacitor management system for supercapacitor module for e-bike	August, 2020
11	Synthesis of electro-catalysts for use in fuel cells	August, 2020
12	Exploring the efficacy of UV-C BOX against SARS-COV2	September, 2020
13	Easy to clean coating (superhydrophobic) sol composition and coating technique on PV panels	September, 2020
14	Development and setting-up of pilot-scale production facility of supercapacitor grade activated carbon derived from coconut shell based charcoal for electrical energy storage application	October, 2020
15	Render consultancy w.r.t.hypochlorous acid solution for surface disinfection and co-develop human disinfection systems	November, 2020
16	Development of tungsten fibre reinforced tungsten composite for plasma facing component	February, 2021

Option Agreements

Sl. No.	Purpose	Month/Year of Signing
1	Evaluation of anti-reflective coating technology	December, 2020
2	Evaluation of easy-to-clean coating (anti-soiling) for solar PV glass panels	December, 2020

Technical Service Agreements

Sl. No.	Purpose	Month/Year of Signing
1	Real time stability analysis & validation of thermic fluids at process temperature by using parabolic concentrated solar thermal rig	May, 2020

Agreements for Access and Benefit Sharing

Sl. No.	Purpose	Month/Year of Signing
1	To facilitate for IPR on the invention titled "method of producing graphene like structured nanoporous carbon material from jute stick based bio-waste for energy storage applications and the product thereof"	February, 2021
2	To facilitate for IPR on the invention titled "An improved process of carbon-metal oxide composite prepared by nanocasting of wood and the product thereof"	February, 2021

Conditional Grant Agreements

Sl. No.	Purpose	Month/Year of Signing
1	Development of new Al alloy for additive manufacturing for industrial applications	March, 2021

R&D Collaboration Agreements

Sl. No.	Purpose	Month/Year of Signing
1	Development of high temperature erosion corrosion test rig for testing coating and materials for power plant applications	May, 2020
2	Design and development of an automated assembly line for manufacturing PEMFC	May, 2020
3	Alloy development for additive manufacturing of prostheses and reconstructive implants	May, 2020
4	Collaboration in multiple areas of mutual interest	October, 2020
5	Development of carbon coated Nickel Manganese Cobalt Oxide (C-NMC 532) electrode material for battery applications	March, 2021
6	Joint proposal on setting up of demonstration of Lithium Ferrous Phosphate and/or Graphite Lithium ion cell production facility	March, 2021

Developing R & D roadmaps for upscaling of technologies

R & D laboratories transfer research results to organizations for carrying out the manufacturing activities. When viewed from the perspective of research organizations, R & D Roadmaps help in the planning of necessary in-house activities, make prior arrangements for collaborations to mobilize external resources and capabilities for scale-up efforts, identification of appropriate commercializing entities followed by the identification of post-technology transfer support.

At ARCI, an initiative was undertaken during last year to prepare roadmaps for those research projects which have completed lab scale experimentation for preparing strategies to complete field trials and to make ready transferable technologies. Major points contained in the R & D upscaling roadmap are briefly described below:

APPLICATION DEVELOPMENT PLAN

- Targeted application(s)

COMPETITION ASSESSMENT

- Bench mark product in the market, if any
- Any academic institution(s)/ R & D lab(s) / industrial organization(s) is/are working on the same/competing technology or product for each of the targetted applications
- Technology Competitiveness : Superiority of your technology / process over the available technologies / processes in India or abroad

COLLABORATION NEEDS' IDENTIFICATION

- Arrangements / collaborations required to complete the field trials
- Details of completed / planned field trials
- Possible organization(s) which could be interested/approached to conduct field tests for the targeted application(s)
- Organization(s) to be approached for repeating field test for targeted application (s)?
- Inter-departmental cooperation's forged / to be forged

COST- COMPETITIVENESS EFFORTS

- Cost per unit of the product / service derived from the technology and the cost-cutting efforts
- Cost of comparable / substitute offerings by competitor(s)

SUPPLY CHAIN ASSESSMENT

- Supply chain related challenges (whether process is optimized with raw material of consistent quality / regular availability / economical price)
- Optimizing the process with indigenous raw materials , checking the product consistency with low-cost raw material or any such efforts

PATENT ANALYSIS AND PATENT PORTFOLIO STRATEGY

- Patenting possibilities and status
- Patent portfolio requirements and progress in the direction
- Patent analytics to identify (a) collaborators with complementary Intellectual Property (IP) and (b) partner organization(s) for field trials
- Freedom to Operate (FTO) check

VALIDATION(S)

- Validation requirements (including standards, if any)
- Validation attempts and status

TECHNOLOGY TRANSFER AND COMMERCIALIZATION

- Safety, Health and Environmental issues associated with the future commercialization
- Technology evaluation by a suitable committee
- Making a business case
- Identification of the start-ups/existing companies to commercialize the technology for the target application(s)

Such roadmaps help in creating a consensus across the organizations for adopting a step by step approach to derive optimum value from developing new technologies, processes and products. To derive possible advantage from this methodology, R&D road maps were developed at ARCI by involving teams with complementary skills and capabilities.

Table depicting milestones and activities for preparing R&D roadmaps

Milestones (after repeatability of lab scale experimentation) →	Prototype testing in real-life conditions	Check repeatability / consistency with prototype in field conditions
Activities under each milestone →	Review 1	Review 3
	Application development plan	Application development plan
	Competition assessment	Competition assessment
	Collaboration needs' identification	Collaboration needs' identification
	Cost- competitiveness efforts	Cost- competitiveness efforts
	Supply chain assessment	Efforts to address supply chain challenges
	Patent analysis and patent portfolio strategy	Patent analysis and patent portfolio strategy
	Validation(s)	Validation(s)
	Review 2	Technology transfer efforts
	Other value addition requirement(s) identified	Reviews (internal and external)
		Value addition requirement(s) identified and action points to make a business case before undertaking technology transfer to an indentified technology recipient organization

Contributors: Sanjay Bhardwaj, G. Padmanabham, Arun Seetharaman and Priya A. Mathews

Linking intellectual property, prior art search & analysis to the technology upscaling process

Technology upscaling process at ARCI has been managed by using Intellectual Property Development Indices (IPDI) based Collaborative and Technology Transfer Models (ICTTMs). Securing Intellectual Property Rights (IPRs) and IPR related analysis find utility and importance at various stages and milestones in the ICTTMs. In the initial stages of the IPDIs (1-2), study of pre-existing Intellectual Property (IP), especially patents play a crucial role. Pre-existing patents, known as patent prior art, are studied in a systematic fashion to identify the research gaps typically called as white spaces. White space analysis helps the scientist form a strategy and initiate planning of research activities. In certain cases, during this stage, it may be potentially beneficial to either collaborate with other organizations with complementary capabilities or bring aboard an expert for further progression in the technology upscaling process. A comprehensive patent portfolio analysis of organizations and inventors, having activities in the relevant domains, will help in the identification of such a resource.

As the research advances further to IPDI (3-4) and development at lab-scale begins to accelerate, prior art search and analysis are conducted to review these developments in terms of novelty of the process, product, material composition etc. Scientist(s) may use this information to re-assess the progress made thus far and change the direction of research, if necessary. When the novelty is ascertained and /or the research is fine-tuned, the R&D progresses to next IPDI level 5. Here, patentability search reports are generated to bring out the unique features of ARCI's invention vis-a-vis that of the existing IP, so that inventiveness can be determined and an informed decision to secure IP rights can be made. Upon the establishment of inventiveness, the patent is filed following due procedures prescribed by the organization (ARCI).

The Ideation to Technology Transfer Value Chain at the IPDI 6-8 is associated with the field demonstration which involves prototype testing in real life conditions. Here, patent analysis reports can be generated to identify suitable collaborators/ partner industrial organizations to forge collaborations for conducting field trials followed by repeatability and consistency. Establishment of repeatability and consistency in real-life conditions is very crucial in this value chain as it determines its readiness for transfer. Freedom to operate (FTO) analysis is conducted at IPDI level 8. FTO clearance minimises the patent infringement risks and helps in smooth transfer and commercialization of technology. Currently FTO clearance is being obtained on a case to case basis (either by ARCI or by the prospective receiver). In addition to FTO analysis, Patent landscaping studies coupled with the market research reports, conducted at this stage, help in formulating collaborative and technology transfer strategies.

The final milestone in the Value Chain at IPDI (9-10) is technology transfer. Through, patent portfolio analysis a prospective technology receiver company can be assessed based on its IP strengths. Such patent based analysis supports the due diligence and outreach activities conducted for identification of a suitable technology recipient for ARCI's technologies. FTO can also be conducted at the beginning of IPDI 9 to prepare a strategy for product launch by avoiding risks of infringing the IPs associated with competing products/ services.

Securing other IP rights such as trade secrets, copyrights, industrial designs and trademarks, can be adopted at various milestones in the ideation to technology transfer value chain especially during later stages of IPDIs (6-10). This could be beneficial when an invention-based-product requires protection by complementary/synergistic IP rights. IP rights, other than patenting , may be leveraged even after the expiry of patent term.

Table depicting linkage between IP, Prior Search & Analysis with IPDI levels

IPDI	1	2	3	4	5	6	7	8	9	10
Linking IP and Prior Art Search & Analysis Reports	• White Space Analysis for identification of Research Gaps • Patent Portfolio Analysis for Identifying - Prospective Research Collaborators - Subject Experts		• Novelty search report for - Assessing novelty cum utility - Fine-tuning of the Research Activities		• Patentability search for securing Patent Rights • Filing Patent	• Patent Portfolio analysis for identifying suitable collaborators/partner industries and forge collaborations to conduct field trials • Secure patents and other forms of IPs		• Freedom to Operate (FTO) • IP portfolio analysis for Market survey and Competitor evaluation • Secure patents and other forms of IPs (Trade secrets, Copyrights, Trademarks, Industrial Designs)	• Freedom to Operate (FTO) • IP portfolio analysis to support Due Diligence and Technology Marketing Activities	• Secure patents and other forms of IPs

Contributors: Priya A. Mathews and Sanjay Bhardwaj

Identifying entrepreneurs for commercialization of advanced materials technologies

For an organization like ARCI, successful transfer of the developed technologies is a crucial indicator of its performance. Towards this purpose, appropriate road maps have been developed to enable transition of the technologies from the laboratory to the market place. Assessment of readiness level of technologies (in terms of IP Development Indices), and availability of complementary resources / capabilities with potential partner organizations are some of the major considerations while scouting entrepreneurs for technology transfer.

Categories of ARCI Technologies and Its Approach

The pool of technologies available at ARCI, are usually categorised into process based and equipment based technologies.

Process based technology - In the process based technology, the know-how about the process and application is demonstrated. For instance: easy-to-clean Coating Technology to protect the solar photovoltaic panels from dust/dirt, corrosion and all sorts of weather conditions. The process involves, pre-cleaning of the solar Photo Voltaic (PV) panel, the coating technique i.e., spraying of the coating sol on the panel using a spray gun, wiping it using a hand held wiper and curing for sufficient time. Later the coating performance has been demonstrated by spraying sand particles and water on the coated and uncoated solar PV panel.

Equipment based technology - In this case, technology transfer involves equipment used to implement the process and develop application(s). For example: Cold Gas Dynamic Spray Coating Technology, a low temperature thermal spray variant, involves accelerating micron sized powder particles to supersonic velocities resulting in the formation of dense, thick and pure coatings with high deposition rates.

Competition Analysis / Market Research

Our methodology entails a combination of primary and secondary research. CTAT attempts to provide the incisive insights mainly with respect to market sizing, possible market trends, application development scenario and competitive benchmarking. Such analysis was conducted for Lithium Iron Phosphate and Lthium Titanate for Li-ion Batteries, Li-ion cell making, anti-bacterial coating for laptops and mobile phones, graphene nanoplates, ready-to-paint coatings on CRCA and GI sheets, Metal Additive Manufacturing for aerospace and healthcare.

Approach being used to forge mutually rewarding partnerships – Streamlining the outreach process for ARCI technologies

Contributors: Arun Seetharaman, Abhishek Bethi (Associate) and Sanjay Bhardwaj

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 22 technologies to 37 receivers and few technologies are under transfer. The following table depicts the technologies transferred:

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

Technologies Available for Adaptation / Transfer

S. No	Technology and Related Issues	Key Features and Applications	
1.	**Ceramic Honeycomb Based Energy Efficient Air Heaters and Eco-friendly Sanitary Napkin Incinerators** IPDI: Technology Readily Available	**Key Features:** • Eco-friendly incinerator • Specially designed, honeycomb based, energy efficient air heaters • Generates > 850°C, which is mandatory to minimize production of dioxins and toxins while burning • Available with power rating 2kW and 4kW • Incineration can be done in batches • Compact in structure • One-to-one replacement of conventional heaters and retrofitting can be done • Energy savings up to 40% • Prolonged life by eliminating hotspots • Low thermal inertia and high coefficient of heat transfer offers higher efficiency	**Possible Applications:** • Industrial Heating such as confectionery industry, welding rod warmers, and large volume air heating, hot air ovens etc. • Sanitary napkin incinerator
2.	**Super Hydrophobic (Easy to Clean) Coating for Self-cleaning of PV Panels and Other Applications** IPDI: Initiate Technology Transfer	**Key Features:** • Low cost production (simple coating technique / easy scalable / curable by ambient temp.) • Highly transparent coating (no loss in transmittance / power conversion efficiency after deposition) • Super hydrophobic property: >1100° water contact angle • High weather stability (withstand long duration accelerated test - IEC 61646 • High mechanical stability • Low dust deposition compared to bare and other commercial coated samples	**Possible Applications:** • Solar PV & CSP cover glass • Optical lenses • Video display panels • Architectural glasses
3.	**Cost-efficient Solar Receiver Tube Technology for Low & Medium Temperature Solar Thermal Applications** IPDI: Initiate Technology Transfer	**Key Features:** • High selective properties (Solar Abs ~95%; Spectral emittance ~0.12) • Low heat loss property: ~0.14 at 300°C • Temperature stability: < 300°C • Corrosion stability: > 200 hrs withstand in salt spray test • High mechanical stability, Long durability and highly enhanced weather protection	**Possible Applications:** • Solar water heater /Solar dryer • Solar desalination • Stream generation for various industrial applications • ORC solar collector based power generation
4.	**Advanced Detonation Spray Coating Technology** IPDI Level: Reassessing feasibility (IP, Competition, Technology, Commercial)	**Key Features:** • High productivity due to high pulse frequency • Less maintenance: absence of mechanically moving parts • Good adhesion strength (>10000 psi) • Dense microstructure (< 1%) • Negligible thermal degradation and excellent tribological properties • Ability to coat wide range of powders, carbide, oxide, metal powders • Lower substrate temperature & low oxide content • Coatings with 50-2000 microns thickness can be produced	**Possible Applications:** • Steel industry application such as Bridle rolls • Textile & Paper industry applications such as wire passing pulleys, plungers, steeped cone pulleys, bearing stopper plates, guide rolls • Gas compressor applications such as spindle valve, compressor disc, compressor shaft • HP & LP turbine blades, compressor discs, LCA nozzles, thrust beating sleeves, propeller shaft seals. • Power and Energy applications such as guide vanes, spindle valves, hydro turbine blades.
5.	**Micro Arc Oxidation Coating Technology (Academic Version)** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Ability to coat Al, Ti, Mg and Zr metals and their alloys • Ease to coat complex shapes and also regions difficult to access • Uniform, dense, hard and thick coatings • Superior coating properties and performance compared to other conventional acid based processes like anodizing and hard anodizing • Excellent tribological properties and corrosion resistance • Eco-friendly • 5-40 times service life improvement	**Possible Applications:** • For a wide array of applications in industry sectors such as textile, automobile etc.
6.	**PEM Fuel Cell Based Power Supply Systems** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Developed Grid Independent fuel cell systems in the range of 1-20kW power • PEM Fuel cells developed have been continuously operated for 500 hrs and intermittently for several thousand hours with stable performance • Suitable control systems for load following cycle, cell monitoring characteristics, power conditioners and thermal management have been developed	**Possible Applications:** • Power generation, EV applications • As decentralized power pack for homes, industries etc. • As combined heat and power units for homes • As uninterrupted power source even when the power outage is for long duration (>8hrs) • As backup power for telecom industries.
7.	**Lead Free Copper Alloys for Bimetallic Bearings** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Elimination of lead as per B-4 emission norms • Yield Strength: 450 MPa (BMC840), 470 MPa (BMC841) • Hardness: 119 HVN (BMC840), 127 HVN (BMC841) • Wear Resistance: 18 μm/h • Fatigue Strength: 110 MPa	**Possible Applications:** • Main bearings and connecting rod bearings for heavy duty vehicles • Cars and motor cycle bearings • Transmission and hydraulic pump bushings • Wear plates • Camshaft bushings for medium size vehicles
8.	**Cold Gas Dynamic Spray Coating Technology** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Indigenously developed state of the art PLC based automated Portable control panel (Max Pressure -20 bar) • Different set of nozzles • For Low melting materials (polymer based) o High deposition rate or coverage area o Low deposition rate or coverage area o For Ni based materials, Steels (Optional) • Compressed AIR as process and carrier gas • Maximum Pressure - 20 bar; Maximum Temperature: 600°C • Cu, Al, Ag, Zn, Sn,Ni, SS, Ta, Nb, Ti and alloys and composites	**Possible Applications:** • Repair and Refurbishment Applications • Coatings for electrical contacts, lugs, EMI shielding, heat sinks • Coatings for high temp. corrosion resistance, bio-medical, sputter target • Cathodic protection coatings • Anodic protection coatings • Wear resistant coatings • Nanostructured / amorphous coatings • High entropy alloy coatings for high temperature applications
9.	**Ceramic Inserts for Anti-Mine Boots** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Ceramic honeycomb inserts: A new concept • Sacrificial inserts and no splinters • Flexible in design and light weight • Reflection of shock waves by air in channels • Higher energy absorption by the ceramic honeycomb configuration • GSQR 1095 – Qualified	**Possible Applications** • Anti-mine boots used in military and mining applications
10.	**Pulse Electro Deposition** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Non line of site process, economical and ecofriendly • Porosity free finished product, higher production rates • Control over microstructure, mechanical properties, particle content in composite coating • Higher current efficiency and deposition rates compared to traditional hard chrome process • Easy technology transfer from research lab to existing infrastructure	**Possible Applications:** • Corrosion resistance and decorative coatings: automobiles include car, truck trim, motorcycle, kitchen and bathroom appliances • Wear resistance: hydraulic actuators, railway engine shafts, aircraft landing gears, shaft journals, farm machinery, earth movers, snow plows, road repair equipment, mining equipment, automobile engine valves • Industrial tools such as rolls for Al and steel manufacturing, stamping tools and dies, molds for plastic manufacturing utilized chrome plating for increasing its (tool) life

S. No	Technology and Related Issues	Key Features and Applications	
11.	**Sintered Silicon Carbide (SiC) Components** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Tunable density and other thermo-mechanical properties. • Flexibility in producing SiC parts incorporating solid-state or liquid phase sintering additives. • Capable to produce SiC components up to 750 mm ϕ. • Critical SiC parts can be manufactured.	**Possible Applications:** • Mechanical seals particularly for corrosive environment. • Impact & abrasion resistance parts. • Light-weight structural parts for aerospace applications. • Impact and wear resistant parts.
12.	**2D-Nanolayered Transition Metal Sulfides (2D-NTMS)** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**Key Features:** • Synthesis of pure as well as mixed WS2/MoS_2 nanosheet powders • Synthesis of doped-WS_2/MoS_2 nanosheet powders • Reasonably good oxidation resistance • Feasibility to synthesize 2D-nanostructures of other transition metal sulphides • Scalable process for bulk production	**Possible Applications:** • Solid lubricant for aerospace and automotive sector • Solid lubricant for forging and other manufacturing processes • Additive to automobile Lub-oil • Additive to grease for improved performance under high shear stress • Petrochem catalyst • Electrocatalysts for HER • Li-ion battery electrode • Self-lubricating composites and coatings (metallic/ceramics/ polymer) • Sensors and actuators
13.	**Repair and Refurbishment of Pressure Die Casting Components Using Laser Cladding** IPDI Level: Check Repeatability/ Consistency at Prototype Level	**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:** • Wear plates for different applications • Component repair and refurbishment
14.	**Development of Indigenous Electrode Material, Lithium Iron Phosphate (LFP) for EV Applications** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Identified sources of lithium and iron precursors • Designing of suitable large capacity furnace and optimum heating cycles with less time • ARCI developed LFP's electrochemical performance in terms of specific capacity; cyclic stability and rate capability is at par with the performance of the commercially available LFP • Considering the existing facilities for LFP the batch size is 29 kgs per day is being produced.	**Possible Applications:** • LiB batteries used in electric vehicle applications
15.	**Development of Indigenous Electrode Material, Lithium Titanate (LTO) for EV Applications** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Identified sources of lithium and Ti precursors • Designing of suitable large capacity furnace and optimum heating cycles with less time • ARCI developed LTO's electrochemical performance in terms of specific capacity; cyclic stability and rate capability is at par with the performance of the commercially available LTO • Considering the existing facilities for LTO, the batch size of 72 kgs per day could be produced	**Possible Applications:** • LiB batteries used in electric vehicle applications
16.	**Scratch resistant coatings on retro reflective lenses of road markers** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • High scratch hardness and abrasion resistance • Long life and good adhesion • Colored coatings possible • Can be coated on Polycarbonate, PMMA etc	**Possible Applications:** • Road markers • Helmet visors

S. No	Technology and Related Issues	Key Features and Applications	
17.	**Smart carbon based C-TiO_2 for heat transfer, lubrication and self-cleaning applications** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Good visible light photocatalytic activity for indoor/ outdoor self cleaning applications • Prototype fabric has been developed and validated • High heat capacity and thermal conductivity for heat transfer application • Low coefficient of friction compared to base lubricant oil • Good visible light photocatalytic activity for indoor/ outdoor self-cleaning application • Cost effective and easy to scale up	**Possible Applications:** • Industrial heat transportation • Solar thermal power generation • Cooling of microchips • Lubricants in machinery • Self-cleaning activity on incorporation with TiO_2 • Self cleaning textiles
18.	**Cathodic Arc Physical Vapor Deposition Facility (CAPVD)** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Films/coatings of different structures with good control over chemistry and thickness can be developed: (i). Mono-layer, (ii) Multi-layer, (iii) Gradient and (iv) Functionally multi-layered/graded • Films/coatings containing Ti, Cr, AlSi & AlTi can be coated in pure metallic or nitride or carbide form. i.e. TiN, CrN, TiAlN, TiAlSiN, CrAlSiN, TiCrAlSiN, TiC, TiCN, TiAlCN, etc. • Physical and mechanical properties can be tuned by varying deposition conditions • Environmentally green and easily up scalable process with high production rates	**Possible Applications:** • Hard and wear resistant coatings for cutting tools – up to hardness of 45 GPa • Wear resistant coatings for dies, bearings, etc. – Low friction coefficient of < 0.2 • Erosion resistant coatings for compressor blades – A thickness of 20 µm is achieved • Solar selective coatings for solar thermal applications – ~ α: 0.96 & ε: 0.09 at 400°C • Diffusion barrier coatings for electronic components • Decorative coatings for aesthetic applications, etc.
19.	**Pet coke derived carbon based super capacitors** IPDI Level: Prototype testing in real-time conditions	**Key Features:** • Developed a graphene-like activated porous carbon by a single step chemical activation process using petroleum coke as raw material • Successfully fabricated Indigenous supercap with the specifications of 1200 F, 2.7V and 1.2Wh • Demonstrated E-bicycle using module made from petcoke derived supercapacitor devices	**Possible Applications:** • Regenerative braking • Cranking of EVs • Public transport • Portable Electronics • Backup/Emergency power source
20.	**Dual functional anti-fogging and antireflective coatings for optical, solar and display applications** IPDI Level: Check repeatability/ consistency at coupon level	**Key Features:** • High transmittances in visible and solar regions: >98% (in visible) >96% (in solar) • Low temperature curable (80-100°C) • High temperature stability: Max up to 1000°C • Weather stability: > 200 hrs withstand in high humidity (>90%) at 50°C • High mechanical stability and Long durability • Coat effective coating technique	**Possible Applications:** • Solar PV & CSP cover glass • Optical lenses • Video display panels • Architectural glasses • High power lasers
21.	**Anti-bacterial coatings on scrub pads** IPDI Level: Check repeatability/ consistency at coupon level	**Key Features:** • Prevents and controls the formation of new and growth of existing bacteria • Transparent, imperceptible by touch, feel and look remains unchanged • Chemical resistant and non-toxic • Minimization of the infection risk • Can be coated on any surface. • Forms a strong bond with its substrate • Helps prevent discoloration and degradation	**Possible Applications:** • Glass(borosilicate glass, soda-lime glass, quartz glass etc.) • Ceramics (tiles etc.) • Metal(SS, chrome, aluminum etc.) • Plastics (polycarbonate, PMMA, etc.) • Wooden structures • Contact eye lenses case • Non woven fabrics

Support Groups

Electronics and Instrumentation Group

The Electronics and Instrumentation Group (E&IG) at ARCI has an important role to play as a part of the support system at ARCI. Some of the roles and responsibility of this group are depicted below:

Some of the major activities undertaken by E&IG are as follows:

Advanced Detonation Spray Coating: Design and development of a PLC-HMI based automated ADSC control system and preparation of the operation Manual with schematics.

Cold Spray Automation: Derived the technical specifications for the automation of a PLC-HMI based control process along with suitable control cabinet. Work is under progress.

Capacitor Management System for supercapacitor module: Associated with the design and development of a Capacitor balancing and protection board for ARCI supercapacitor bank and integration of the same with the bicycle along with charge /discharge controller. The demonstration (Fig. 1) of the capacitor-powered bicycle was accomplished in December 2020:

Fig.1 Bicycle with CMS & data logger

Fig. 2 EV data logger

- Developed 16 channel data acquisition system for recording the charging and discharging profiles of Individual Super capacitors in a bank
- Development of EV Data logger for E-Auto (Fig. 2) with LabVIEW GUI and microcontroller.

Application of LDR for automatic switching of Street Lights: ARCI developed LDR sensor installed on top of one of the street lamp posts. Instead of depending on the time, introduced an ambient light response voltage system which will depend only on light intensity converted to voltage. This will ensure that the street light switching at the required darkness irrespective of time of the day. The data gets stored in the SD card (Fig. 3) for extended periods of time to evaluate the performance of LDR (Graph 1).

Fig. 3 Circuit for Auto switching of street lights

Automatic Siren System: The automatic siren system is built using Arduino Mega 2560 microcontroller board along with RTC and SD card shield. The enclosure shown in Fig. 4 is built in house using the available 3D printer to accommodate the LCD display, Control boards, Connectors and Switches.

- Implementation of automatic Siren system helps to avoid human errors that may occur with the manual operation.

Fig. 4 Siren control system

Designed CAD models and printed enclosures using 3D printer:

- For Ignition control of Advance Detonation Spray Coating system
- For water Flow and Temperature control of Electron Beam Physical Vapor Deposition system

Other support activities which are noteworthy are:

- Developed an automatic hand sanitizer as a part of COVID-19 preventive measures at ARCI
- Taken part in the pre-installation and commissioning of sophisticated multidisciplinary equipment for the new NCCCR&D (National Centre for Clean Coal Research and Development) project at ARCI namely: HVAF, Axial Plasma, Chillers, ABB robotic manipulators, Creep testing etc.
- Completed Magnetron PVD HIPIMs Interfacing and Integration
- Developed applications using LabVIEW software, Microcontrollers to control, Acquire and analyze data from different equipment and processes.
- Real Time Data logger for Solar Strings to carry out performance evaluation studies (17 panels in each String, each panel of 45V connected in series)
- Instrumental in implementing Fiber to the Home (FTTH) optical fiber technology in order to address repeated breakdowns of telephone communications due to underground copper cabling.

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Electrical and Civil Infrastructure

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, do augmentations and alterations to the existing systems; 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 spread across a land area of 30 acres. During the year, the group carried out the regular preventive maintenance jobs of the 33 KV & 11 KV vacuum circuit breakers (VCB- Siemens make) and air circuit breakers (L&T make). The group has established electrical distribution systems for newly installed and shifted 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. Some critical equipment fed exclusively by the CPP. 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. A major breakdown maintenance work of 1500 KVA DG set also is underway.

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. Recently the daily demand reduced to 215 KL/ day from the previous 250 KL/day. This is achieved by meticulously monitoring the usage points and analysing the meter reading data.

Under civil maintenance, the group constructs new buildings expanding the existing infrastructure of various COEs and also do required alterations and modifications to existing spaces so that the changing needs of new programs and equipment can be accommodated. During the year, the group completed augmentation and alteration works worth Rs. 50 lakhs(civil & electrical) for various COEs. Taken up minor repairs and maintenance works of the existing about 25000 sqmts of built up area.

In the area of 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 maintained water dispensers/coolers connected with the Aqua-guard water purifiers at 36 buildings across the campus. About 10 tons of new AC units installed this year as replacement of old units.

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 518 KWp grid connected Roof Top Solar (RTS) plant. This project has been completed and the plant is spread over three rooftops; at Centre for Nanomaterials, Centre for Engineered Coatings and Centre for Sol-gel Processing. The plant is supplied and installed by BHEL. Monitoring, data collection and recording is being done by SCADA system.

SCADA user interface of 518 KWp solar plant

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). ARCI is executing this project with the help of a consultancy firm. A proposal is put forth to DST to take up upgradation of Infrastructure systems such as substations, water pipe lines, safety & security systems etc. Detailed works involved at site for upgradation and cost estimation are been prepared by the team with help of competent external agency.

A project for improving life of Lead-Acid battery of electric vehicles, employing super capacitors also is taken up. Power management software development was done and the trial run of the prototype vehicle is in progress.

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Centre for Information Technology Services

The Centre for Information Technology Services (CITS) provides various computer resources and services that support administrative, management, and research needs for ARCI.

The role of CITS in providing IT services include:

- Provide and manage IT and Communication infrastructure services
- Develop and maintain ARCI's custom ERP software.
- Administration of email, Internet and web hosting services.
- Provide and manage the telepresence system, a high definition video conferencing system, that connected ARCI's offices in Hyderabad, Chennai and Gurgaon.

During COVID-19 pandemic lockdown phase, the work from home option was provided to all the officials with enabling Secured Socket Layer - Virtual Private Network (SSL VPN) feature of the existing Sophos XG310 Firewall. The SSL VPN provides users with remote access to ARCI network resources via a secure and authenticated path by encrypting all network traffic. This enabled users to securely access enterprise resource planning (ERP) applications and network computers on their PCs (the model shown in Figure 1).

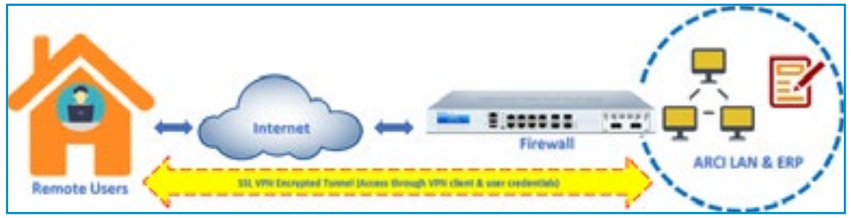

Fig. 1 SSL-VPN Connectivity

The Microsoft Teams virtual platform was introduced to organize online meetings in order to create an organizing team for all ARCI users on the same team. The CITS set up and coordinated several online videoconference meetings, including a one-on-one meeting between the Director and the scientists.

Cisco Webex has been implemented for the webinars. The CITS could manage events using the software's host control to plan events, start and end meetings, recordings and grant access to participate, present and discuss.

Fig. 2 Digital Signage Software Implementation

The digital display (Digital Signage) software was successfully implemented to deliver content on the screens connected to the network. The legacy digital display hardware was not working and was outdated. The Centre provided a solution using an open-source product, WordPress content management system with its plugin named foyer; MXQ Pro TV Box has Android operating system was used to connect the displays (see Figure 2). This software tool is useful for the management of slides, channels and displays for this setup.

Implemented Spiceworks software to register and record events related to IT support. The solution helped users register their complaints, view the status of their tickets, and troubleshooting steps followed by the IT support team. Once the ticket is generated, the system automatically sends an email alert to all admins for their actions. This system also includes provisions for managing and overseeing IT assets within the network. The system generates automated alerts for administrators of devices that are faulty, vulnerable, and require updates.

ERP Developments:

1. Implemented and integrated Project Monitoring System with Common Application and Finance Systems for the technical update of the projects from time to time by the concerned project team. Also, monitoring of funds, publications/patents updates, and view of Statement of Expenditures / Utilization Certificates, etc., features included into it.
2. Inventory Confirmation Module has been developed for the confirmation of the availability of individual inventory items with them.
3. In the Payroll System, implementation of Income-tax calculations as per the old regime and new regime options chosen by the employee, promotion arrears calculation and posting of promotion arrears and related deductions in respective employees' salary processing.
4. In Finance System, developed various MIS reports based on Single projects, etc., as per the requirement.

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Events, Data and Statistics

Major Events

International Yoga Day

In view of COVID-19 pandemic and imposed lockdown, employees were advised to celebrate "International Yoga Day (IYD)" on June 21, 2020 at their homes alongwith their family members. This year's theme for IYD was "I do Yoga at Home". Employees and their family members have performed yoga with great enthusiasm at their homes.

Independence Day

ARCI celebrated Independence Day on August 15, 2020. Dr. G. Padmanabham, Director ARCI hoisted the National Flag and addressed the employees virtually.

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. Following Covid-19 protocols, quarterly OLIC meetings were conducted virtually 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 achieved the targets in terms of proper and progressive implementation of official language as set by the D.O.L, Ministry of Home Affairs, Govt. of India. In addition to the regular rajbhasha lectures in quarterly workshops, an effort was made to introduce scientific & technical lectures in Hindi to be delivered by ARCI Scientists. The motive of OLIC in introducing these scientific lectures in Hindi workshops is to motivate the scientists to present their original R&D works in Hindi for the benefit of scientific community of ARCI. ARCI conducted virtual 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 six employees received cash awards, during the year for carrying out official works in Hindi.

Hindi Saptha Celebrations: ARCI celebrated "Hindi Saptha" virtually during September 14-18, 2020. Online Essay competition was conducted for employees and students. Shri Naveen Naithali, Hindi Lecturer, Central Hindi Teaching Scheme, Hyderabad, delivered a lecture on "Problems and Solutions in usage of Hindi". All the nominated employees and research students actively participated in the Hindi Saptha celebrations which concluded on September 18, 2021. All the winners were given cash prizes.

Release of 3rd Annual Hindi Magazine: In continuation to ARCI's efforts in successful promotion of Implementation of Official Language, 3rd issue of Annual Hindi in-house magazine "SRUJAN" was released on 26th January, 2021 by Dr. G. Padmanabham, Director, ARCI in the presence of Associate Directors and OLIC members. The magazine contains scientific and technical research articles, achievements of ARCI and general articles received from staff and research students.

Vigilance Awareness Week

Vigilance Awareness Week was observed at ARCI from 27.10.2020 to 02.11.2020. This years' Vigilance Awareness Week theme was "Satark Bharat, Samriddh Bharat (Vigilant India, Prosperous India)". The messages from the honourable President, honourable Vice President and CVC were read by Dr. L. Ramakrishna, Scientist "F"& Vigilance Officer. In view of Covid-19 protocol, all the staff members and research students were asked to take "Integrity Pledge" in their respective centres. They were also encouraged to take online/e-pledge by visiting the CVC website. On this occasion, posters on vigilance awareness were displayed in the Administrative Building and slogans were also displayed on all the digital boards.

Annual Day

The 24th Annual Day was celebrated at ARCI, Hyderabad on December 31, 2020. Due to prevailed Covid 19 pandemic situation, the annual day event was conducted virtually, with participation of the employees and research students of ARCI Hyderabad, ARCI Chennai Centres and ARCI Gurugram office. The Welfare Committee has coordinated the event by taking the audio and videos (virtually) from the employees and their family to participate in all programs including cultural events. The Annual Day program began in morning with the invocation and was followed by a welcome address by Dr. P. K. Jain, Scientist "G" & Chairman, Welfare Committee. In his annual day address Dr. G. Padmanabham, Director ARCI has briefed about the major achievements of ARCI during year and new initiatives being taken in the forthcoming years. Dr. R. Gopalan, Regional Director, Dr. Tata Narasinga Rao and Dr. Roy Johnson, Associate Directors have also addressed the gathering and encouraged the employees and research students to get involved and be part in ARCI's successful journey. All the employees, research students and their family members actively participated in the virtual cultural events and made the celebrations a grand success!. The celebrations concluded with a vote of thanks by Dr. Gururaj Telasang, Scientist "E", Convenor, Welfare Committee.

Republic Day

ARCI celebrated Republic Day on January 26, 2021. Dr. G. Padmanabham, Director ARCI hoisted the National Flag and addressed the employees virtually.

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

National Science Day

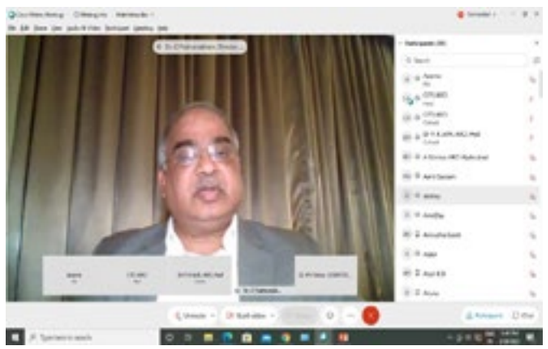
National Science Day (NSD) was celebrated at ARCI during 25-26 February, 2021. This year's theme for NSD was "Future of STI – Impact on Education, Skills and Work".

For the first time, ARCI conducted a national level competition "Science, Technology and Innovation Talks (STIN-2021)" on February 25, 2021 for young research scholars. Dr. P. K. Jain, Scientists "G" and Chairman, National Science day Committee welcomed the Young Researchers for this programme. Dr. G. Padmanabham, Director ARCI briefed about the importance of NSD and the role and contributions of Indian scientists in nation building. About 73 Scholars from some of the premier institutes all over India delivered talks on topics ranging from 3D printing, alloy design, water purification, artificial intelligence, renewable energy, smart materials etc., in the field of Materials Science and Engineering at STIN 2021. The winners were evaluated based on a 3-minute presentation selected by a panel of eminent professors and senior scientists based on the novelty, scientific/technical content and relevance to societal needs.

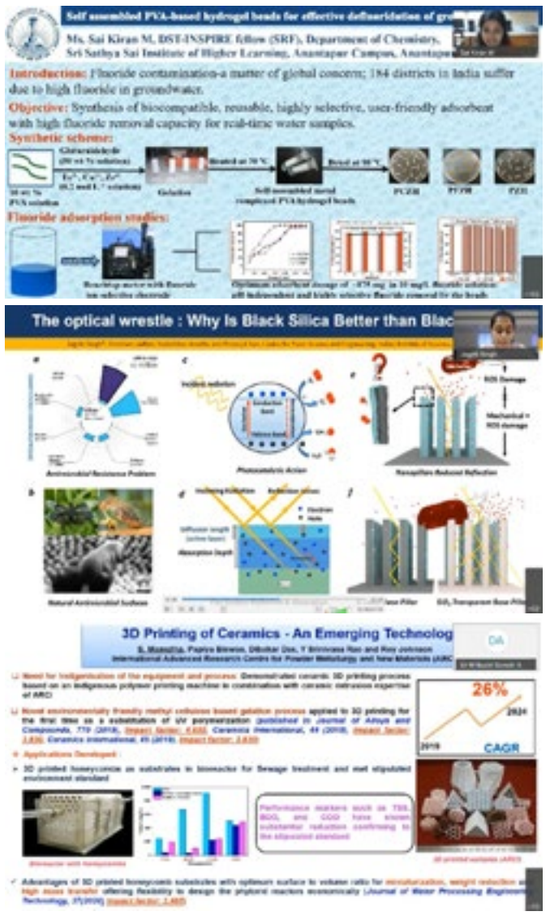
On February 26, 2021, A popular science lecture was delivered by Dr. Rakesh K. Mishra, Director, CSIR's – Centre for Cellular and Molecular Biology (CCMB), Hyderabad followed by distribution of prizes for the winners of STIN talks. Dr Rakesh K Mishra, elucidated the challenge, the exciting

Dr. Rakesh K. Mishra, Director-CSIR-CCMB delivering lecture on National Science Day

Dr. P. K. Jain, Scientist 'G' welcoming the participants during National Science Day celebrations



Dr. G. Padmanabham, Director-ARCI addressing the participants during National Science Day celebrations



Ms. M. Sai Kiran, Ms. Jagiti Singh and Ms. S. Mamatha presenting at the STIN-2021 who won the first, second and thrid prizes respectively

science, the rigour and the practical aspect of deploying a usable vaccine in the current pandemic situation at the National Science Day talk on 'The Science, Development and Deployment of Vaccines'. The prize winners were Ms. M. Sai Kiran, DST Inspire Fellow (SRF) from Sri Sathya Sai Institute of Higher Learning, Anantapur Campus, Ms Jagriti Singh, Research Scholar, Centre for Nanoscience and Engg., IISc, Bangalore and Ms S. Mamatha, Research Scholar, Centre for Ceramic Processing, ARCI, Hyderabad.

On the occasion of NSD, as part of the ARCI's outreach activity, Dr. G Padmanabham, Director-ARCI released ten 'Science and Technology Demo Videos for Students' on ARCI YouTube channel based on ARCI technology developments.

A slide show on Dr. CV Raman's life and his achievements were displayed in all the digital boards. Apart from Young Researchers from all over the country, the virtual programme was well attended by the employees and research students of ARCI Hyderabad, Chennai and Gurugram office.

Safety

ARCI observed National Safety Week during March 4-10, 2021. 50th National Safety Day celebrations were held virtually on March 4, 2021. On this occasion, safety pledge was administered, lectures and interactive sessions were organized focusing on relevance and importance of this year's National Safety Week Theme, "Learn from Disaster and Prepare for a Safer Future". Dr. Roy Johnson, Associate Director and Chairman, Safety Committee, welcomed the online participants and in his address highlighted that ARCI's has in place a policy to give high priority for the safety, health and environment. Dr. G. Padmanabham, Director-ARCI emphasized that safety should evolve as a habit of every individual which shall propagate as one of the prime cultures in the centre. Dr. R. Gopalan Regional Director and Dr. T. Narasinga Rao, Associate Director have also stressed on the safety norms, procedures and protocols to be followed by each one of us. Shri D. Ramesh, Security, Fire & Safety

Dr. G. Padmanabham, Director, ARCI presenting a Memento to Dr. K. Srinivas Vice-President, M/s. Ramky Enviro Engineers Ltd., Hyderabad

Officer presented the activities undertaken by ARCI Safety Committee and Safety and Health Pledge was administered in Hindi and English respectively by the Team Leaders and Safety Coordinators of each Centre of Excellence. Dr. K. Srinivas Kesavaraparu, Vice President, M/s. Ramky Enviro Engineers Ltd., Hyderabad who was the chief guest for the occasion delivered Safety Day lecture. Competition on safety slogans were conducted for the employees and research students and prizes were distributed. The virtual programme was well attended by the employees and research students of ARCI Hyderabad, ARCI Chennai Centres and ARCI Gurugram office. The programme concluded with vote of thanks by Dr. Nitin P. Wasekar, Scientist "E" & Safety Coordinator.

Dr. G. Padmanabham, Director-ARCI administering the safety pledge along with Dr. K. Srinivas

Employees administering the safety pledge

Certificates being awarded to winners of safety slogan competition held in Hindi, English and Telugu

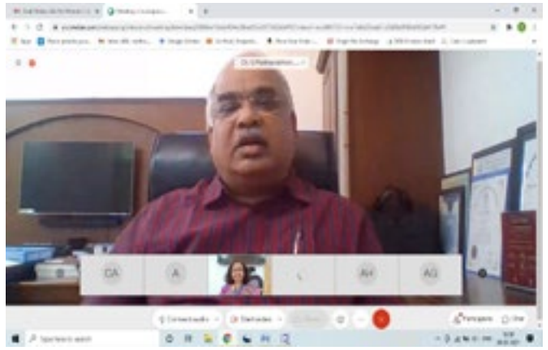
ARCI Internal Complaints Committee

ARCI Internal Complaints Committees (AICCs) are functioning both at Hyderabad and Chennai Centres. Both these Committees are actively involved in promoting awareness regarding Sexual Harassment of Women at Workplace. Awareness posters in bilingual are displayed at prominent locations in ARCI Hyderabad and Chennai campuses.

International Women's Day Celebrations

International Women's Day (IWD) was celebrated on virtual platform at ARCI, Hyderabad on March 8, 2021. Dr. Neha Y. Hebalkar, Member Secretary-AICC welcomed the participants and Dr. Malobika Karanjai, Scientist "F" and Chairperson, AICC briefed about various activities taken up by AICC. Dr. G. Padmanabham, Director, ARCI, addressed the gathering, especially inspired the women colleagues and promised his full support and encouragement for women's progress and safety at work place. Associate Directors Dr. T. Narasinga Rao and Dr. Roy Johnson addressed the participants on the occasion. Dr. Preeti Banzal, IES, Indian Telecommunications Service Officer, Advisor & Scientist G, Office of Principal Scientific Advisor, Govt. of India, New Delhi delivered a motivational talk on "Women in Disaster Management". Employees and research students have attended the programme.

On the occasion of IWD, Smt. A. Jyothirmayi, Technical Officer "E" whose superannuation from the services of ARCI was during 2021 was felicitated for her valuable and dedicated service in ARCI.



Dr. G. Padmanabham, Director-ARCI addressing the participants during Women's Day celebrations at ARCI-Hyderabad

Dr. Preeti Banzal delivering a talk on "Women in Disaster Management"

At ARCI Chennai Centre, International Women's Day (IWD) was celebrated on March 9, 2021. Dr. K. Ramya, Senior Scientist and Chairperson, AICC welcomed the gathering. Ms. Hemalatha Annamalai, TiE Women Global and Angel Investor and Mentor W electric was the Chief Guest. All the employees and research students attended the celebrations.

Dr. G. Padmanabham, Director-ARCI presenting a sapling to Mrs. A. Jyothirmayee, Technical Officer 'E'

Ms. Hemalatha Annamalai delivering a talk on the occasion of Women's Day organized by ARCI-Chennai

Conference/Workshops/Symposia Organized by ARCI

1. **Golden Jubilee Celebrations of Department of Science and Technology at ARCI**: As part of Golden Jubilee Celebrations of Department of Science and Technology (DST), Govt. of India, a series of events were held at ARCI during the period (May 2020-May 2021). A committee Chaired by Dr. P. K. Jain, Scientist 'G', with Dr. R. Subasri, Scientist 'F', Dr. Pramod H. Borse, Scientist 'F', Dr. M.Buchi Suresh, Scientist 'E', Dr. R. Easwaramoorthi, Scientist 'E', Mrs. N. Aparna Rao, Communications and Public Relations Officer (Convenor) and Shri M. R. Renju, Technical Officer 'B' as Members was formed to conduct the events at ARCI. An Informative, Invigorating and Inspirational (I3T) Talk Series with 25 talks by Senior Scientists of ARCI and popular talks by Eminent experts in the areas related to materials and materials processing, like nanomaterials, ceramics, engineered coatings, fuel cells, carbon materials, sol-gel coatings, laser materials processing, solar energy and automotive energy materials were organized on the occasion. Two workshops on 'H2 Workshop on National Hydrogen and Fuel Cell Day' and 'One Day Workshop on Materials Characterization and Testing' were successfully conducted which were well attended by industries and college students. All the events at ARCI like the National Science Day, India International Science Festival, National Safety Week etc., were also celebrated under this umbrella. Ten short videos explaining the processes involved in the technologies developed, suitable for easy understanding by the school students were released on the occasion of National Science Day 2021 and placed on ARCI website.

   Contributions about ARCI were made for the Coffee Table Book released by DST on the occasion. A short film on ARCI was made with the help of Vigyan Prasar showcasing the activities of ARCI-Hyderabad and Chennai Centres.

2. **Third One-Day Workshop on Accelerating Hydrogen and Fuel Cell Technology:** To celebrate the advancements made in hydrogen and fuel cell technologies in India ARCI conducted 3rd One-Day Workshop to commemorate "National Hydrogen and Fuel Cell Day" on October 8 (10.08), a reference to the atomic weight of hydrogen (1.008 amu), with the theme of 'Accelerating Hydrogen and Fuel Cell Technology'. The workshop was conducted online to facilitate wider outreach and safer participation in the existing COVID-19 pandemic situation. It brought the hydrogen and fuel cell experts at a common platform to discuss the roadmap for further advancements of clean energy technologies and to address the missing technological gaps. The workshop was also a part of the DST Golden Jubilee celebrations to celebrate and acknowledge the DST's pivotal role in promotion of science & technology in the country. Dr. G. Padmanabam, Director, ARCI delivered the welcome address and stressed upon the relevance of hydrogen and fuel cell technologies in sustainable energy sector. The workshop was introduced by Dr. R. Gopalan, Regional Director, ARCI. This was followed by the address, by Guest of Honour Dr. P. C. Maithani, Advisor, Ministry of New & Renewable Energy (MNRE). The dignitaries emphasized upon the role of sustainable energy sector in the Indian economy and its contribution towards Atmanirbhar Bharat. The workshop also encompassed a collaborative panel discussion on the "Suitability of Fuel cells for Stationary/Transport applications from the Indian Perspective" to understand the current status of fuel cell technologies in such strategic sectors in India. The workshop was attended by 200 participants from various reputed Governmental agencies, Educational institutions and industries.

Participants at the One-Day Workshop on Accelerating Hydrogen and Fuel Cell Technology

3. **Curtain Raiser for IISF-2020 at ARCI**: ARCI organized a Curtain Raiser on November 27, 2020 for the 'India International Science Festival (IISF-2020)'.

   A **one-day Workshop on Materials Characterization** was conducted online on the occasion. Around 260 participants attended the Workshop. The proceedings started with the inaugural address by Dr. G. Padmanabham, Director, ARCI, welcoming the participants and providing brief introduction to the facilities at the Centre for Materials Characterization and Testing in ARCI. Dr. G. Ravi Chandra, Scientist 'G' & Head, Centre for Materials Characterization and Testing spoke about the India International Science Festival, and provided an introduction to Vijnana Bharathi (Vibha). Mrs. A. Jyothirmayi introduced the speakers, and also compered the proceedings. Talks were given by Dr. G. Ravi Chandra on "An Overview of Materials Characterization", Dr. L. Venkatesh on Introduction to Scanning Electron Microscopy", Mr. M. Ramakrishna on "Microstructural observations using Transmission electron microscopy", Dr. K. Suresh on "Probing nanostructure using complementary techniques (SAXS, TEM, and APT)" and Dr. N. Ravi on "Mechanical Characterization of Materials" at the one-day workshop.

   Vigyan Yatra celebrations at ARCI: Institutions in Hyderabad were scheduled to participate online on December 13, 2020. The common programme for all the participating Organizations was conducted by Vibha-Telangana from 10:00 to 11:30 hrs on that day. Directors of INCOIS, NGRI, NIAB and ARCI spoke on the occasion. President, VIBHA-Telangana and Representative, IISF 2020, also addressed the participants. This was followed by a Guest Lecture on "Earth Sciences for Self-reliant India" by the Chief Guest of the day, Dr. Shailesh Nayak, Director, NIAS, Bengaluru. ARCI celebrated Vigyan Yatra from 11:35 to 13:00 hrs. Dr. G.Padmanabham, Director-ARCI, delivered the inaugural address.

   Dr. T. Narasinga Rao, Associate Director-ARCI gave a talk on "Innovations in Energy Materials Research: ARCI's Approach" and Dr. L. Ramakrishna, Scientist 'F' gave a talk on "Surface Engineering Technologies for Life Extension of Aerospace Components". The event ended with concluding remarks by Dr. B.V. Sarada, Scientist 'F'.

Human Resource Development

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

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

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

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

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

List of Project Scientits/Research Fellows who Completed Ph.D. during the year 2020-21

Name of the Project Scientist/Fellow	Topic	Ph.D. Registered at	Degree Awarded on
JA Prithi Project Scientist "B"	Corrosion and Impurity Tolerance Study of Platinum Electrocatalysts for Proton Exchange Membrane Fuel Cells	Indian Institute of Technology, Madras	26.03.2021
S. Vasu Project Scientist "B"	Enhancement of Cycle Life Lithium Ion Battery by In-situ Carbon Encapsulation on Layered Oxide based Cathode Materials	Indian Institute of Technology, Madras	28.01.2021
S. Sasikala Senior Research Fellow	Structure and Electrochemical Property Correlation of Ni Rich Layered Oxides for Lithium Ion Battery Application	Indian Institute of Technology, Madras	02.12.2020
Dr. Sumit Ranjan Sahu Project Scientist "B"	Carbon Nano Horns based Anode Material for Lithium-Ion Battery	Indian Institute of Technology, Madras	25.09.2020
Dr. L. Subhashini Senior Research Fellow	Laser- MIG Hybrid Welding of Special Steels in a Single Pass	University of Hyderabad, Hyderabad	15.09.2020
Dr. Amol C. Badgujar Project Scientist "B"	Development of Copper Indium Gallium Diselenide CIGS Solar Cells by Non-Vacuum Techniques	Indian Institute of Technology, Bombay	23.08.2020
Dr.K. Nanaji Project Scientist "B"	Development of Porous Carbon Electrode Materials for Super Capacitors	Indian Institute of Technology, Madras	17.07.2020
Dr.S. Bhuvaneshwari Senior Research Fellow	Synt rochemical performance of Scandium Doped Li Magnate Spinel Phases as Lithium Ion Battery Cathode Materials	Indian Institute of Technology, Madras	17.07.2020

Post Graduate/Graduate Trainees and M.Tech. /B.Tech. /M.Sc. Project Students joined during the Year at ARCI

Post Graduate Trainees	03
Graduate and Diploma Trainees	12
M. Tech. Project Students	16

Diploma/B. Tech. / M.Sc. Projects Students	04
Summer Research Interns	Nil*

** Due to Covid-19, Summer Research programme could not be conducted.*

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

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

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
1.	VVN Phani Kumar	Investigation on Natural and Synthetic Polymer as on Aqueous Binder for Anode of Li-Ion Battery (Li-Bs)	National Institute of Technology, Warangal
2.	Ravi Gautam	Microstructure- Magnetic Properties Correlation of Fe-P based Soft Magnetic Alloy	Indian Institute of Technology, Madras
3.	Vallabharao Rikka	Study on Ageing Mechanism of Lithium Ion Battery	Indian Institute of Technology, Bombay
4.	Kumari Konda	Electrochemical Performance of various Cathode Materials using Half and Full Cell	Indian Institute of Technology, Bombay
5.	Srinivasa Rao Atchuta	Development of Stable Selective Solar Absorber Coating for Concentrated Solar Thermal Application	AcSIR – National Aerospace Laboratories, Bangalore
6.	P. Mahender	Development of Composite Cathode Materials for High Energy Density Li-ion Battery	Indian Institute of Technology, Madras
7.	Muni Bhaskar Siva Kumar	Microstructure – Magnetic Properties Correction in Grain Boundary Diffused NdFeB Magnetic Material	Indian Institute of Technology, Madras
8.	Pothula Vijaya Durga	Processing and Evaluation of Micro Structural and Mechanical Properties of Oxide Dispersion Strengthened Iron Aluminides for High Temperature Applications	Indian Institute of Technology, Madras
9.	Puppala Laxman Mani Kanta	Development of High Energy Density Electrode Materials for Sodium Ion Battery	Indian Institute of Technology, Madras
10.	G. Vijayaraghavan	Microstructure-Property Correlation of High Performance Sm-Fe-N Permanent Magnetic Materials	Indian Institute of Technology, Madras
11.	S. Ramakrishnan	Corrosion protection Coatings on Metallic Flow Field Plates for PEM Fuel Cell (Lt-PEM)	Indian Institute of Technology, Kanpur
12.	Minati Tiadi	Nanoscale Thermoelectric Materials and Devices for Sustainable Applications	Indian Institute of Technology, Madras
15.	V. Tarun Kumar	Ongoing Course Work	Indian Institute of Technology, Bombay

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

Sl. No	Name of the Student Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
1.	P. Tejassvi	Electro Spun Nano Fibrous Materials Li-ion and Li-s Batteries	National Institute of Technology, Warangal
2.	T. Ramesh	Development of Novel Porous Carbons using Agricultural Biomass for High Performance and Cost Effective Electrodes for Supercapacitor Application	National Institute of Technology, Warangal
3.	PM Pratheeksha	Development of Nano Structured Electrodes for High Energy Density Lithium Ion Batteries Strategies for Improved Performance and Bulk Synthesis.	National Institute of Technology, Warangal
4.	VV Ramakrishna	Micro Structure and Magnetic Property Correlation in Rare Earth Free Permanent Magnets – Mnbi Alloy	National Institute of Technology, Tiruchirappalli
5.	S. Harish	Design, Fabrication and Performance Evaluation of a Thermoelectric Generator for Automotive Exhaust Waste Heat Recovery	Indian Institute of Technology, Madras
6.	Imran Karajagi	Development of Secondary Zinc Air Battery	Indian Institute of Technology, Bombay
7.	S. Manasa	Nano Clay-based Self-Healing, Corrosion Protection Coatings on Aluminium Alloys AA2024-T4 and A356.0	National Institute of Technology, Warangal
8.	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
9.	T. Mitravinda	Methods and Modifications of nano Porous carbon materials to Augment the Super Capacity Performance.	Indian Institute of Technology, Hyderabad
10.	Brijesh Singh Yadav	Development and detailed Investigation of Chalcopyrite CIGS Absorber layer	Indian Institute of Technology, Hyderabad
11.	B. Jayachandran	Interface Engineering of Medium Temperature Thermoelectric Device Performance	Indian Institute of Technology, Bombay
12.	M. Shiva Prasad	Development of Solar Selective Absorber Coatings for Concentrating Solar Power Applications	National Institute of Technology, Warangal

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
13.	B. Priyadarshini	Synthesis and Characterization of Magnesium Silicide and Zinc Anti Monide based Thermoelectric Materials Applications	National Institute of Technology, Tiruchirappalli
14.	Keerthi Sangamitra Kollipara	Study of Thermo-physical Properties of Aerogel Products for Thermal Insulation Application	National Institute of Technology, Warangal
15.	Shaik Mubina	Processing and Properties Evaluation of Carbon nanofibers Dispersed SiC based Composites	National Institute of Technology, Warangal
16.	Y. Madhavi	Plain High Cycle Fatigue and Corrosion-Fatigue Behavior of Micro Arc Oxidation Coated 6061-T6Al Alloy	National Institute of Technology, Warangal
17.	Swapnil Hanmant Adsul	Development of Nano Container based Self – Healing coatings for Corrosion Protection of Magnesium Alloys AZ9ID.	National Institute of Technology, Warangal
18.	Adigilli Harish Kumar	2D-Nanolayered WS2 based Self Lubricating Composites	National Institute of Technology, Warangal
19.	Mohd. Aqeel	Suitability of Laser Hybrid Welding of Inconel 617 Alloy for Steam Boilers	University of Hyderabad, Hyderabad
20.	E. Anusha	Optimization and Control of Heat Input in Laser Based Manufacturing Processes	National Institute of Technology, Warangal
21.	V.P. Madhurima	Synthesis of Carbon Nano Materials and their Composites	National Institute of Technology, Warangal
22.	P. Samhita	Development of Nano structure Metal Oxide based Electrode Material for Super Capacitor	Indian Institute of Technology, Hyderabad
23.	KK Phani Kumar	Development of Nano Composite Based Solar Selective Absorber Coatings	Indian Institute of Technology, Bombay
24.	P. Sreeraj	Studies on Precious Component recovery form PEM Fuel Cell	Indian Institute of Technology, Bombay
25.	Narendra Chundi	Development of Anti Soiling Coating and their Evaluation for Applications of Photovoltaic Modules	Indian Institute of Technology, Bombay
26.	Battula Ramya Krishna	Detailed Investigation on the Degradation of Organo Metal Halide Perovskite Solar Cells	Indian Institute of Technology, Madras
27.	Surabattula Yasodhar	Multiphase Flow Analysis and Performance of Aqueous Methanol Electrolyser	Indian Institute of Technology, Madras
28.	V. Sai Harsha Swarna Kumar	Development of Metallic Bipolar Plates of PEM Electrolyser for Hydrogen Production	Indian Institute of Technology, Madras
29.	A.B. Aravind	Development of Secondary Aluminium based Batteries.	National Institute of Technology, Tiruchirappalli
30.	M. Tarun Babu	Structure Property Correlation of Cold Sprayed Aluminium Alloys	Indian Institute of Technology, Madras
31.	D. Nazeer Basha	Laser Surface Texturing of Automotive Engine Components using Ultrafast Laser	Indian Institute of Technology, Madras
32.	Bathini Lava Kumar	Fatigue and Corrosion Fatigue of PED Coated Monolayer and Multilayer Ni-W Coatings	Indian Institute of Technology, Bombay
33.	K. Sriram	Development of Conductive and Corrosion Resistant Coatings over Metallic Bipolar Plates for PEM Fuel Cells Applications	Indian Institute of Technology, Madras
34.	M. Venkatesh	Development of Low Cost and High Specific Energy Electrode Materials for Sodium-Ion Battery	Indian Institute of Technology, Madras
35.	Vikrant Trivedi	Nanostructured Cosb3 Type Skutterudite Thermoelectro Materials for waste Heat Energy recovery Application	Indian Institute of Technology, Madras
36.	P. Raju	Investigations on the Applicability of Pressure Slip Casting for Al2O3 and Al2O3-TiO2 & Al2O3-ZrO2 Systems.	National Institute of Technology, Warangal
37.	D. M. Santoshsarang	Design and Modelling of Residual Stresses of additive Manufacturing	Indian Institute of Technology, Madras

Sl. No	Name of the Project Scientist Mr./Ms.	Ph. D. Topic	Ph.D. Registered at
38.	S. Mamatha	Near-net shaping of Simple and Complex Ceramic Parts by 3D Printing and Investigations on Physico-Chemical, Mechanical and Microstructural Properties	University of Hyderabad, Hyderabad
39.	Jyothi Gupta	Investigation of Efficient and Stable Nanostructured Mo based Chalcogenides Electrocatalyst for Hydrogen Evolution Reaction	University of Hyderabad, Hyderabad
40.	B. Amarendhar Rao	Laser Assisted Machining of Nickel based Super Alloys IN617, IN625 with Surface Textured Carbide Cutting Tools	National Institute of Technology, Warangal
41.	Kanchi Anjali	Microstructural studies on refractory multi component alloys	University of Hyderabad, Hyderabad
42.	Rahul Jude Alroy	Structure-Property Correlation Studies on HVAF Sprayed CrC - NiCr Coatings for Erosion and Corrosion Resistant Applications.	Indian Institute of Technology, Madras
43.	Aarti Gautam	Self Healing Corrosion Protection Coatings on Mild Steel	National Institute of Technology, Warangal
44.	A. R. Dilipan	High Entropy Alloy based Permanent Magnetic Materials	Indian Institute of Technology, Madras
45.	K. Reshma Dileep	Carbon based Perovskite Solar Cell	Indian Institute of Technology, Bombay
46.	Guduru Neelima Devi	Cold Spray Deposition of Nickel based Alloys	National Institute of Technology, Warangal
47.	Harita Seekala	Measuring the Rate Depends of Strength at Small Scales in Heterogenous Microstructures	Indian Institute of Technology, Madras
48.	N. Ravikiran	Synthesis of Carbon 2D Hybrid Materials for Friction and Wear Reduction	University of Hyderabad, Hyderabad
49.	B. Kumaar Swamy Reddy	Photo Detector	Indian Institute of Technology, Hyderabad
50.	Rentala Jayasree	Development of Functionally Graded Materials for Bio Applications	Indian Institute of Technology, Kharagpur
51.	D. Vijaya Lakshmi	Structure-Property-Performance Correlation Studies on Detonation and HVAF Sprayed Wear and Corrosion Resistant Coatings	Indian Institute of Technology, Bombay
52.	Baswanta Sainath Patil	Additive Manufacturing of Precipitation Gardening Stainless Steel	Indian Institute of Technology, Hyderabad

Regular/Contract Appointments

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

Employee Name	Designation	Date of Joining
K. Prashanth	Assistant 'A'	03.07.2020
P. Prasad Babu	Assistant 'A'	22.07.2020
Dr. T. Mohan	Senior Scientist (Contract)	12.08.2020
Thati Thoti T Koteswar Rao	Assistant 'A'	12.08.2020
Pakanati Ashoka Reddy	Assistant 'A'	13.08.2020
Nalamasa Sampathkumar	Assistant 'A'	23.09.2020
Ramavath Sunil Naik	Assistant 'A'	23.09.2020
Dr. V. Ganapathy	Scientist (Contract)	01.01.2021
Dr. Bijoy Kumar Das	Scientist (Contract)	04.01.2021
Dr. Srikanti Kavitha	Scientist (Contract)	04.01.2021
Shri S. Ramakrishnan	Scientist (Contract)	04.01.2021
Shri Vallabharao Rikka	Scientist (Contract)	04.01.2021
Dr. K. Nanaji	Scientist (Contract)	04.01.2021
Dr. Ravi Gautam	Scientist (Contract)	04.01.2021
Dr. J.A. Prtihi	Scientist (Contract)	04.01.2021

Employee Name	Designation	Date of Joining
L. Babu	Technical Officer "C" (Contract)	04.01.2021
Kadiri Sai Charan	Technician 'A'	11.01.2021
Sushant Nayak	Technician 'A'	15.01.2021
Desetti Bala Surya Krishna	Technician 'A'	22.01.2021
Gedela Janaki Rao	Technician 'A'	25.01.2021
Rasikanta Maharana	Technician 'A'	01.02.2021
Gugulothu Murthy	Technical Assistant 'A'	01.02.2021

Re-employment Appointments

Dr. R. Gopalan was re-employed in the grade of Scientist "G" (Pay Level 14), w.e.f 01/12/2020 for a period of 2 years with the approval of ACC.

Promotions

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

Name of the Promotees	Effective Date	Promotion for the post	
		From	To
P. Ashok	July 6, 2020	Driver "B"	Driver "B" (MACP)
Dr. R. Subasri	October 1, 2020	Scientist "F"	Scientist "G"
V. Balaji Rao	October 1, 2020	Scientist "F"	Scientist "G"
Dr. Neha Yeshwanta Hebalkar	October 1, 2020	Scientist "E"	Scientist "F"
Dr. S.B. Chandrasekhar	October 1, 2020	Scientist "E"	Scientist "F"
Dr. S. Kumar	October 1, 2020	Scientist "D"	Scientist "E"
Priya Anish Mathews	October 1, 2020	Scientist "D"	Scientist "E"
Dr. Prasenjit Barick	October 1, 2020	Scientist "D"	Scientist "E"
Dr. Naveen Manhar Chavan	October 1, 2020	Scientist "D"	Scientist "E"
M. Ramakrishna	October 1, 2020	Scientist "D"	Scientist "E"
Balaji Padya	October 1, 2020	Scientist "D"	Scientist "E"
S. Sudhakara Sarma	October 1, 2020	Scientist "D"	Scientist "E"
Smt. A. Jyothirmayi	October 1, 2020	Technical Officer "D"	Technical Officer "E"
Shri V. Mahender	October 1, 2020	Technical Officer "C"	Technical Officer "D"
Shri J. Nagabhushana Chary	October 1, 2020	Technical Officer "B"	Technical Officer "C"
Shri A. Raja Shekhar Reddy	October 1, 2020	Technical Officer "B"	Technical Officer "C"
Shri M. R. Renju	October 1, 2020	Technical Officer "A"	Technical Officer "B"
Shri E. Konda	October 1, 2020	Technician "D"	Technician "E"
Shri A. Satyanarayana	October 1, 2020	Technician "D"	Technician "E"
Shri B. Venkanna	October 1, 2020	Technician "D"	Technician "E"
Shri A. Jagan	October 1, 2020	Technician "C"	Technician "D"
Shri Sushanta Mukhopadhyay	October 1, 2020	Technician "C"	Technician "D"
Shri M. Satyanand	October 1, 2020	Technician "C"	Technician "D"
Rajalakshmi Nair	October 1, 2020	Assistant "B"	Assistant "B" (MACP)
Md. Sadiq	October 1, 2020	Driver "C"	Driver "C" (MACP)

Superannuation

Employee Name	Designation Held	Date of Superannuation
Dr. N. Rajalakshmi	Senior Scientist (Contract)	31/10/2020
Shri Prabir Kumar Mukhopadhyay	Technician "D"	31/01/2021

Resignations

Employee Name	Designation Held	Date of Relieving
Dr. Sumit Ranjan Sahu	Scientist (Contract)	26/03/2021

Obituary

Employee Name	Designation Held	Date of Demise
Shri J. Venkateswara Rao	Technician "D"	25/03/2021

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 18.49%, S.T is 5.20%, OBC is 27.16% and that of persons with disabilities is 1.73% and 1 person belongs to EWS as on March 31, 2021.

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 delivered online 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.

Papers Presented at Indian Conference/ Symposia

1. Mr. Vikrant Trivedi (Dr. Manjusha Battabyal) presented a paper on Effect of Tantalum Filling and Nanostructuring on Thermoelectric Properties of CoSb3 Skutterudites at the 'Virtual Conference on Thermoelectrics (VCT-2020)' organized by International Thermoelectric Society (ICT) during July 21-23, 2020.
2. Ms. Minati Tiadi (Dr. Manjusha Battabyal) presented a paper on Enhanced Thermoelectric Performance and Positive Magnetoresistivity in p- Type Mg3Sb2 at 'VCT-2020' organized by ICT during July 21-23, 2020.
3. Ms. P. Samhita (Dr. B.V. Sarada) made a poster presentation on Design and Fabrication of Economic and Scalable all Electrodeposited NiCo2S4 Iron Oxide based Asymmetric Supercapacitor at the '71st Annual Meeting of the International Society for Electrochemistry' organized by International Society for Electrochemistry during August 30– September 04, 2020.
4. Ms. P. Samhitha (Dr. B. V. Sarada) made a poster presentation on Binder-Free Electrodeposited NiCo2O4 with Enhanced Oxygen Vacancies as an Effective Electrode Material for Supercapacitors at the 'LatinXChem Online Twitter Poster Competition' conducted by LatinXChem during September 07-08, 2020.
5. Mr. N. Ravikiran (Dr. P.K. Jain) presented a paper on Exfoliated Graphite Derived Nanographene Sheets as Lubricant Additive at the 'Virtual International Tribology Research Symposium (ITRS 2020) Theme: Impact of Tribology on Society' by SRM Institute, Chennai during November 05-07, 2020.
6. Mr. S. Rajesh (Mr. Manish Tak) presented paper on an Experimental Investigation of Laser-Assisted Machining of EN24 Steel at the 'Nnational E-Conference on Sustainable Machining Strategies for Better Performance' on November 27-28, 2020.
7. Ms. ShaikMubina (Dr. B. P. Saha) presented a paper on High Temperature Oxidation Behaviour of CDV SiC Coated Cf/C-SiC Hybrid Composite Tubes Processed through Si-Infiltration at the '84th Annual Session of the Indian Ceramic Society and National Conference on Propelling Innovations in Glass and Ceramics for Atmanirbhar Bharat' organized by Indian Ceramic Society during December 10-12, 2020.
8. Ms. D. Chandrakala (Dr. B. P. Saha) presented a paper on Effect of Nano and Micron Boron Nitride on Mechanical and Dielectric Properties of BN/SiAlON Ceramics at the '84th Annual Session of Indian Ceramic Society and 'National Seminar on Propelling Innovations in Glass and Ceramics for Atmanirbhar Bharat' organized by Indian Ceramic Society during December 10-12, 2020.
9. Ms. S. Mamatha (Dr. Roy Johnson) presented a paper on Fluoride Removal Studies in Portable Water is using Gamma-Alumina coated 3D Printed Ceramic Honeycomb Substrates at the '84th Annual Session of Indian Ceramic Society and National Seminar on Propelling Innovations in Glass and Ceramics for Atmanirbhar Bharat' organized by Indian Ceramic Society during December 10-12, 2020.
10. Mr. P. Raju (Dr. Y. Srinivasa Rao) presented a paper on Pressure Casting and Mechanical Characterization AL2O3 Ceramics at the '84th Annual Session of Indian Ceramic Society and National Seminar on Propelling Innovations in Glass and Ceramics for Atmanirbhar Bharat' organized by Indian Ceramic Society during December 10-12, 2020.
11. Mr. D. M. Santhosh Sarang (Dr. Gururaj T.) presented a paper on Microstructural and Mechanical Property Correlation of Additively Manufactured AISI H13 Hot Work Tool Steel at the '3rd Structural Integrity Conference and Exhibition (SICE 2020) e-Conference on Indian Structural Integrity Society (InSIS)' organized by Indian Institute of Technology Mumbai during December 11-20, 2020
12. Ms. V.P. Madhurima (Dr. P. K. Jain) presented a paper on Impact of Pyrolysis Temperature and Atmosphere of Carbon-based Inorganic Polymeric photocatalyst on Organic Contaminant Photo Degradation at the 'Conference on Advances in Catalysis, Energy and Environment Research' organized by Tata Institute of Fundamental Research (TIFR), Hyderabad during December 16-19, 2020.
13. Ms. Aarti Gautam (Dr. R. Subasri) presented a paper on Benzotriazole Encapsulated Nanocontainer based Self-Healing Coatings for Corrosion Protection of Mild Steel at the 'National Symposium on Electrochemical Science and Technology [NSEST -2020]' organized by Electrochemical Society of India (IISc) during December 17-18, 2020.

14. Mr. A. Srinivasa Rao presented a paper on Wet-Chemical based Air Stable Solar Selective Absorber Coating for Concentrated Solar Thermal Application at the 'NSEST-2020 'organized by IISc and the Electrochemical Society of India during December 17-18, 2020.

15. Mr. D. Nazeer Basha (Dr. Ravi Bathe) presented a paper on Laser Surface Texturing of Automotive Components for Improving Tribological Performance at the 'Young Scientists Conference-6th India International Science Festival 2020 (IISF 2020)' held during December 22-24, 2020.

16. Dr. Ramkrishna Sahoo presented a paper on Electrochemical Behaviour of Mixed Valance Vanadium Oxide as Potential Negative Electrode at the 'Young Scientist Conference 6th India International Science Festival 2020 (IISF 2020)' held during December 22-25, 2020.

17. Mr. D. Nazeer Basha (Dr. Ravi Bathe) presented presentation on Ultrafast Laser Pulses – A Ray of Pulses for an Unpredictable Innovations for the Best Human Life at the 'Science, Technology and Innovation Talks (STIN 2021), Young Research Fellows, a National Level Competition' organized by ARCI during December 25-26, 2020.

18. Ms. B. Ramyakrishna (Dr. R. Easwaramoorthy) presented a paper on Development of Single: Crystalline Mapbl3 Films on Device Quality Substrates for Photovoltaic Applications at the '6th International Conference on Nanoscience and Nanotechnology' organized by SRM Institute of Technology during February 01-03, 2021

19. Mr. Brijesh Singh Yadav (Dr. Sanjay R. Dhage) presented a paper on A Printable Solar Cell Thinner than Human Hair' under the Augmenting Writing Skills for Articulating Research (AWSAR 2020) Awards programmes organized by the National Council for Science and Technology Communication, DST on February 28, 2021

20. Mr. Swapnil H. Adsul (Dr. R. Subasri) presented a paper on Autonomic Healing Corrosion Protection Coatings for Magnesium Alloy AZ91D at the 'STIN-2021, Young Research Scholars' organized as a part of 'National Science Day Celebrations' by ARCI, Hyderabad during February 25-26, 2021

21. S. Manasa (Dr. R. Subasri) presented a paper on Clay Nanopackets as Self-Healing Agents for Anti-Corrosion Coatings at the 'Science Technology and Innovation Talks (STIN-2021) by Young Research Scholars' organized as a part of 'National Science Day Celebrations' by ARCI, Hyderabad during February 25-26, 2021

22. Ms. Priya Anish Mathews presented a paper on Protective Materials and Coatings for Solar Energy Devices: Patent Roundup at the 'Recent Technologies and Advanced Materials for Green Energy and Sustainable Environment (RTAMGESE 2021)' organized by National Institute of Technology (NIT), Tiruchirapalli during March 12-13, 2021

23. Dr. M. B. Sahana presented a paper on Comprehensive Effort on Electrode Slurry Preparation for Better Electrochemical Performance of $LiFePO_4$ Battery at the 'International Workshop on Energy Storage Technologies for E-Mobility (IWESTE-2021)' organized by SRM Institute of Science and Technology (in association with SPARC (MHRD), KAIST and Energy Science Society of India (ESSI) on March 25-27, 2021.

Participation in Training Programmes in India

1. Dr. Sanjay R. Dhage, Dr. Kaliyan Hembram, Mr. Manish Tak, Mr. D. Ramesh and Mr. A.R. Srinivas attended the training programme on The Siemens Global Skills Centre for Occupational Safety (SITRUST) on October 19, 2020.

2. Mr. P. Nagendra Rao and Mr. A. Srinivas attended training workshop on Vigilance Awareness Week - 2020 organized by Department of Science and Technology (DST), New Delhi on October 29, 2020.

3. Dr. P. K. Jain and Dr. R. Vijay attended training programme on Managing Technology Value Chains for Directors and Division Heads conducted by Administrative Staff College of India (ASCI) during November 02-06, 2020.

4. Mr. R. Sunil Naik and Mr. P. Ashok Reddy attended a workshop on Noting and Drafting organized by Institute of Secretariat Training and Management's (ISTM) during November 06-08, 2020.

5. Mr. Sudheendra attended a training programme on Pay Fixation Cases organized by Institute of Secretariat Training and Management's (ISTM) during November 06-08, 2020.

6. Mr. Sudheendra and Mr. R. Sunil Naik attended a training programme on Establishment Rules-I (ER-1-03) organized by Institute of Secretariat Training and Management's (ISTM) during November 16-20, 2020.

7. Mr. A. Srinivas and Mr. Sudheendra attended a webinar on Transparency Audit with Respect of Compliance under Section 4 of RTI Act, 2005 organized by Indian Rubber Manufacturers Research Association (IRMRA) during December 03-04, 2020.

8. Mr. A. Srinivas, Mr. G M Rajkumar, Mr. G. Gopal Rao, Mr. B. Laxman, Ms. Madhura Vani, Mr. B. Venkatesham, Mr. R. RangaNaik, Mr. Sai Kishore, Mr. Ch. Venugopal, Mr. A. Balraj and Mr. J. Bansilal attended the training programme on Conduct Rules and CCA (CCS) Rules organized by National Productivity Council on February 19, 2021.

9. Dr K. Pradeep Premkumar, Mr Swapnil H. Adsul, Ms. Aarti Gautam, Mr Ramay Patra (Dr. R. Subasri) attended a workshop on "Surface engineering and Modification for Better Performance" organized by "IISc Bengaluru" on September 19, 2020.

10. Dr Pradeep Premkumar, Mr Swapnil H. Adsul, Ms. Aarti Gautam, Mr Ramay Patra (Dr. R. Subasri) attended a Workshop on "Material Characterization" organized by "ARCI Hyderabad" on November 27, 2020.

11. Dr Pradeep Premkumar, Mr Swapnil H. Adsul, Ms. Aarti Gautam, Mr Ramay Patra (Dr. R. Subasri) attended Workshop on "Metallurgy for Non-Metallurgists (MFNM-2021)" organized by "Indian Institute of Metals Baroda Chapter and Federation of Indian Chambers of Commerce and Industry (FICCI)" on March 20, 2021.

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

1. Dr. L. Rama Krishna attended the Conference on Aerospace and Defence Manufacturing Technologies organized by Society of Indian Defence Manufacturers (SIDM) in association with Confederation of Indian Industry(CII) on July 15, 2020

2. Mr. G.M. Rajkumar, Mr. Anirban Bhattacharjee, Mr. Narendra K Bhakta, Mr. D. Prabhu, Mr. K. Naresh Kumar, Mr. M.R. Renju and Mr. E. Ramesh participated in GeM CII-National Public Procurement Conclave (NPPC) 2020 organized by Ministry of Commerce and Industry on August 09-10, 2020

3. Dr. G. Padmanabham attended virtual conference on Role of Hydrogen in India's Energy Transition organized by Federation of Indian Chambers of Commerce and Industry (FICCI) on November 27, 2020.

Lectures by ARCI Personnel in India

1. Dr. Neha Hebalkar delivered an invited lecture on Nanoporous aerogels for energy conservation organized by Amity Institute of Nanotechnology, Noida on April 04, 2020

2. Dr. Tata N. Rao delivered an invited lecture on Energy materials and emerging trends in India at the 'SRM IST Webinar Series Emerging Trends and Challenges in Advanced Research Areas of Science and Technology' organized by SRM Institute of Science and Technology, Chennai on May 25, 2020

3. Dr. B. V. Sarada delivered an invited lecture on Advanced characterization techniques: scientific and technological aspects of nanomaterials at the 'National Webinar: Techno Science-2020' organized by Layola Academy, Secunderabad during May 27-28, 2020

4. Dr. Mani Karthik delivered an invited lecture on Design and fabrication of supercapacitor as the next generation energy storage device for electric vehicles: Material design to prototype demonstration organised by SRM University, Chennai on June 01, 2020

5. Dr. V. Ganapathy delivered an invited lecture on Perovskite solar cells: Progress and their challenges at the 'Webinar on Futuristic Medicinal and Materials Chemistry (FMMC-2020)' organized B. S. Abdur Rahman Crescent Institute of Science and Technology, Chennai on June 10, 2020

6. Dr. R. Balaji delivered an invited lecture on Electrochemistry and its application in niche area at the 'Electrochemistry Webinar' conducted by Sri Renganathar Institute of Technology, Coimbatore during June 10,2020

7. Dr. S. Anandan delivered an invited lecture on Recent development of advanced nano-structured electrode materials for high performance energy storage application at an 'Event on Emerging Materials for Energy Harvesting, Conversion and Storage' organized by Department of Science and Humanities, MLR Institute of Technology, Hyderabad during June 19-23, 2020.

8. Dr. S. Anandan delivered an invited lecture on Development of advanced nano-structured electrode materials for high performance energy storage applications at the 'Online Faculty Development Programme on Advances in Energy Materials for Storage Systems' organized by GMR Institute of Technology, Rajam during June 23-26, 2020.

9. Dr. K. Ramya delivered a invited lecture on PEMFC development for hybrid electric vehicle at the 'International Virtual Conference on Electric Mobility 2020' organized by TIFAC-CORE centre of Vellore Institute of Technology (VIT), Vellore on June 25, 2020.

10. Dr. S. Anandan delivered an invited lecture on Large scale synthesized high performance electrode materials for energy storage application: Material to prototype device at the 'National Webinar on Prospective necessity of solar energy conversion and waste management' organized by Department of Chemistry, Marudhar Kesari Jain College for Women, Vaniyambadi during June 25-27, 2020.

11. Dr. Raman Vedarajan delivered an invited lecture on Science and engineering of PEM fuel cell stack at the 'Electrochemical Webinar Series' conducted by BS Abdul Rahaman Crecent Institute of Science and Technology, Chennai on June 29, 2020.

12. Dr. S. Anandan delivered an invited lecture on Development of advanced energy storage materials (Li-ion battery and supercapacitor) for electric vehicles application at the 'Recent Trends on Hybrid and Electric Vehicle Technologies (RTHEVT-2020)'organized by Department of Mechanical Engineering at MVGR College of Engineering, Vizianagaram during July 06-11, 2020.

13. Dr. Neha Hebalkar delivered an invited lecture on Insight to Nanotechnology and essentials of nanomaterials in everyday life at a webinar organized by Department of Engineering Sciences, Marathwada Mitra Mandal's College of Engineering, Pune on July 09, 2020

14. Dr. Krishna Valleti delivered a keynote lecture on Enhancing tool performance through advanced coatings at the '2nd International Conference on Design and Manufacturing Aspects for Sustainable Energy-2020 (ICMED 2020)'organized at Gokaraju Rangaraju Institute of Engineering and Technology (GRIET), Hyderabad during July 10-12, 2020

15. Dr. Mani Karthik delivered an invited lecture on

Advanced porous materials for supercapacitor applications at the 'FDP on Advanced Materials in Energy Storage Applications' organised by Velammal Institute of Technology during July 18-22, 2020

16. Dr. R.Gopalan made a presentation on Setting up of pilot plant for manufacturing Nd-Fe-B magnets by an ultimate rare earth magnet manufacturing technology, to the Indian Rare Earths Ltd, Technology Board, Mumbai on July 21, 2020
17. Dr. D. Sivaprahasam delivered an invited lecture on Challenges in the thermoelectric modules fabrication at the 'Training Programme on Research and Innovation in Materials and Methods-2020' organized at SRM Institute of Science and Technology, Chennai on July 22, 2020.
18. Dr. Tata N. Rao delivered an invited lecture on Over view of nanomaterials at the 'Faculty Assistance Programme' organized by National Academy of Defence Production Ambajhari, Nagpur on July 25, 2020
19. Dr. Mani Karthik delivered an invited lecture on Advanced carbon materials for energy storage for the Chikkanna Government Arts College, Tirupur on July 25, 2020
20. Dr.R. Balaji delivered an invited lecture on Hydrogen energy for sustainable future at the 'FDP on Emerging Trends in Energy, Environment and Nanomaterials. (EEN 2020)' organized by Sri Vengateswara College of Engineering, Chennai on July 27, 2020
21. Dr. V. Ganapathy delivered an invited lecture on Solar cell devices at the 'Summer Training Programme in Physics (STPIP 2020)' for the M.Sc Physics students organized by University of Madras, Chennai on July 27, 2020
22. Mr. K. V. Phani Prabhakar delivered an expert lecture on Recent trends in manufacturing at the 'FDP' organized by the Dept. of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Hyderabad on July 30, 2020
23. Dr. Mani Karthik delivered an invited lecture on Design and development of supercapacitor for electrical energy storage applications organised by College of Engineering Pune on July 31, 2020
24. Dr. Mani Karthik delivered an invited lecture on Technology challenges and progresses of electrical energy storage at the 'National Level E-FDP on Challenges in Chemistry and its Applications towards Energy Resources' organised by Dr. M.G.R. Educational and Research Institute, Chennai, during August 03-07, 2020
25. Dr. Tata N. Rao delivered an invited lecture on The power of nanomaterials at the 'International Webinar on Nanomaterials from Renewable Resources and their Applications' organized by Osmania University, Hyderabad on August 04, 2020
26. Dr. K. Suresh delivered an invited lecture on Probing Nanostructures at the 'Webinar on Materials Characterization' organized by Kakatiya Institute of Technology and Science, Warangal on August 05, 2020.
27. Dr. B. V. Sarada delivered an invited lecture on Advances in science and technology organized by Mahatma Gandhi University, Nalgonda on August 08, 2020
28. Dr. Sanjay Bhardwaj delivered the Chief Guest speech on Safety and hazard management in view of the current scenario in the chemical industries during a student panel discussion organized by Department of Chemical Engineering, Anurag University, Hyderabad on August 19, 2020
29. Dr.R. Balaji delivered an invited lecture on An overview of hydrogen production –R&D status at the 'Short Term Training Programme (STTP) on Fuel Cell Technologies for Hybrid and Electric Vehicles' conducted by MVGR College of Engineering, Vizianagaram on August 20, 2020.
30. Dr. S. Sakthivel delivered a keynote lecture on Importance of energy storage for economical concentrated solar thermal power generation and e-mobility at the 'ATAL Academy sponsored Faculty Development Programme (FDP) on energy storage and E mobility' organised by Syed Ammal Engineering College, Tamil Nadu during August 24-28, 2020.
31. Dr. Mani Karthik delivered an invited lecture on Electrical energy storage materials and devices for E-mobility: Current opportunities and challenges at the 'ATAL Academy sponsored FDP on energy storage and E mobility' organised by Syed Ammal Engineering College, Tamil Nadu during August 24-28, 2020.
32. Dr. Sanjay Bhardwaj delivered a lecture on Climate change and sustainable development as the Guest of Honour for the inaugural function of 'AICTE sponsored Short Term Training Programme on Industrial Pollution & Control Strategies', organized by Department of Chemical Engineering, Anurag University, Hyderabad during August 24-29, 2020
33. Dr. Raman Vedarajan delivered an invited lecture on Polymer electrolyte membrane fuel cell - the science and technology at the ' Electrochemistry Webinar Series' conducted by Electrochemical Society of India (ECSI), on August 30, 2020
34. Dr. V. Ganapathy delivered an invited lecture on Recent solar technologies and future perspectives at the 'International webinar on smart technologies for drug design, energy and environment (IFSDE-20)' organized as a part FDP by Kumaraguru College of Technology, Coimbatore on September 02, 2020.
35. Dr. Sanjay Bhardwaj delivered an invited lecture on Intellectual Property (IP) Commercialization at the 'IPR Certification Programme' organized by Gujarat Student Startup and Innovation Hub (i-Hub), an initiative of the Education Department of Gujarat Government on September 02, 2020
36. Dr. R. Gopalan delivered a talk on Opportunities in Li-ion battery and magnets technology for electric mobility at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on September 18, 2020
37. Dr. V. Ganapathy delivered an invited lecture on Research mobility experience at the 'Virtual Foundation and Advanced Course for Materials Synthesis and Applications-Bulk to Nano' organized by Manonmaniam Sundaranar University,Tirunelveli on September 21, 2020
38. Dr. S. Sakthivel delivered an invited lecture on 'Functional materials/ nanocoatings for solar thermal and PV applications at the 'Workshop on Functional Materials, Dye-Sensitized Solar Cells and Perovskite Solar Cells' organized by Kongu Engineering College, Tamil Nadu on September 21-25 2020
39. Dr. V. Ganapathy delivered invited lectures on a) Carbon materials for dye-sensitized solar cells and b) Nanomaterials and perovskite sensitizers for perovskite solar cells at the 'Workshop on Functional Materials, Dye-Sensitized Solar Cells and Perovskite Solar Cells' organized by Kongu Engineering College, Tamil Nadu during September 21-25, 2020
40. Dr Easwaramoorthi Ramasamy delivered an invited lecture on Advanced concepts and performance measurements in next generation solar cells at the 'Workshop on Functional Materials, Dye-Sensitized Solar Cells and Perovskite Solar Cells' organized by Kongu Engineering College, Tamilnadu during September 21-25, 2020.
41. Dr. Raman Vedarajan delivered an invited lecture on Fuel cell technology and engineering at the 'Foundation and Advanced Course (FAC) on Electrochemistry' conducted by Manonmaniam Sundranar University, Tirunelveli during September 24, 2020
42. Dr Easwaramoorthi Ramasamy delivered an invited lecture on Perovskite solar cells: present status and future prospects at the 'International Conference in Renewable Energy Science and Technology' organized by Alagappa University, Karaikudi, during September 28-29, 2020
43. Dr. Raman Vedarajan delivered an invited lecture on Science and technology of batteries - measurement and analysis at the 'FAC-2020 on Electrochemistry' conducted by Manonmaniam Sundranar University, Tirunelveli on September 29, 2020.
44. Dr. Malobika Karanjai delivered invited lectures on a) Biomaterials and PM processing and b) Composites and friction materials at the 'Powder Metallurgy Short Course 2020' organised by Powder Metallurgy of India during September 29-30, 2020
45. Dr Easwaramoorthi Ramasamy delivered an invited lecture on Basics of solar photovoltaics at the 'Foundation and Advanced Courses (FAC-2020) on Renewable Energy' organized by Manonmaniam Sundaranar University Tirunelveli, on September 30, 2020.
46. Dr. Tata. N. Rao delivered an invited talk on Powerful nanomaterials for energy storage applications at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on October 01, 2020
47. Dr Roy Johnson delivered a talk on Ceramics for health, energy and environment applications at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on October 01, 2020
48. .Dr.R. Balaji delivered an invited lecture on PEM fuel cell system- fundamentals and applications organized by Yeshwantrao Chavan College of Engineering, Nagpur on October 01, 2020
49. Dr. S. Sakthivel delivered an invited lecture on Functional materials and nanocoating for PV and solar thermal application at the 'AICTE-ATAL FDP on Energy Storage and Conversion with Efficient Nanomaterials' organized by Bharathiar University, Coimbatore during October 05-09, 2020
50. Dr. Easwaramoorthi Ramasamy delivered an invited lecture Advanced concepts and performance measurements at the 'AICTE-ATAL FDP on Energy Storage and Conversion with Efficient Nanomaterials' organized by Bharathiar University, Coimbatore during October 05-09, 2020
51. Dr.R. Balaji delivered an invited lecture on Hydrogen fuel cell- an alternative energy solution for e-vehicles at the 'AICTE-ATAL FDP on Energy Storage and Conversion with Efficient Nanomaterials' conducted by Bharathiyar University, Coimbatore on October 07, 2020
52. Dr. Sanjay Bhardwaj delivered an invited lecture on Research collaborations at the 'Science Administration and Research Management Programme for Scientists' sponsored by DST and organized by ASCI, Hyderabad on October 09, 2020
53. Dr. R. Vijay delivered a Guest lecture on Advanced processing of materials at ARCI at the AICTE sponsored 'FDP on Molecular Manufacturing' organized by Chaitanya Bharathi Institute of Technology (CBIT), Hyderabad during October 19-23, 2020.
54. Dr. Tata. N. Rao delivered an invited lecture on Indigenizing the nanotechnology – energy applications at the AICTE sponsored 'FDP on Molecular Manufacturing' organized by CBIT, Hyderabad during October 19-23, 2020.
55. Mr. S. Sudhakara Sarma delivered an invited lecture on Preparation and characterisation of nano Boron by cryo milling at the AICTE sponsored 'FDP on Molecular Manufacturing' organized by CBIT, Hyderabad during October 19-23, 2020.
56. Dr. G. Ravi Chandra delivered an invited lecture on Study of mechanical properties of small volumes of materials at the 'FDP on Recent Advances in Materials

Characterization Techniques' organized by National Institute of Technology (NIT), Nuzvid on October 21,2021

57. Dr. R. Gopalan delivered the Chief Guest lecture on Li-ion battery and magnet technology for EV application at the 'eVIT-2.0 Virtual Conclave' organized by VIT, Vellore during October 23 -24, 2020

58. Dr. G. Sivakumar delivered an invited lecture on Realizing solution precursor plasma spray technique towards deposition of functional coatings at the 'FDP on Advance Materials and Surface Properties' organized by GMR Institute of Technology, Hyderabad during October 26–30, 2020

59. Dr. Gururaj Telasang delivered an invited lecture on Hybrid metal AM process and metal AM based tooling at the 'Short-term Training Programme on Additive Manufacturing for Medical and Aerospace Applications' organized by Shri Vishnu Engineering College for Women, Bhimavaram during October 26-31, 2020.

60. Dr. R. Gopalan delivered an invited lecture on Materials and components technology for electric mobility at the 'India Energy Storage Week(IESW)' organized by organized by IESA, Delhi during November 02-06, 2020

61. Dr. S. Sakthivel delivered an invited lecture on Highly weather stable anti-soiling coating for photovoltaic application at the 'Indo-UK PV Soiling Workshop' jointly organized by Indian Institute of Technology (IIT) Bombay and Loughborough University, UK under UK-India Research Initiative (DST, India) on November 04, 2020

62. Dr. G. Ravi Chandra delivered an invited online lecture on A virtual tour of ARCI at the 'DST Programme on Enhancing Accountability and Responsiveness in Scientific Organisations' organized by the Institute of Public Enterprise, Hyderabad, on November 05, 2020.

63. Dr. G. Ravi Chandra delivered an invited lecture on Electron Backscatter Diffraction (EBSD) and its applications at the 'Online Seminar on Special Techniques in Electron Microscopy for Materials Sciences Applications (STEM-2020)', jointly organized by Electron Microscope Society of India-East zone, Indian Institute of Technology Bhubaneswar and CSIR-Institute of Minerals and Materials Technology, on November 06, 2020.

64. Dr. Tata. N. Rao delivered an invited lecture on Li-ion batteries and supercapacitors for EV applications at the AICTE Sponsored STTP Expert Lecture organized by Kakatiya Institute of Technology and Science (KITS), Warangal on November 07, 2020

65. Dr. Sanjay Bhardwaj delivered a talk on Research collaborations and technology transfer strategies at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on November 12, 2020.

66. Dr. S. Anandan delivered an invited lecture on Development of indigenous energy storage materials for electric vehicles (EVS) applications: Requirement and challenges at the 'A Virtual 6th International Conference on Chemical and Environmental Research (ICCER-2020)'organized by PG and Research Department of Chemistry, Jamal Mohamed College, Tiruchirappalli on November 12, 2020.

67. Dr. Mani Karthik delivered an invited lecture on Recent research and developments in supercapacitor devices at the 'AICTE funded Training Programme on Nanomaterials for Clean Energy and Environmental Applications' organised by Dr. Mahalingam College of Engineering and Technology, Tamilnadu during November 23-28, 2020.

68. Dr. R. Gopalan delivered an invited lecture on Rare earths: Critical survey and their role for magnet technology at the 'Webinar on Value Addition of Beach Sand Minerals' organised by The Associated Chambers of Commerce of India (ASSOCHAM) on November 26, 2020.

69. Dr R. Subasri delivered an invited lecture on Wet chemically derived nanocomposite protective coatings for marine applications during the 'Continuing Education Program on Protection Technologies for Naval Ships and Submarine Against Corrosion' organized by Naval Materials Research Laboratory (NMRL), Ambernath on November 26, 2020.

70. Dr. Sanjay Bhardwaj delivered an invited lecture on Research collaborations at the 'DST sponsored programme on General Management for Women Scientists' sponsored by DST and organized by ASCI, Hyderabad on December 02, 2020.

71. Dr. R. Prakash delivered an invited lecture on Energy materials for e-mobility applications at the '3rd International Conference on Automotive Materials and Manufacturing 2020 (AM&M 2020)- a Digital Conference' organized by ARAI Pune, during December 03-04, 2020.

72. Dr. Gururaj Telasang delivered an invited lecture on Subtractive-additive hybrid manufacturing approach for forming tool at the 'AM&M 2020' organized by ARAI Pune, during December 03-04, 2020.

73. Dr. Mani Karthik delivered an invited lecture on Electrical energy storage: supercapacitor as next generation energy storage device at the 'International Virtual Conference on Smart Advanced Material Science and Engineering Applications - 2020 (IVCSAMSEA-2020)' organised by Koneru Lakshmaiah Education Foundation (K L University), Vijayawada during December 03-05, 2020.

74. Dr. G. Sivakumar delivered an introductory lecture on Surface engineering research at ARCI at the 'Digitalized Surface Manufacturing Consortium Network of EPSRC, UK' organized by University of Manchester, UK on December 04, 2020.

75. Dr. Y. Srinivasa Rao delivered a talk on An Overview on the activities at Centre for Ceramic Processing at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on December 11, 2020.

76. Dr. Sanjay Bhardwaj delivered an invited lecture on R & D collaborations and technology transfer at the 'Science Administration and Research Management Programme for Scientists' sponsored by DST and organized by ASCI, Hyderabad on December 14, 2020.

77. Dr. S. Anandan delivered an invited lecture on Development of energy storage (Li-ion battery and supercapacitor) materials for electric vehicles application; Requirement and challenges at the 'Short Term Training Programme (STTP) Phase-III on Automotive Technology for a Sustainable Future)'organized by GRIET, Hyderabad during December 14-19, 2020.

78. Dr. R. Prakash delivered an invited lecture on Lithium-ion cell technology and materials development at ARCI at the 'Indo-African Bilateral Workshop' organized by DST on December 16, 2020 .

79. Dr. Prabhu D delivered an invited lecture on Nano engineered magnets at 'MHRD-RUSA 2.0 sponsored Entrepreneurship and Career Hub Skill based Internship Programme' organized by University of Madras on December 17, 2020.

80. Dr. G. Padmanabham delivered a lecture on Metal additive manufacturing at the 'Conference on Processing and Characterization of Materials (CPCM 2020)' organized by NIT, Rourkela on December 18, 2020.

81. Dr. Sanjay Bhardwaj delivered an invited lecture on Maximizing IP utilization in R & D organizations at the '8th Annual Conference of World Intellectual Property Forum (WIPF)' held during December18-19, 2020.

82. Dr. R. Gopalan delivered a keynote lectures on a) Materials challenges for electric mobility and b) Materials for 21st century energy crisis for sustainable transport applications at the 'National Workshop on Emerging Technologies of Electric Vehicles and Hybrid Electric Vehicles: Challenges in Design, Manufacturing and Control Systems (EV-2020)' organized by Birla Institute of Technology and Science (BITS) Pilani, Hyderabad during December 19 -20, 2020.

83. Dr. Tata. N. Rao delivered an invited lecture on Role of nanomaterials in energy storage device balancing the power and energy on the occasion of 'CARBON Laboratory 10th Year Celebration' organized by IIT Hyderabad on December 20, 2020

84. Dr. S. Anandan delivered invited lectures on a) Batteries and b) Supercapacitors at the 'Internship programme on Nano-Enabled Devices and Products' organized by National Center for Nanoscience and Nanotechnology, Madras University, Chennai on December 26, 2020.

85. Dr. B. V. Sarada delivered an invited lecture on Nanostructured materials by electrochemical routes for energy storage applications at the 'International Symposium on Recent Advances in Chemical Sciences' organized by Sri Sathya Sai Institute of Higher Learning (SSSIHL), Prasanthinilayam during January 01-02, 2021.

86. Dr. R. Balaji delivered an invited lecture on An overview on materials development for hydrogen energy technology at the 'Skill based programme-RUSA' conducted by Madras University, Chennai on January 04, 2021.

87. Dr. Gururaj Telasang delivered an invited lecture on Metal additive manufacturing for aerospace and tooling applications at the 'AICTE ATAL FDP on 3D Printing and Design' organized by Lords Institute of Engineering and Technology, Hyderabad, during January 04-08, 2021.

88. Dr. S. Sakthivel delivered an invited lecture on Functional coatings for concentrated solar thermal and PV applications at the ' DST-Purse Phase II sponsored Webinar on Recent Trends in Chemistry-2021' organized by Bharathiar University, Coimbatore on January 05, 2021.

89. Dr. D. Sivaprahasam delivered a lecture on Performance of bismuth telluride thermoelectric module under non-steady-state heat input condition at the AICTE ATAL FDP on 3D Printing' organized by Indian Institute of Information Technology Design and Manufacturing (IIITDM), Kanchipuram on January 06, 2021.

90. Dr. Tata. N. Rao delivered an invited lecture on Applications of nano materials at the 'Short Terms Course on Nanomaterials Characterization Techniques' organized by Jawaharlal Nehru Technological University (JNTU), Hyderabad on January 09, 2021

91. Dr. R. Prakash delivered an invited talk on An overview of lithium-ion battery technology and materials development at ARCI at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on January 22, 2021.

92. Dr. Gururaj Telasang delivered an invited lecture on Case studies of selective laser melting: DFAM and conformal cooling channels at the 'AICTE Sponsored FDP on Frontier of 3D Printing Technology and its Industrial Applications (Phase-II)' organized by Lakireddy Bali Reddy College of Engineering Mylavaram, Andhra Pradesh, held from January 25 - February 06, 2021.

93. Dr. Sanjay Bhardwaj delivered an invited lecture on Research collaborations at the 'General Management Programme for Scientists' Sponsored by DST and organized by ASCI, Hyderabad on January 27, 2021.

94. Dr. S. Sakthivel delivered an invited lecture on Self-cleaning coating for solar panels organized by Centre of Excellence of Advanced Materials for Research, Rabindranath Tagore University, Bhopal on January 28, 2021.

95. Dr. R. Balaji delivered an invited lecture on The role of electrochemistry in surface engineering at the 'FDP on Advances in Surface Engineering' conducted by Thiyagaraja college of Engineering, Madurai on January 30, 2021.

96. Dr. Mani Karthik delivered an invited lecture on Recent research progress in supercapacitor technology and its potential applications at the 'FDP on energy storage' organized by GITAM University, Hyderabad during February 01-05, 2021.

97. Dr. M. Buchi Suresh delivered an invited lecture on Ceramic processing and characterization techniques at a 'Refresher Course in Material Sciences: Recombination Memetics', organized by UGC-HRDC (Academic Staff College), Osmania University, Hyderabad during February 01-13, 2021.

98. Dr R. Subasri delivered a talk on Environment friendly (hybrid) sol-gel nanocomposite coatings at the 'Golden Jubilee Celebrations of DST @ ARCI Talk Series: Informative, Invigorating and Inspirational (I3T)' organized by ARCI, Hyderabad on February 12, 2021.

99. Dr. M. B. Sahana delivered an invited lecture on Lithium ion batteries and beyond for electric vehicle applications at the 'Webinar 2021' organized by the Indian Society of Analytical Scientists on February 13, 2021.

100. Dr. Gururaj Telasang delivered an invited lecture on Metal additive manufacturing: materials and applications at the 'Webinar series on Advanced Materials Processing' organized by IIT, Dhanbad during February 17-18, 2021.

101. Dr. Sreekanth M. delivered an invited lecture on Solution processed materials for energy applications at the 'Chemical Engineering Department Colloquium' organized by NIT, Warangal on February 19, 2021.

102. Dr. S. Sakthivel delivered an invited lecture on Functional materials/coatings and nano photocatalysts for solar and environmental applications at the 'CPCB sponsored Training Programme on Advanced Oxidation Technology-A Futuristic Way Forward for Treatment of Recalcitrant Pollutants' organized by Anna University, Chennai on February 24, 2021.

103. Dr.R. Balaji delivered an invited lecture on Hydrogen energy technology for electric vehicle at the 'Induction Programme on Recent Trends in EV Technologies- Phase 1' conducted by Easwari Engineering College, Chennai on February 26, 2021l

104. Dr. Sanjay Bhardwaj delivered an invited lecture on Leveraging ARCI knowledge-base for strategic sector at the 'Technical Session on Environmental, Defence and Aerospace Technologies' in the CII Telangana Tech Summit – Enriching Industry – Institutional Collaboration on Research and Technology held on February 26, 2021 l

105. Dr. G. Padmanabham delivered an expert talk on Laser-arc hybrid welding (LAHW) of high performance materials as part of the 'Series of Expert Talks' organised by Indian Institute of Welding on February 27, 2021l

106. Dr. Tata. N. Rao delivered a Keynote lecture on Indigenous development of energy storage technologies (a step towards self-reliant India) on the occasion of 'National Science Day' organized by Sathyabama Institute of Science and Technology, Chennai on February 27, 2021l

107. Dr. Srinivasan Anandan delivered an invited lecture on Development of energy storage (li-ion battery and supercapacitor) materials for electric vehicles application; requirement and challenges at the 'International Virtual Conference on Energy and Environment (IVCEE 2021)'organized by Thiruvalluvar University, Vellore on March 01, 2021.

108. Dr. Sanjay R. Dhage, delivered an invited lecture on Overview and challenges of thin film solar cell technologies at the 'AICTE-ISTE sponsored Refresher Programme on Recent Development in Advance Materials Phase-I' organized by G.H. Raisoni College of Engineering and Management, Pune during March 01-06, 2021l

109. Dr. Raman Vedarajan delivered an invited lecture on Application of fuel cell at the 'Green Energy Webinar' conducted by Dr. M.G.R Educational and Research Institute, Chennai on March 05, 2021.

110. Dr. Sanjay Bhardwaj delivered an invited lecture on Research collaborations at the 'Advanced Techno Management Programme for Scientists' sponsored by DST and organized by ASCI, Hyderabad on March 05, 2021.

111. Dr. K.Ramya delivered a invited lecture on Polymer-assisted fabrication of inorganic nanoparticles for electrochemical devices at the '12th International Conference on Advancements in Polymeric Materials' organized by Central Institute of Petrochemicals Engineering and Technology (CIPET)-School for Advanced Research in Petrochemicals (SARP)-Laboratory for Advanced Research in Petrochemical Materials (LARPM)), Bhubaneswar during March 09-13, 2021.

112. Dr. Manjusha Battabyal delivered an invited lecture on Development of high-efficient thermoelectric skutterudites and modules for waste heat harvesting at the 'Indo-Polish International Conference on Advances in Energy Harvesting Technology (ICAEHT-2021)' organized by BLDEA's V.P. Dr. P.G. Halakatti College of Engineering, Vijayapur and Lublin University of Technology, Poland during March 18-20, 2021.

113. Dr. G. Sivakumar delivered an invited lecture on Liquid based plasma spraying for functional coatings at the 'TEQIP-III sponsored FDP on Novel Engineering Materials and Processing Techniques' organized by Coimbatore Institute of Technology during March 18-22, 2021.

114. Dr. V. Ganapathy delivered an invited lecture on Nanomaterials synthesis and its application in solar cells at the 'National Symposium on Fundamentals and Advancements in Chemistry' organized by Chevalier T. Thomas Elizabeth College for Women, Chennai on March 19, 2021.

115. Dr Roy Johnson delivered an invited lecture on Transparent polycrystalline ceramics in the 'Lecture series' organized by Indian Ceramic Society, Bengaluru on March 23, 2021.

116. Dr. S. Anandan delivered an invited lecture on Development of energy storage (li-ion battery and supercapacitor) materials for electric vehicles application; requirement and challenges at the 'International Virtual Conference on Advanced Nanomaterials and Their Applications (ICANTA 2021)' organized by Vels University, Chennai during March 24-25, 2021.

117. Dr. Gururaj Telasang delivered an invited lecture on Metal additive manufacturing and applications at the 'AICTE-IST sponsored Induction Programme on Rapid Prototyping and Artificial Intelligence for Industrial Application' organized by St.Martin's Engineering College, Secunderabad, during March 25 -31, 2021.

118. Dr.R. Balaji delivered an invited lecture on The role of fuel cell in hydrogen energy technology at the 'Induction Programme on Recent Trends in EV Technologies- Phase II' conducted by Easwari Engineering College, Chennai on March 29, 2021.

119. Dr. Neha Hebalkar delivered an invited lecture on Nanoporous aerogels : The best thermal insulators at the Webinar on 'Women in Material Science' organized by MRSI, Pune Chapter and Maharashtra Academy of Sciences, March 30, 2021.

120. Dr. R. Gopalan delivered a guest lecture on Opportunities in materials to LIB cell manufacturing technology for EV applications organized by Department of Chemical Engineering-IIT Bombay, Mumbai on March 31, 2021.

Lectures by Indian and Forigen Experts

1. Prof. Arumugam Manthiram, Director, Texas Materials Institute, Austin, USA delivered a lecture on Next-generation Battery Chemistries on August 28, 2020

Panel Discussion

Name	Title of the presentation	Technical Session Topic	Event Name	Date
Dr. Roy Johnson	Web seminar Vertical: V9-Materials and Processing Technologies, H1-Structural Materials		Vaishwik Bhartiya Vaigyanik (VAIBHAV) Summit	October 07, 2020
Dr. S. Sakthivel	Anti-Soiling Coatings suitable for Indian Solar PV power generation	Soiling of PV Panels	Indo-UK PV Soiling Workshop, jointly organized by IITB and Loughborough University, UK under Uk-India research initiative (DST, India)	November 04, 2020
Dr. Ravi Bathe	Laser Processing for Electric Vehicles	Role of Laser in India's EV Manufacturing Journey	Laser World of Photonics India	December 9-11, 2020
Dr. G. Padmanabham	Laser based Manufacturing: Trends and Future	Photonics market in India	Laser World of Photonics India	December 9-11, 2020
Dr. R. Vijay	Nanomaterials and Powder Metallurgy activities at ARCI	Cooperation in new and emerging areas like Nano-technologies, Quantum Technologies, Renewable Energy, Water, Cyber Physical System, 5G and Artificial Intelligence, etc.	The 11th Joint Working Group on Cooperation in Science and Technology between India and Russia	December 17, 2020

Patents' Portfolio

National Patents Granted

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
1.	A Solar Drier	184674	23/09/2000	487/MAS/1994	08/06/1994
2.	A Solar Cooker	184675	25/05/2001	498/MAS/1994	13/06/1994
3.	An Indirect Heated Catalytic Converter for use with Vehicles	185433	10/08/2001	809/MAS/1994	25/08/1994
4.	A Process for the Preparation of Short Ceramic Fibres	186751	07/06/2002	537/MAS/1994	20/05/1994
5.	A Process of Producing Chemically Treated Expanded Graphite and a Device having Such Graphite	187654	05/12/2002	562/MAS/1994	07/06/1995
6.	A Process for Preparation of Reaction Bonded Silicon Carbide Components	195429	31/08/2006	1886/MAS/1996	28/10/1996
7.	New Composite Material Having Good Shock Attenuating Properties and a process for the Preparation of Said Material	194524	02/01/2006	976/MAS/1998	06/05/1998
8.	Improved Process for the Preparation of Magnesium Aluminate Spinel Grains	200272	02/05/2006	29/MAS/1999	07/01/1999
9.	Ceramic Honey Comb Based Energy Efficient Air Heater	200787	02/06/2006	30/MAS/1999	07/01/1999
10.	A Process for the Preparation of Improved Alumina Based Abrasive Material, an Additive Composition and a Process for the Preparation of the Composition	198068	16/02/2006	122/MAS/2000	18/02/2000
11.	A Process for the Production of Dense Magnesium Aluminate Spinel Grains	198208	16/02/2006	520/MAS/2000	06/07/2000
12.	An Improved Method for Making Honeycomb Extrusion Die and a Proc ess for Producing Ceramic Honeycomb Structure using the Said Die	198045	13/01/2006	538/MAS/2001	03/07/2001
13.	Device for Gas Dynamic Deposition of Powder Materials	198651	25/01/2006	944/MAS/2001	22/11/2001
14.	An Evaporation Boat useful for Metallization and a Process for the Preparation of Such Boats	201511	01/03/2007	882/CHE/2003	31/10/2003
15.	Process for Carbothermic Reduction of Iron Oxide in an Immiscible Flow with Constant Descent in Vertical Retort of Silicon Carbide	205728	16/04/2007	546/CHE/2003	01/07/2003
16.	A Process for Preparing Ceramic Crucibles	207700	20/06/2007	806/MAS/2000	26/09/2000
17.	A Process for Forming Coatings on Metallic Bodies and an Apparatus for Carrying out the Process	209817	06/09/2007	945/MAS/2001	22/11/2001
18.	A Method and a Device for Applying a Protective Carbon Coating on Metallic Surfaces	211922	13/11/2007	719/MAS/1999	08/07/1999
19.	An Improved Boronizing Composition	220370	27/05/2008	289/MAS/2001	03/04/2001
20.	Titanium Based Biocomposite Material useful for Orthopedic and other Implants and a Process for its Preparation	228353	03/02/2009	2490/DEL/2005	14/09/2005
21.	An Improved Method of Forming Holes on a Substrate using Laser Beams	239647	29/03/2010	3205/DEL/2005	29/11/2005
22.	A Method of and an Apparatus for Continuous Humidification of Hydrogen Delivered to Fuel Cells	247547	19/04/2011	670/CHE/2007	30/03/2007
23.	An Improved Process for the Preparation of Doped Zinc Oxide Nanopowder useful for the Preparation of Varistors	254913	03/01/2013	1669/DEL/2006	20/07/2006
24.	A Device for Controlling the On & Off Time of the Metal Oxide Semi Conductor Field Effect Transistor (MOSFET), A Device for Spark Coating the Surfaces of Metal Workpiece Incorporating the said Control Device and a Method of Coating Metal Surfaces using the said Device	262189	05/08/2014	1610/DEL/2005	21/06/2005
25.	An Improved Catalyst Ink useful for Preparing Gas Diffusion Electrode and an Improved PEM Fuel Cell	277778	30/11/2016	680/DEL/2008	18/03/2008
26.	An Improved Process for the Preparation of Exfoliated Graphite Separator Plates useful in Fuel Cells, the Plates Prepared by the Process and a Fuel Cell Incorporating the Said Plates	281504	20/03/2017	1206/DEL/2006	17/05/2006
27.	Improved Method of Producing Highly Stable Aqueous Nano Titania Suspension	282988	28/04/2017	730/DEL/2009	09/04/2009
28.	A Process for the Preparation of Nanosilver and Nanosilver-Coated Ceramic Powders	284812	30/06/2017	2786/DEL/2005	19/10/2005
29.	An Improved Method for Preparing Nickel Electrodeposited having Predetermined Hardness Gradient	285178	14/07/2017	1455/DEL/2009	15/07/2009
30.	An Improved Method for the Generation of Hydrogen from a Metal Borohydride and a Device Therfor	285257	17/07/2017	1106/DEL/2007	23/05/2007
31.	Improved Process for the Preparation of Stable Suspension of Nano Silver Particles having Antibacterial Activity	289543	14/11/2017	1835/DEL/2010	04/08/2010
32.	Improved Method for Producing Carbon Containing Silica Aerogel Granules	290370	07/12/2017	2406/DEL/2010	08/10/2010
33.	An Improved Composition for Coating Metallic Surfaces, and a Process for Coating Such Surfaces using the Composition	290592	14/12/2017	620/DEL/2010	17/03/2010
34.	Improved Catalyst Ink for Catalyst Coated Membrane of Electrode Membrane Assembly and the Process Thereof	290765	18/12/2017	631/DEL/2008	13/03/2008
35.	Improved Process for the Preparation of Bi-Functional Silica Particles useful for Antibacterial and Self Cleaning Surfaces	291408	04/01/2018	3071/DEL/2010	22/12/2010
36.	A Hydrophilic Membrane based Humidifier useful for Fuel Cells	291871	18/01/2018	95/DEL/2007	16/01/2007
37.	An Improved Method for Producing ZnO Nanorods	293775	05/03/2018	2759/DEL/2010	19/11/2010
38.	Improved Scratch and Abrasion Resistant Compositions for Coating Plastic Surfaces, a Process for their Preparation and a Process for Coating using the Compositions	295221	28/03/2018	2427/DEL/2010	12/10/2010
39.	An Improved Abrasion Resistant and Hydrophobic Composition for Coating Plastic Surfaces and a Process for its Preparation	297072	24/05/2018	1278/DEL/2011	02/05/2011
40.	Improved Fuel Cell having Enhanced Performance	301158	19/09/2018	606/DEL/2007	21/03/2007
41.	An Improved Process for Preparing Nanotungsten Carbide Powder useful for Fuel Cells	303338	22/11/2018	81/DEL/2007	12/01/2007
42.	An Improved Solar Selective Multilayer Coating and a Method of Depositing the Same	303791	30/11/2018	1567/DEL/2012	22/05/2012
43.	An Improved Method of Preparing Porous Silicon Compacts	304349	12/12/2018	912/DEL/2011	31/03/2011
44.	An Improved Coating Composition to Provide Flame Retardant Property to Fabrics and Process of Preparing the Same	305214	01/01/2019	201611040091	23/11/2016
45.	An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	305898	18/01/2019	2141/DEL/2015	15/07/ 2015
46.	Novel Copper Foils having High Hardness and Conductivity and a Pulse Reverse Electrodeposition Method for their Preparation	306501	29/01/2019	1028/DEL/2009	20/05/2009
47.	A Process for Preparing Nanocrystalline Olivine Structure Transition Metal Phosphate Material	310620	31/03/2019	405/DEL/2012	14/02/2012
48.	Process for Producing Anti-Reflective Coatings with Scratch Resistance Property	314900	27/06/2019	1777/DEL/2012	11/06/2012
49.	A Method for Synthesis of Tungsten Disulphide Nanosheets	320209	11/09/2019	1703/DEL/2012	04/08/2012
50.	Improved Magnetron Cathode and a Process for Depositing Thin Films on Surfaces using the said Cathode	320582	16/09/2019	21/DEL/2008	03/01/2008
51.	Fuel Cell System Equipped with Oxygen Enrichment System using Magnet	321825	27/09/2019	2985/DEL/2012	25/09/2012
52.	An Improved Hybrid Methodology for Producing Composite Multilayered and Graded Coatings by Plasma Spraying Utilizing Powder and Solution Precursor Feedstock	323443	22/10/2019	2965/DEL/2011	17/10/2011

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
53.	A High Thermal Stable Selective Solar Absorber Layer with Low Emissive Barrier Coating over a Substrate and a Process of Producing the Same	323497	23/10/2019	3312/DEL/2012	29/10/2012
54.	Catalytically and Chemically Modified Carbon Nanostructures for Storage of Hydrogen	323653	24/10/2019	405/CHE/2013	30/01/2013
55.	An Improved Process for Preparation of Nanosilver Coated Ceramic Candle Filter	327532	17/12/2019	1249/DEL/2011	28/04/2011
56.	An Improved Gas Flow Field Plate for Use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	332242	18/02/2020	2339/DEL/2008	13/10/2008
57.	Production of Graphene-Based Materials by Thermal Spray	335723	22/04/2020	2626/DEL/2015	25/08/ 2015
58.	Method of Producing Multifunctional Self Assembled Mixed Phase Titania Spheres	335724	22/04/2020	3777/DEL/2014	19/12/2014
59.	A Method and an Apparatus for Preparing Nickel Tungsten based Nanocomposite Coating Deposition	337108	20/05/2020	201611001190	13/01/2016
60.	A Novel Electrochemical Method for Manufacturing CIGS Thin Film Containing Nanomesh Like Structure	337455	28/05/2020	426/DEL/2015	16/02/2015
61.	An Improved Process to Make Coating Compositions for Transparent, UV blocking Coatings on Glass and a Process of Coating the Same	338641	17/06/2020	1152/DEL/2014	29/04/2014
62.	A Polymer Electrolyte Membrane (PEM) Cell and a Method of Producing Hydrogen from Aqueous Organic Solutions	338862	19/06/2020	3313/DEL/2012	29/10/2012
63.	Methods of Preparation of High Performance ZnO Varistors and Improved compositions	339072	22/06/2020	2765/DEL/2015	03/09/2015
64.	Process for Producing Anti-Reflective Coatings With Anti-Fogging (Super Hydrophilic), UV, Weather and Scratch Resistance Properties	339326	25/06/2020	2919/DEL/2013	03/10/2013
65.	Enhanced Thermal Management Systems for Fuel Cell Applications using Nanofluid Coolant	339836	30/06/2020	1745/DEL/2012	07/06/2012
66.	An Improved Composition for Coating Anodizable Metal Surfaces and a Process of Coating the Same`	339945	30/06/2020	1310/DEL/2013	03/05/2013
67.	An Improved Composition for Solar Selective Coatings on Metallic Surfaces and a Process for its Preparation and a Process for Coating using the Composition	340426	03/07/2020	3324/DEL/2011	22/11/ 2011
68.	Method of Producing Nano Structured C-TIO2 Composite Material for Visible Light Active Photocatalytic Self-Cleaning Applications	340592	06/07/2020	201811011478	28/03/2018
69.	An Improved Composition for Antireflective Coating with Improved Mechanical Properties and a Process of Coating the Same	342046	20/07/2020	2330/DEL/2013	05/08/2013
70.	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	343375	05/08/2020	3072/DEL/2013	17/10/2013
71.	A Novel Laser Surface Modification Technique for Hardening Steel	343960	12/08/2020	337/DEL/2013	06/02/2013
72.	An Improved Performance of Nanocomposite Oxide Selective Absorber Coating with Excellent Optical and Thermal Resistant Properties and Method of Manufacturing the Same	345443	28/08/2020	1111/DEL/2015	22/04/ 2015
73.	Method of Producing Hollow MgF2 Nanoparticles, Anti-Reflection Coating Sols and Coatings for Optical and Solar Applications	348807	07/10/2020	201611041804	07/12/2016
74.	A Process to Improve Strength and Fatigue Life of HR Grade Low Carbon Steel Sheet by Laser Surface Hardening Adaptable to Produce Automotive Component	349560	19/10/2020	600/KOL/2012	25/05/2012
75.	A Method of Preparation of Supported Platinum Nano Particle Catalyst in Tubular Flow Reactor via Polycol Process	350276	28/10/2020	1571/DEL/2013	24/05/2013
76.	Electronically and Ionically Conducting Multi-Layer Fuel Cell Electrode and a Method for Making the Same	351830	20/11/2020	2198/DEL/2012	17/07/2012

Sl. No.	Title of Patent	Patent Number	Date of Grant	Application Number	Date of Filing
77.	Method of Deposition of Double Perovskite of Sr-Fe Niobium Oxide Film on a Substrate by Spray Coating Technique and the Coated Substrate Thereof	356708	27/01/2021	1151/DEL/2014	29/04/2014
78.	Ambient Condition Curable Transparent Super Hydrophobic Coating for Easy to Clean Applications and Method of Producing the Same	361991	18/03/2021	201911009429	11/03/2019

National Patent Applications Awaiting Grant

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
1.	Novel Ceramic Materials Having Improved Mechanical Properties and Process for their Preparation	3396/DEL/2005	19/12/2005
2.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	1829/DEL/2008	01/08/2008
3.	An Improved Gas and Coolant Flow Field Plate for use in Polymer Electrolyte Membrane Fuel Cells (PEMFC)	1449/DEL/2010	22/06/2010
4.	An Improved Method for Making Sintered Polycrystalline Transparent Sub-Micron Alumina Article	1358/DEL/2011	10/05/2011
5.	A Process and a Multi-Piston Hot Press for Producing Powder Metallurgy Component, such as Cerametallic Friction Composite	3844/DEL/2011	28/12/ 2011
6.	A Device for and A Method of Cooling Fuel Cells	1408/DEL/2012	08/05/2012
7.	An Improved Aqueous Method for Producing Transparent Aluminium Oxy Nitride (ALON) Articles	1409/DEL/2012	08/05/2012
8.	An Improved Test Control System Useful For Fuel Cell Stack Monitoring and Controlling	269/DEL/2013	31/01/2013
9.	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
10.	Exfoliated Graphite Separator based Electrolyzer for Hydrogen Generation	3073/DEL/2013	17/10/2013
11.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	1411/KOL/2013	13/12/2013
12.	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	13/02/2014
13.	High Temperature Polymer Electrolyte Membrane Fuel Cells with Exfoliated Graphite based Bipolar Plates	494/DEL/2014	20/02/2014
14.	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
15.	Process and Apparatus for Protection of Structural Members from Wear, Corrosion and Fatigue Damage	1839/DEL/2015	22/06/ 2015
16.	A Method of Preparing of Anti Tarnishing Organic-Inorganic Hybrid Sol-Gel and Coating the Same	2049/DEL/2015	07/07/2015
17.	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
18.	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
19.	A Process for In-Situ Carbon Coating on Alkali Transition Metal Oxides	201611007451	03/03/2016
20.	An Improved Process for the Preparation of Stable Nano Silver Suspension having Antimicrobial Activity	201611027145	09/08/2016
21.	A Laser-based Surface Processing Apparatus and a Method to Process Metallic Materials and Components	201611034362	07/10/2016

Sl. No.	Title of Patent	Patent Application Number	Date of Filing
22.	An Improved Process of Carbon - Metal Oxide Composites Prepared by Nano Casting of Wood and the Product Thereof	201611034531	07/10/2016
23.	A Method for Producing Inorganic Bonded Silica based Eco-friendly Artificial Marble Articles and the Product Thereof	201611036479	25/10/2016
24.	A Method of Producing High Performance Lithium Titanate Anode Material for Lithium Ion Battery Applications	201711006147	21/02/2017
25.	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
26.	An Improved Gas Dynamic Cold Spray Device and Method of Coating a Substrate	201711006749	26/02/2017
27.	A Novel Equipment to Accomplish Power Metallurgy Processing Starting from the 'Raw Materials' to Finished Product	201711011552	30/03/2017
28.	An Improved Process for Preparing Durable Multifunctional Coatings on Metal/Alloy Substrates	201711020529	12/06/2017
29.	A System for Treating a Surface of Bearing Components and a Process Thereof	201711046511	23/12/2017
30.	An Ecofriendly Incinerator to Dispose of the used Sanitary Napkins And Bio Medical Waste	201821021430	07/06/2018
31.	Process for Preparing Durable Solar Control Coatings on Glass Substrates	201811024034	27/06/2018
32.	Laser Based Clad-Coatings for Protecting the Power Plant Components for Life Enhancement	201811039663	19/10/2018
33.	Process of Electroless Nickel/Nickel Phosphide (EN) Deposition on Graphite Substrates	201811041418	01/11/2018
34.	A Grid Independent Fuel Cell System With a Unitized (DC & AC) Power Conditioner	201911006700	20/02/2019
35.	Refurbishment of Aircraft Components using Laser Cladding	201911007994	28/02/2019
36.	Microwave Assisted Sol-Gel Process for Preparing In-Situ Carbon Coated Electrode Materials and the Product Thereof	201911008004	28/02/2019
37.	Method of Fabricating Tungsten based Composite Sheets by Spark Plasma Sintering Technique for Making Components	201911014933	13/04/2019
38.	Transition Metal-Based Solar Selective Absorber Coated Substrate and Method of Manufacturing the Same	201911019139	14/05/2019
39.	Process for Producing the Nano Boron by Cryo-Milling	201911025690	27/06/2019
40.	Method of Preparing Gas Diffusion Layer for the Electrode of ECMR Cell for Hydrogen Generation Method of Preparing Gas Diffusion Layer for the Electrode of ECMR Cell for Hydrogen Generation	201911030852	31/07/2019
41.	Antimicrobial Aqueous Based Sol-Gel Composition For Coating On Substrate And Process Of Preparing The Same	201911045386	07/11/2019
42.	A Method of Preparing the Thermoelectric Module for Power Generation from Automotive Exhaust and the Thermoelectric Module Thereof	201911045857	11/11/2019
43.	Method of Producing Nanoporous Graphene Sheet-like Structured High and Low Surface Area Carbon Sheets from Petroleum Coke	20201100739	20/02/2020
44.	Method of Producing Carbon Nanostructure Materials for Heat Transfer, Lubrication and Energy Storage Applications	202011017775	25/04/2020
45.	A Device for Disinfecting and/or Decontaminating Personal Protective Equipments and the Method Thereof	202011020124	13/05/2020
46.	Method For Preparing Multifunctional Isotropic and Uni-Directional Superhydrophobic Surfaces on Substrates using Femtosecond Laser	202011022242	27/05/2020
47.	Method of Producing Porous Particles-Fibers Carbon Composite Material for Supercapacitor Applications and the Product Thereof	202011027265	26/06/2020
48.	Method of Preparation of Carbon Supported Platinum Electrode Catalyst for FEM Fuel Cells and Product Thereof	202011035825	20/08/2020
49.	Oxide Dispersion Strengthened Iron Aluminides with High Strength and Ductility and Method of Preparation of the Same	202011044124	09/10/2020
50.	Method of Manufacturing the Catalyst coated Membrane for the Proton Exchange Membrane Fuel Cells	202011046496	25/10/2020
51.	Method of Producing Single Layer Omnidirectional Broadband Antireflective and Super Hydrophilic Coatings for Solar and Other Applications	202011051833	27/11/2020
52.	Process for the Fast Formation of Solid Electrolyte Interphase Layer on the Anode Surface in Lithium-Ion Battery	202011052906	04/12/2020
53.	Method of Producing In-situ Carbon coated Lithium Iron Phosphate Cathode Material for Lithium Ion Batteries	202011056608	28/12/2020
54.	Biofilm Inhibiting Sol-Gel Composition for Coating on Substrates and Process of Preparing the Same	202111001104	11/01/2021
55.	Post-Calcination modification of Morphology and Improvement of Coercivity in High Energy-Milled strontium Hexaferrite Powders	202111003235	23/01/2021
56.	A Method of Producing Strontium Hexaferrite Powders having High Coercivity Suitable for Bonded Magnets	202111008252	26/02/2021

International Patents Granted and Awaiting Grant

Sl. No.	Title of Patent	Country	Patent Number/ Application Number	Date of Grant	Date of filing with patent office	Indian Patent/ Family 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	IN 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	IN 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	IN284812
		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 with patent office	Indian Patent/ Family 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	IN 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	IN 289543
7.	A Process for Continuous Coating Deposition and an Apparatus for Carrying out the Process	USA	US9365945B2	14/06/2016	14/06/2016	1829/ DEL/2008; Divisional patent of US8486237B2
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	IN 323443
		Canada	2784395	16/09/2014	31/07/2012	
9.	Multi-Track Laser Surface Hardening of Low Carbon Cold Rolled Closely Annealed (CRCA) Grades of Steels	USA	15/103343	---	10/12/2014	1411/KOL/2013
		Australia	AU2014362928	21/02/2019	10/12/2014	
		Europe	EP3080313A1	---	10/12/2014	
10.	An Improved Process for Producing Silica Aerogel Thermal Insulation Product with Increased Efficiency	UAE	P6000095/2018	-	11/01/2018	IN 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	
		Korea	1020187003173	-	01/02/2018	
11.	A Method of Producing High Performance Lithium Titanate Anode Material for Lithium Ion Battery Applications	Japan	2019-520394	-	10/04/2019	IN 201711006147
		Germany	112018000205.5	-	28/06/ 2019	
		USA	16/463088	-	22/05/2019	
		China	201880004507.0	-	22/05/2019	
		Korea	10-2019-7019218	-	02/07/2019	
12.	An Improved Gas Dynamic Cold Spray Device and Method of Coating a Substrate	China	201880013832.3	-	26/08/2019	IN 201711006749
		Russia	2744008	01/03/2021	24/09/2019	
		Canada	3054112	-	09/09/2019	
13.	Microwave assisted sol-gel process for preparing in-situ carbon coated electrode materials and the product thereof	Japan	2020-550159	-	16/09/2020	IN 201911008004
		Republic of Korea	10-2020-7025994	-	09/09/2020	
		Europe	20763813.1	-	11/09/2020	

Journal Publications

1. K. Kumari, M.B. Sahana, P.L. Kumar, M. Battabyal, Jyoti R. Seth, V.A. Juvekar and R. Gopalan, Comprehensive Effort on Electrode Slurry Preparation for Better Electrochemical Performance of LiFePO4 , Journal of Power Sources, Vol. 480, Article No. 228837 , 2020

2. S. Kavita, V.V. Ramakrishna, S. Behara, S. Suganthi, D.N. Kar, T.Tiju, T.Ramesh, K. Sethupathi and R. Gopalan, Investigation of Magnetocaloric and Mechanical Properties of Ni49-xMn39Sb12Cox Alloys, Journal of Alloys and Compounds Vol. 847, Article No. 156558, 2020

3. T. Mitravinda, M. Karthik, S. Anandan, C.S. Sharma and T.N. Rao, Fabrication of Bio-Waste derived Carbon-Carbon based Electrodes for High-Performance Supercapacitor Applications, Indian Journal of Engineering and Materials Sciences, Vol. 27 (6) SI, p 1080-1090, 2020

4. D. Spandana, H. Desai, D. Chakravarty, R. Vijay and K. Hembram, Fabrication of a Biodegradable Fe-Mn-Si Alloy by Field Assisted Sintering, Advanced Powder Technology, Vol. 31(12), p 4577-4584, 2020

5. V.P. Madhurima, P.H. Borse, K. Kumari, T.N. Rao and P.K. Jain, Improved Photocatalytic Activity of Carbon-Based Polymeric Semiconductor for Efficient Decontamination of Wastewater: Effect of Reaction Atmosphere and Pyrolysis Temperature, Optical Materials, Vol. 110, Article No. 110523, 2020

6. A. Bharti, T. Ramesh and N. Rajalakshmi, Promising Co/NC Nanocomposite Electrode Material Derived from Zeolitic Imidazolate Framework for High Performance and Durable Aqueous Symmetric Supercapacitor, Journal of Energy Storage, Vol. 32, Article No. 101969, 2020

7. K. Moses, R. Kali, A. Bello, B. Padya, G.M. Kalu-Uka, J. Wasswa, P.K. Jain, P.A. Onwualu and N.Y. Dzade, Modified Activation Process for Supercapacitor Electrode Materials from African Maize Cob, Materials Vol.13 (23), Article No. 5412, 2020

8. V.V. Ramakrishna, S. Kavita, T. Ramesh, R. Gautam and R. Gopalan, On the Structural and Magnetic Properties of Mn-Bi Alloy Jet Milled at Different Feed Rates, Journal of Superconductivity and Novel Magnetism, Vol. 34, p 733-737, 2020

9. R. Ramarajan, N. Purushothamreddy, R.K. Dileep, K. Reshma, M. Kovendhan, V. Ganapathy, K. Thangaraju and D.P. Joseph, Large-Area Spray Deposited Ta-doped SnO2 Thin Film Electrode for DSSC Application, Solar Energy, Vol. 211, p 547-559, 2020

10. K. Praveen, G. Sivakumar and G. Shamnugavelayutham, Volcanic Ash Infiltration Resistance of New-Generation Thermal Barrier Coatings at 1150C, Surface and Coatings Technology, Vol.401, Article No.126226, 2020

11. J. Shanker, R.V. Kumar, M.B. Suresh and D.S. Babu, Impact of Fe Substitution on Electrical Properties of ErCrO3 Semiconductor Perovskite Ceramic Nanoparticles, Journal of Alloys and Compounds, Vol. 841, Article No. 155730, 2020

12. M. Roy, Saha, S. Saha and K. Valleti, Microstructure and Wear of Cathodic Arc Physical Vapour Deposited on TiAlN, TiCrN and n-TiAlN/alpha-Si3N4 Films, Defence Science Journal Vol.70(6), p 656-663, 2020

13. C.D. Patel, P.N. Dhruv, S.S. Meena, C. Singh, S. Kavita, M .Ellouze and R.B. Jotania, Influence of Co4+-Ca2+ Substitution on Structural, Microstructure, Magnetic, Electrical and Impedance Characteristics of M-type Barium-Strontium Hexagonal Ferrites, Ceramics International Vol. 46(16), p 24816-24830, 2020

14. V. Manikandan, A. Mirzaei, I. Petrila, S. Kavita, R.S. Mane, J.C. Denardin, S. Lundgaard, S. Juodkazis, J. Chandrasekaran and S. Vigneselvan, Effect of Neodymium Stimulation on the Dielectric, Magnetic and Humidity Sensing Properties of Iron Oxide Nanoparticles, Materials Chemistry and Physics, Vol. 254, Article No. 123572, 2020

15. J. Gupta, D. Das and P.H. Borse, Nanosheets Decorated MoS (2) Micro Balls: Effect of 1T/2H Composition, Chemistryselect, Vol.5(38), p 11764-11768 , 2020

16. N.P. Wasekar, L. Bathini, L. Rama Krishna, D.Srinivasa Rao and G. Padmanabham, Pulsed Electrodeposition, Mechanical Properties and Wear Mechanism in Ni-W/SiC Nanocomposite Coatings used for Automotive Applications, Applied Surface Science, Vol. 527, Article No. 146896, 2020

17. A.Sai Jagadeeswar, S. Kumar, B. Venkataraman, P.S. Babu and A. Jyothirmayi, Effect of Thermal Energy on the Deposition Behaviour, Wear and Corrosion Resistance of Cold Sprayed Ni-WC Cermet Coatings, Surface and Coatings Technology, Vol. 399 Article No. 126138, 2020

18. S. Mahade, S. Bjorklund, G. Sivakumar, M.Olsson and S. Joshi, Novel Wear Resistant Carbide-Laden Coatings Deposited by Powder-Suspension Hybrid Plasma Spray: Characterization and Testing, Surface and Coatings Technology, Vol. 399 Article No. 126147, 2020

19. R. Indhu, M. Tak, L. Vijayaraghavan and S. Soundarapandian, Microstructural Evolution and its Effect on Joint Strength during Laser Welding of Dual Phase Steel to Aluminium Alloy, Journal of Manufacturing Processes, Vol.58, p 236-248, 2020

20. A.C. Badgujar, R.O. Dusane and S.R. Dhage, Cu(In,Ga) Se-2 Thin Film Solar Cells produced by Atmospheric Selenization of Spray Casted Nanocrystalline Layers, Solar Energy, Vol. 209, p 01-10, 2020

21. P. Biswas, S. Mamatha, K. Varghese, R. Johnson, R. Vijay and R. Kumar, 3D Printing of High Surface Area Ceramic Honeycombs Substrates and Comparative Evaluation for Treatment of Sewage in Phytorid Application, Journal of Water Process Engineering, Vol. 37, Article No. 101503, 2020

22. B. Prasanth, B. Jayachandren, N. Hebalkar, R. Gopalan, S.B. Chandrasekhar and D. Sivaprahasam, Improved Thermal Stability of Thermoelectric Mg2Si0.4Sn0.6, Materials Letters, Vol. 276, Article No. 128204, 2020

23. M.Usha Rani, K. Nanaji, T.N. Rao and A.S. Deshpande, Corn Husk Derived Activated Carbon with Enhanced Electrochemical Performance for High-Voltage Supercapacitors, Journal of Power Sources, Vol. 471, Article No. 228387, 2020

24. I. Karajagi, K. Ramya, P. C. Ghosh, A. Sarkar and N. Rajalakshmi, Co-doped Carbon Materials Synthesized with Polymeric Precursors as Bifunctional Electrocatalysts, RSC Advances, Vol. 10 (59), p 35966-35978, 2020.

25. A. Bharti and N. Rajalakshmi, Recovery of Expensive Pt/C Catalysts from the End-of-Life Membrane Electrode Assembly of Proton Exchange Membrane Fuel Cells, RSC Advances, Vol. 10 (58), p 35057-35061, 2020

26. A.S. Ganeshraja, S. Maniarsu, P.V. Reddy, V. Ganapathy, V. Karthikeyan, K. Nomura and J.H. Wang, Hierarchical Sn and AgCl Co-Doped TiO2 Microspheres as Electron Transport Layer for Enhanced Perovskite Solar Cell Performance, Catalysis Today, Vol.355 (SI), p 333-339, 2020

27. N. Chundi, B. Das, C.S.R. Kolli, M. Shiva Prasad, K. Suresh, R. Easwaramoorthi and S. Sakthivel, Single Layer Hollow MgF2 Nanoparticles as High-Performance Omnidirectional Broadband Antireflective Coating for Solar Application, Solar Energy Materials and Solar Cells, Vol. 215. Article No. 110680, 2020

28. K. Valleti, G. Smita Rao, P. Miryalkar, A. Sandeep and D.S. Rao, Cr-(CrN/TiAlN)(m)-AlSiN-AlSiO Open-Air Stable Solar Selective Coating for Concentrated Solar Thermal Power Applications, Solar Energy Materials and Solar Cells, Vol. 215 Article No. 110634, 2020

29. H.N. Chaudhari, P.N. Dhruv, C. Singh, S.S. Meena, S. Kavita, and J.B. Rajshree, Effect of Heating Temperature on Structural, Magnetic, and Dielectric Properties of Magnesium Ferrites prepared in the Presence of Solanum Lycopersicum Fruit Extract, Journal of Materials Science-Materials in Electronics, Vol.31 (21), p 18445-18463, 2020

30. P. Biswas, M. Swathi, Y. Srinivasa Rao and R. Johnson, Studies on Correlation of Surface Properties, Colloidal Shaping and Transparency of Magnesium Aluminate Spinel Powder, Materials Chemistry and Physics, Vol. 252, Article No. 123372, 2020

31. L.A. Boatner, C. Bryan, P. Sudharshan Phani, S.N. Dryepondt, A. Shaw, J. Qu, A.E.M. Rossy, M.A. McGuire, J.A. Kolopus and E. Lara-Curzio, Cryo-Quenched Fe-Ni-Cr Alloy Decorative Steel Single Crystals II: Alloy Phases, Structure, Hardness, Tensile, Tribological, Magnetic and Electronic Properties, Journal of Alloys and Compounds, Vol. 835, Article No. 155169, 2020

32. E.Hari Mohan, K. Nanaji, S. Anandan, B.V. Appa Rao and T.N. Rao, Porous Graphitic Carbon Sheets with High Sulfur Loading and Dual Confinement of Polysulfide Species for Enhanced Performance of Li-S Batteries, Journal of Materials Science, Vol. 55(35), p16659-16673, 2020

33. P.V. Durga, K.S. Prasad, S.B. Chandrasekhar, A.V. Reddy, S.R. Bakshi and R Vijay, Microstructural and Mechanical Properties of Oxide Dispersion Strengthened Iron Aluminides produced by Mechanical Milling and Hot Extrusion, Journal of Alloys and Compounds , Vol. 834 Article No. 155218, 2020

34. H. Jain, Y. Shadangi, V. Shivam, D. Chakravarty, N.K. Mukhopadhyay, and D. Kumar, Phase Evolution and Mechanical Properties of Non-Equiatomic Fe-Mn-Ni-Cr-Al-Si-C High Entropy Steel, Journal of Alloys And Compounds, Vol. 834 Article No. 155013, 2020

35. J.A. Prithi, R. Shanmugam, G. Ranga Rao and N. Rajalakshmi, Experimental and Theoretical Study on SO(2) Tolerance of Pt Electrocatalysts: Role of Carbon Support, Electroanalysis, Vol. 32(11), p 2555-2563, 2020

36. S. Sudhakara Sarma, J. Joardar, R Vijay and T.N. Rao, Preparation and Characterization of Nano Boron by Cryo-Milling, Advanced Powder Technology, Vol.31(9), p 3824-3832, 2020

37. P.S. Phani, W.C. Oliver and G.M. Pharr, Understanding and Modeling Plasticity Error during Nanoindentation with Continuous Stiffness Measurement, Materials and Design, Vol. 194 Article No. 108923, 2020

38. P.S. Phani, W.C. Oliver and G.M. Pharr, An Experimental Assessment of Methods for Mitigating Plasticity Error during Nanoindentation with Continuous Stiffness Measurement, Materials and Design, Vol. 194, Article Number: 108924 , 2020

39. M. Shiva Prasad, B. Sobha, K. Suresh and S. Sakthivel, Cu(Mn0.748Ni0.252)(2)O-4/SiO2 Nanoparticle Layers for Wide-Angle Spectral Selectivity and High Thermal Stability, ACS Applied Nano Materials, Vol.3(8), p 7869-7878, 2020

40. R.K. Battula, V. Ganapathy, P. Bhyrappa, C. Sudakar and R. Easwaramoorthi, Stability of MAPbI(3) Perovskite Grown on Planar and Mesoporous Electron-Selective Contact by Inverse Temperature Crystallization, RSC Advances Vol.10(51), p 30767-30775, 2020

41. V. Manikandan, I. Petrila, S. Kavita, R.S. Mane, J.C. Denardin, S. Lundgaard, S. Juodkazis, S. Vigneselvan and J. Chandrasekaran, Effect of Vd-doping on Dielectric, Magnetic and Gas Sensing Properties of Nickel Ferrite Nanoparticles, Journal of Materials Science-Materials in Electronics, Vol.31(19), p 16728-16736, 2020

42. A.B. Kotta, D. Narsimhachary, S.K. Karak, and M. Kumar, Studies on the Mechanical and Physical Properties of Hematite Iron Ore Pellets Prepared under Different Conditions, Transactions of the Indian Institute of Metals, Vol. 73(10), p 2561-2575, 2020

43. P. Suresh Babu, Y. Madhavi, L. Rama Krishna, G. Sivakumar, D. Srinivasa Rao and G. Padmanabham, Thermal Spray Coatings for Erosion-Corrosion Resistant Applications, Transactions of the Indian Institute of Metals, Vol.73(9), p 2141-2159, 2020

44. S. Natarajan, M.B. Sahana, P. Haridoss and R. Gopalan, Concentration Gradient-driven Aluminum Diffusion in a Single-Step Coprecipitation of a Compositionally Graded Precursor for LiNi0.8Co0.135Al0.065O2 with Mitigated Irreversibility of H2 <-> H3 Phase Transition, ACS Applied Materials and Interfaces, Vol.12(31), p 34959-34970, 2020

45. P. Samhita, K. Nanaji, M. Sreekanth, T.N. Rao, S.K. Martha and B.V. Sarada, Cost-Effective Synthesis of Electrodeposited NiCo2O4 Nanosheets with Induced Oxygen Vacancies: A Highly Efficient Electrode Material for Hybrid Supercapacitors, Batteries and Supercaps, Vol.3(11), p1209-1219, 2020

46. R.Dom, G. Sivakumar, S.V. Joshi and P.H. Borse, A Solar-Responsive Zinc Oxide Photoanode for Solar-Photon-Harvester Photoelectrochemical (PEC) Cells, Nanoscale Advances, Vol. 2(8), p 3350-3357, 2020

47. S. Goel, S. Bjorklund, N. Curry, G. Sivakumar, U. Wiklund, C. Gaudiuso and S. Joshi, Axial Plasma Spraying of Mixed Suspensions: A Case Study on Processing, Characteristics, and Tribological Behavior of Al2O3-YSZ Coatings, Applied Sciences-Basel, Vol.10(15), Article No. 5140, 2020

48. N. Purushothamreddy, M. Kovendhan, R.K. Dileep, V. Ganapathy, K.S. Kumar, D.P. Joseph, Synthesis and Characterization of Nanostructured La-doped BaSnO3 for Dye-Sensitized Solar Cell Application, Materials Chemistry and Physics, Vol. 250 Article No. 123137, 2020

49. M. Vijayakumar, A.B. Sankar, D.S. Rohita, K. Nanaji, T.N. Rao and M. Karthik, Achieving High Voltage and Excellent Rate Capability Supercapacitor Electrodes Derived from Bio-Renewable and Sustainable Resource, Chemistryselect, Vol.5(28), p 8759-8772, 2020

50. S.R. Sahu, V.R. Rikka, P. Haridoss, A. Chatterjee, R. Gopalan and R. Prakash, A Novel Alpha-MoO3/Single-Walled Carbon Nanohorns Composite as High-Performance anode Material for Fast-Charging Lithium-Ion Battery, Advanced Energy Materials, Vol.10(36), Article No. 2001627, 2020

51. D.D. Parmar, P.N. Dhruv, S.S. Meena, S. Kavita, C.S. Sandhu, M. Ellouze, and R.B. Jotania, Effect of Copper Substitution on the Structural, Magnetic, and Dielectric Properties of M-type Lead Hexaferrite, Journal of Electronic Materials, Vol.49(10), p 6024-6039, 2020

52. S. Amruthaluru, H. Sampatirao, M. Palanivel, L.Rama Krishna and R. Nagumothu, Effect of Laser Treatment on Morphology and Corrosion Behaviour of the Plasma Electrolytic Oxidation Coatings developed on Aluminized Steel, Surface and Coatings Technology, Vol. 394 Article No. 125888, 2020

53. S. Patibanda, V.J. Nagda, J. Kalra, G. Sivakumar, R. Abrahams and K.N. Jonnalagadda, Mechanical Behavior of Freestanding 8YSZ Thin Films Under Tensile and Bending Loads, Surface and Coatings Technology, Vol. 393 Article No. 125771, 2020

54. K.P. Remya, D. Prabhu, J. Joseyphus, A.C. Bose, C. Viswanathan and N. Ponpandian, Tailoring the Morphology and Size of Perovskite BiFeO3 Nanostructures for Enhanced Magnetic and Electrical Properties, Materials and Design, Vol.192, Article No. 108694, 2020

55. G.Rajender, Y. Markandeya, B. Shashidhar, K. Suresh and G. Bhikshamaiah, Effect of Al on Structure, Magnetic, Resistivity, and Magneto Resistance Studies of Ba2FeMoO6, Journal of Superconductivity and Novel Magnetism, Vol. 33(7), p 2101-2108, 2020

56. B.S. Yadav, K. Suresh, S.R. Dey and S.R. Dhage, Microstructural Investigation of Inkjet Printed Cu(In,Ga)Se-2 Thin Film Solar Cell with Improved Efficiency, Journal of Alloys And Compounds, Vol.827, Article No. 154295, 2020

57. N.V. Challagulla, M. Vijayakumar, D.S. Rohita, Elsa George, A.B.Sankar, T.N. Rao and M. Karthik, Hierarchical Activated Carbon Fibers as a Sustainable Electrode and Natural Seawater as a Sustainable Electrolyte for High-Performance Supercapacitor, Energy Technology, Vol. 8(9), Article No. 2000417, 2020.

58. G. Rajender, Y. Markandeya, K. Suresh and G. Bhikshamaiah, Structural, Magnetic, Resistivity, and Magnetoresistance Studies of Ba(2)Fe(1-x)Ni(x)MoO(6) Double Perovskite, Journal of Materials Science-Materials in Electronics, Vol.31(14), p 11938-11948, 2020

59. S.M. Muthu, M. Arivarasu, T.Hari Krishna, S. Ganguly, K.V. Phani Prabhakar and S. Mohanty, Improvement in Hot Corrosion Resistance of Dissimilar Alloy 825 and AISI 321 CO2-Laser Weldment by HVOF Coating in Aggressive Salt Environment at 900oC, International Journal of Minerals Metallurgy and Materials, Vol.27(11), p1536-1550, 2020

60. S. Mubina, A.K. Khanra, Asit Kumar and B.P. Saha, Enhancement of Oxidation Resistance of CVD SiC Coated C-f/C-SiC Hybrid Composite Tubes Processed through Si-Infiltration, Journal of Alloys and Compounds, Vol.826, Article No.154107, 2020

61. B. Padya, P.K. Enaganti, R. Kali, N. Ravikiran, N. Narasaiah and P.K. Jain, A Controlled Process of Atomic-Scale Material Design Via Temperature-Mediated Grain Refinement of NiCo2O4 Rods for Capacitive Energy Storage, Journal of Science-Advanced Materials and Devices, Vol.5(2), p173-179, 2020

62. M. Nagini, K.G. Pradeep, R. Vijay, A.V. Reddy, B.S. Murty and G. Sundararajan, A Combined Electron Microscopy, Atom Probe Tomography and Small Angle X-ray Scattering Study of Oxide Dispersion Strengthened 18Cr Ferritic Steel, Materials Characterization, Vol.164, Article No. 110306, 2020

63. A. Gangadharan, S. Mamidi, C.S. Sharma and T.N.Rao,

Urea-Modified Candle Soot For Enhanced Anodic Performance for Fast-Charging Lithium-Ion Battery Application, Materials Today Communications, Vol.23. Article No.100926, 2020

64. A.K. Othayoth, B. Srinivas, K. Murugan, and K. Muralidharan, Poly(methyl methacrylate)/ Polyphosphate Blends with Tunable Refractive Indices for Optical Applications, Optical Materials, Vol. 104. Article No. 109841, 2020

65. K. Godbole, C.R. Das, J. Joardar, S.K. Albert, M. Ramji and B.B. Panigrahi, Toughening of AISI 410 Stainless Steel Through Quenching and Partitioning and Effect of Prolonged Aging on Microstructure and Mechanical Properties, Metallurgical and Materials Transactions A-Physical Metallurgy And Materials Science Vol.51(7), p 3377-3383, 2020

66. W. Arnold, R. Birringer, C. Braun, H. Gleiter, H. Hahn, S.H. Nandam, S.P. Singh, Elastic Moduli of Nanoglasses and Melt-Spun Metallic Glasses by Ultrasonic Time-of-Flight Measurements, Transactions of the Indian Institute of Metals, Vol.73(5), p 1363-1371, 2020

67. P. Barick, B.V. Shalini, M. Srinivas, D.C. Jana and B.P. Saha, A Facile Route for Producing Spherical Granules Comprising Water Reactive Aluminium Nitride added Composite Powders, Advanced Powder Technology, Vol.31(5), p 2119-2127, 2020

68. E. Anusha, A. Kumar and S.M. Shariff, A Novel Method of Laser Surface Hardening Treatment Inducing Different Thermal Processing Condition for Thin-Sectioned 100Cr6 Steel, Optics and Laser Technology, Vol. 125, Article No. 106061, 2020

69. P.Sudharshan Phani and W.C.Oliver, Critical Examination of Experimental Data on Strain Bursts (Pop-In) during Spherical Indentation, Journal of Materials Research, Vol.35(8), p 1028-1036, 2020

70. H.Gupta, M. Sagar, R. McGlynn, D. Carolan, P. Maguire, D. Mariotti, P.K. Jain, T.N. Rao, G. Padmanabham and S. Chakrabarti, Activated Functionalized Carbon Nanotubes and 2D Nanostructured MoS2 Hybrid Electrode Material for High-Performance Supercapacitor Applications, Physica Status Solidi A-Applications and Materials Science, Vol.217(10), Article No. 1900855, 2020

71. A.G. Popov, O.A. Golovnia, V.S. Gaviko, D.Y. Vasilenko, D.Y. Bratushev, V.I.N. Balaji, A. Kovacs, K.G. Pradeep and R. Gopalan, Development of High-Coercivity State in High-Energy and High-Temperature Sm-Co-Fe-Cu-Zr Magnets upon Step Cooling, Journal of Alloys and Compounds, Vol. 820, Article No. 153103, 2020

72. N.P. Wasekar, N. Hebalkar, A. Jyothirmayi, B. Lavakumar, M. Ramakrishna and G. Sundararajan, Influence of Pulse Parameters on the Mechanical Properties and Electrochemical Corrosion Behavior of Electrodeposited Ni-W Alloy Coatings with High Tungsten Content, Corrosion Science, Vol.165, Article No. 108409, 2020

73. P.H. Borse, Spoof Surface Plasmon Metamaterials, MRS Bulletin, Vol.45 (4)SI, p 318, 2020

74. R. Vemoori, V.P. Bogu, R. Johnson and A.K. Khanra, Effect of Nickel Coating on the Mechanical Behaviour of Polymer Replicated Al2O3 Foams, Ceramics International, Vol. 46(5), p 6871-6877, 2020

75. N. Manjula, R. Balaji, K. Ramya and N. Rajalakshmi, Hydrogen Production by Electrochemical Methanol Reformation using Alkaline Anion Exchange Membrane based Cell, International Journal of Hydrogen Energy, Vol.45(17), p 10304-10312, 2020

76. A.C. Badgujar, R.O. Dusane and S.R. Dhage, Pulsed Laser Annealing of Spray Casted Cu(In,Ga)Se-2 Nanocrystal Thin Films for Solar Cell Application, Solar Energy, Vol.199, p 47-54, 2020

77. S.R. Atchuta, S. Sakthivel and H.C. Barshilia, Selective Properties of High-Temperature Stable Spinel Absorber Coatings for Concentrated Solar Thermal Application, Solar Energy, Vol.199, p 453-459, 2020

78. K. Hembram, T.N. Rao, M. Ramakrishana, R.S .Srinivasa and A.R. Kulkarni, Influence of CaO Doping on Phase, Microstructure, Electrical and Dielectric Properties of ZnO Varistors, Journal of Alloys and Compounds , Vol. 817, Article No. 152700, 2020

79. S. Kavita, G. Anusha, P. Bhatt, V. Suresh, R. Vijay, K. Sethupathi and R. Gopalan, On the Giant Magnetocaloric and Mechanical Properties of Mn-Fe-P-Si-Ge Alloy, Journal of Alloys and Compounds, Vol. 817, Article No. 153232, 2020

80. N. Purushothamreddy, R.K. Dileep, V. Ganapathy, M. Kovendhan and D.P. Joseph, Prickly pear fruit extract as photosensitizer for dye-sensitized solar cell, Spectrochimica Acta Part A-Molecular And Biomolecular Spectroscopy, Vol. 228, Article No. 117686, 2020

81. L. Subashini, K.V.P. Prabhakar, S. Ghosh and G. Padmanabham, Comparison of Laser-MIG Hybrid and Autogenous Laser Welding of M250 Maraging Steel Thick Sections-Understanding the Role of Filler Wire Addition, International Journal of Advanced Manufacturing Technology, Vol. 107 (3-4), p 1581-1594, 2020

82. K. Barat, K. Panbarasu, R. Bathe and K. Venkateswarlu, Influence of Post-Weld Processing Techniques on Laser Beam-Welded Al-3Mg-0.25Sc Alloy Sheets, Transactions of the Indian Institute of Metals, Vol. 73(6), p 1461-1468, 2020

83. N.S. Anas, L. Rama Krishna, R.K. Dash and R.Vijay, Tribological Performance of Al Alloys Dispersed with Carbon Nanotubes or Ni-Coated Carbon Nanotubes Produced by Mechanical Milling and Extrusion, Journal of Materials Engineering and Performance, Vol.29(3), p 1630-1639, 2020

84. V. Bharti, A. Gangadharan, T.N. Rao and C.S. Sharma, Carbon Soot Over Layered Sulfur Impregnated Coconut Husk Derived Carbon: An Efficient Polysulfide Suppressor for Lithium Sulfur Battery, Materials Today Communications, Vol.22, Article No. 100717, 2020

85. E. Anusha, A. Kumar and S.M. Shariff, Diode Laser Surface Treatment of Bearing Steel for Improved Sliding Wear Performance, Optik, Vol. 206, Article No.163357, 2020

86. P. Joshi, R. Vedarajan, A. Sheelam, K. Ramanujam, B. Malaman and N. Matsumi, An all Solid-State Li Ion Battery Composed of Low Molecular Weight Crystalline Electrolyte, RSC Advances, Vol.10(15), p 8780-8789, 2020

87. S.S. Sravanthi, S.G. Acharyya, J. Joardar and V.N.S.K.Chaitanya, A Study on Corrosion Resistance and Mechanical Performance of 6061 Aluminium Alloy: Galvanized Mild Steel Electron Beam Welds at Varying Welding Parameters, Transactions of the Indian Institute Of Metals, Vol.73(4), p 881-895, 2020

88. J. Senthilselvan, K. Monisha, M. Gunaseelan, S. Yamini, S.A. Kumar, K. Kanimozhi, J. Manonmani, S.M. Shariff and G. Padmanabham, High Power Diode Laser Nitriding of Titanium in Nitrogen Gas Filled Simple Acrylic Box Container: Microstructure, Phase Formation, Hardness, Dendrite and Martensite Solidification Analyses, Materials Characterization, Vol. 160, Article No. 110118, 2020

89. N.S. Anas, M. Ramakrishna and R. Vijay, Microstructural Characteristics and Mechanical Properties of CNT/Ni coated CNT-Dispersed Al Alloys Produced by High Energy Ball Milling and Hot Extrusion, Metals and Materials International, Vol.26 (2), p 272-283, 2020

90. G. Rajender, Y. Markandeya, K. Suresh, A.K. Singh and G. Bhikshamaiah, Correlation among the Crystal Structure, Degree of Ordering, Magnetization and Magnetoresistance Studies of SrBaFexMo2-xO6 (0.8 <= x <= 1.4) Double Perovskites, Journal of Materials Science-Materials in Electronics, Vol.31(4), p 2877-2886, 2020

91. M.A. Shaik, G. Brahma Raju and P. Suresh Babu, Processing and Characterization of Extremely Hard and Strong Cu-(0-15 wt pct)Al Alloys, Metallurgical and Materials Transactions A-Physical Metallurgy and Materials Science, Vol.51(2), p 708-724, 2020

92. N. Rajalakshmi, Hydrogen and Fuel Cell for Sustainable Future, International Journal Of Hydrogen Energy, Vol.45(4), p 3391-3393, 2020

93. V.V.N. Phanikumar, B.V.A. Rao, K.V. Gobi, R. Gopalan and R. Prakash, A Sustainable Tamarind Kernel Powder based Aqueous Binder for Graphite Anode in Lithium-Ion Batteries, Chemistryselect, Vol.5(3), p 1199-1208 , 2020

94. K.H. Gopi, A. Nambi and N. Rajalakshmi, Design and Development of Open Cathode PEM Fuel Cell - Flow Analysis Optimization by CFD, Fuel Cells, Vol.20(1), p 33-39, 2020

95. A.K. Haridas, A. Jyothirmayi, C.S. Sharma and T.N. Rao, Synergic Effect of Nanostructuring and Excess Mn3+ Content in the Electrochemical Performance of Li4Ti5O12-LiNi0.5Mn1.5O4 Li-Ion Full-Cells, Journal of Materials Research, Vol.35(1), p 42-50, 2020

96. K. Imran, K. Ramya, P.C. Ghosh, A. Sarkar and N. Rajalakshmi, Nickel Integrated Carbon Electrodes for Improved Stability, Journal of the Electrochemical Society, Vol.167(13), Article No. 130510, 2020

97. R. Indhu, S. Radha, E. Manikandan, B.S. Sreeja and R.N. Bathe, Development and Characterization of Laser Ablated Polymeric Microchannels, Lasers in Engineering, Vol. 47(1-3), p 125-132, 2020

98. M. Sirisala, P. Biswas, D. Das and R. Johnson, 3D Printing of Cordierite Honeycomb Structures and Evaluation of Compressive Strength under Quasi-Static Condition, International Journal of Applied Ceramic Technology, Vol. 17(1), p 211-216, 2020

99. T. Ramesh, R. Vedarajan, N. Rajalakshmi and L.R.G. Reddy, Dynamic Electrochemical Impedance Spectroscopy as a Rapid Screening Tool for Supercapacitor Electrode Materials, Journal of Materials Science-Materials in Electronics, Vol.31(2), p 1681-1690, 2020

100. V.R. Rikka, S.R. Sahu, A. Roy, S.N. Jana, D. Sivaprahasam, R. Prakash, R. Gopalan, Raghavan and G. Sundararajan, Tailoring Micro Resistance Spot Welding Parameters for Joining Nickel Tab to Inner Aluminium Casing in a Cylindrical Lithium Ion Cell and its Influence on the Electrochemical Performance, Journal of Manufacturing Processes, Vol. 49, p 463-471, 2020

101. R. Gautam, D.B. Prabhu, V. Chandrasekaran, R. Gopalan and G. Sundararajan, Influence of Nanoprecipitates, Solid Solution and Grain Size on the Magnetic and Electrical Properties of Fe-P-Si Alloys, Journal of Magnetism and Magnetic Materials, Vol. 493, Article No. 165743, 2020

102. M. Battabyal, N. S. Karthiselva, P. Rajesh and R. Gopalan, Pressure Induced Enhancement in the Thermoelectric and Mechanical Properties of Ni-doped Skutterudites during Spark Plasma Sintering, Materials Research Innovations, Vol.25(4), p 227-232, 2020

103. B.V. Sarada, R. Vijay, R. Johnson, T. Narsinga Rao and G. Padmanabham, Fight against COVID-19: ARCI's Technologies for Disinfection, Transactions of the Indian National Academy of Engineering, Vol. 5, p 349–354, 2020

104. M. Sreekanth, P. Misra, B. Divya, T.N. Rao and B.V. Sarada, Economic Pulse Electrodeposition for Flexible CuInSe2 Solar Cells, Materials for Renewable and Sustainable Energy, Vol. 9(3), Article.No 19, 2020.

105. S. Chaki, D. Bose and Ravi N. Bathe, Multi-Objective Optimization of Pulsed Nd: YAG Laser Cutting Process using Entropy-Based ANN-PSO Model, Lasers in Manufacturing and Materials Processing Vol. 7 (1), p 88-110, 2020

106. A S Jagadeeswar, S Kumar, B Venkataraman, P S Babu and A Jyothirmayi, Effect of thermal energy on the deposition behaviour, wear and corrosion resistance of cold sprayed Ni-WC cermet coatings, Surface and Coatings Technology, 399, 126-138, 2020

107. A Sangeetha, L. Samyuktha, A. Kapley, Neha Hebalkar, R.K. Sharma, S.G. Uppin and K. Jamil, Induction of Oxidative Stress, DNA Damage, Hematological and Histopathological Effects of Silica Nanoparticles and Ethanol (solvent) in Swiss Albino Mice , Nano Progress., Vol. 2(4), p 32-39, 2020

108. A Sangeetha, L. Samyuktha, A. Kapley, Neha Hebalkar, R.K. Sharma, S.G. Uppin and K. Jamil, In Vivo Interactions of Nanosized Anatase and Rutile Particles Following Oral Administration, Nano Progress, Vol.2(3), p 11-20, 2020

109. A Sangeetha, L. Samyuktha, A. Kapley, Neha Hebalkar, R.K. Sharma, S.G. Uppin and K. Jamil, Evaluation of Biological Effects and Toxicity of Cetyltrimethylammonium Bromide Stabilized Silver Nanoparticles and Cetyltrimethylammonium Bromide Alone Following Intravenous Injection in Mice, Current Nanomedicine, Vol.11(1), p 70-80, 2021.

110. A. Karati, T. Parida, J. Gupta, H.K. Adigilli, P.H. Borse and J. Joardar, Band-Gap Engineering in Novel Delafossite-Type Multicomponent Oxides for Photocatalytic Degradation of Methylene Blue, Materials Research Bulletin, Vol. 137, Article No. 111181, 2021

111. B. Jayachandran, B. Prasanth, R. Gopalan, T. Dasgupta and D. Sivaprahasam, Thermally Stable, Low Resistance Mg2Si0.4Sn0.6/Cu Thermoelectric Contacts Using SS 304 Interlayer by One Step Sintering, Materials Research Bulletin, Vol.136, Article No. 111147, 2021

112. S.Harish, D. Sivaprahasam, B. Jayachandran, R. Gopalan and G. Sundararajan, Performance of Bismuth Telluride Modules under Thermal Cycling in an Automotive Exhaust Thermoelectric Generator, Energy Conversion and Management, Vol.232, Article No. 113900, 2021

113. A. Bharti and R. Natarajan, Robust Co-embedded Nitrogen doped Carbon Catalyst for Oxygen Reduction Reaction in Proton Exchange Membrane Fuel Cell, Chemistryselect, Vol. 6(9), p 2298-2305, 2021

114. R. Badam, R. Vedarajan, K. Okaya, K. Matsutani and N. Matsumi, Ionic Liquid Mediated Decoration of Pt Nanoparticles on Graphene and its Electrocatalytic Characteristics, Journal of the Electrochemical Society, Vol.168(3), Article No. 036515, 2021

115. S. Loganathan, S. Santhanakrishnan, R. Bathe and M. Arunachalam, FTIR and Raman as a Noninvasive Probe for Predicting the Femtosecond Laser Ablation Profile on Heterogeneous Human Teeth, Journal of the Mechanical Behavior of Biomedical Materials,Vol.115, Article No. 104256, 2021

116. S.Sharma, M. Narayanan, R. Gautam, R. Gopalan and P. Swaminathan, Effect of Processing Route on the Structural and Functional Properties of Manganese doped Zinc Oxide, Materials Chemistry and Physics, Vol. 261 Article No. 124206, 2021

117. R.V. Kumar, R. Harichandran, U. Vignesh, M. Thangavel, S.B. Chandrasekhar, Influence of Hot Extrusion on Strain Hardening Behaviour of Graphene Platelets Dispersed Aluminium Composites, Journal of Alloys and Compounds, Vol. 855, Article No. 157448, 2021

118. A. Das, A. Chauhan, V. Trivedi, M. Tiadi, R. Kumar, M. Battabyal and D.K. Satapathy, Effect of Iodine Doping on the Electrical, Thermal and Mechanical Properties of SnSe for Thermoelectric Applications, Physical Chemistry Chemical Physics, Vol.23(7), p 4230-4239, 2021

119. J. Das, S. Vajjala, M. Tak, Manish, J.R. Jabbireddy and B.P.V.Velidandla, Formation of Nano-ZrO2 by Laser Surface Treatment of ZrB2-SiC-based Composite, International Journal of Applied Ceramic Technology,Vol.18(3), p 1004-1016, 2021

120. M. Sreekanth, P. Misra, B. Divya, T.N. Rao and B.V. Sarada, Solar Energy Harvesting through Photovoltaic and Photoelectrochemical Means from Appositely Prepared CuInGaSe2 Absorbers on Flexible Substrates by a Low-Cost and Industrially Benign Pulse Electrodeposition Technique, Industrial and Engineering Chemistry Research, Vol. 60(5), p 2197-2205, 2021

121. V.Trivedi, M. Battabyal, S. Perumal, A. Chauhan, D.K. Satapathy, B.S. Murty and R.Gopalan, Effect of Refractory Tantalum Metal Filling on the Microstructure and Thermoelectric Properties of Co4Sb12 Skutterudites, ACS Omega, Vol.6(5), p 3900-3909, 2021

122. A. Rebekah, S. Sivaselvam, C. Viswanathan, D. Prabhu, R. Gautam and N. Ponpandian, Magnetic Nanoparticle-Decorated Graphene Oxide-Chitosan Composite as an Efficient Nanocarrier for Protein Delivery, Colloids and Surfaces A-Physicochemical and Engineering Aspects, Vol. 610 Article No. 125913, 2021

123. A. Kumar, D. Sivaprahasam and A.D.Thakur, Colossal Seebeck Coefficient in Aurivillius Phase-Perovskite Oxide Composite, Journal of Alloys and Compounds, Vol. 853, Article No. 157001, 2021

124. M.Sagar, H. Gupta, P.K. Jain, T.N. Rao, G. Padmanabham and S. Chakrabarti, Functionalized Carbon Nanotube and MnO2 Nanoflower Hybrid as an Electrode Material for Supercapacitor Application, Micromachines, Vol.12(2), Article No. 213, 2021

125. M. Ramakrishna, K. Suresh, T. Gururaj, K. Rajesh and G. Padmanabham, Effect of Solutionizing Temperature on the Microstructural Evolution during Double Aging of Powder Bed Fusion-Additive Manufactured IN718 Alloy, Materials Characterization, Vol.172 Article No. 110868, 2021

126. X.S.Zou, M. Rachakonda, S.F. Chu, X.R.Zhao, J. Joardar and K.M.Reddy, Structure and Mechanical Properties of Nanostructured Rhombohedral Cr5Al8, Materials Characterization, Vol.172, Article No. 110862, 2021

127. S.P. Singh and A.D. Sontakke, Transparent Glass Ceramics, Crystals, Vol.11(2), Article No. 156, 2021

128. D. Chakravarty, N. Laxman, R. Jayasree, R.B.Mane, S. Mathiazhagan, P.V.V. Srinivas, R. Das, M. Nagini, M. Eizadjou, L. Venkatesh, N. Ravi, D.R. Mahapatra, R. Vijay, S.P. Ringer, and C.S. Tiwary, Ultrahigh Transverse Rupture Strength in Tungsten-based Nanocomposites with Minimal Lattice Misfit and Dual Microstructure, International Journal of Refractory Metals and Hard Materials, Vol. 95 Article No. 105454, 2021

129. T. Mitravinda, S. Anandan, C.S. Sharma and T.N. Rao, Design and Development of Honeycomb Structured Nitrogen-Rich Cork Derived Nanoporous Activated Carbon for High-Performance Supercapacitors, Journal of Energy Storage, Vol. 34, Article No. 102017, 2021

130. S.R. Dhage, B.S. Yadav, G.K. Jha and A.C. Badgujar, 12.95% Efficient Cu(In,Ga)Se-2 Solar Cells by Single-Step Atmospheric Selenization, Scaled to Monolithically Integrated Modules, ACS Applied Energy Materials, Vol.4(1), p 286-294, 2021

131. S. Mamidi, A. Gangadharan, A.D. Pathak, T.N. Rao and C.S. Sharma, A Three-Dimensional Hybrid Carbon-Microelectromechanical System on a Graphite-Coated Stainless Steel Substrate as a High-Performance Anode for Lithium-Ion Batteries, ACS Applied Energy Materials,Vol.4(1), p 545-553, 2021

132. A.M. Hebbale, M. Tak and R. Bathe, Microstructural Studies of Composite (Cr3C2-NiCr)Laser Clads Developed on Preheated Substrate T91, Transactions of the Indian Institute of Metals, Vol.74(3), p 593-600, 2021

133. B. Padya, R. Kali, P.K. Enaganti, N.Narasaiah and P.K. Jain, Facile Synthesis and Frequency-Response Behavior of Supercapacitor Electrode based on Surface-Etched Nanoscaled-Graphene Platelets, Colloids and Surfaces A-Physicochemical and Engineering Aspects, Vol.609, Article No. 125587, 2021

134. P. Misra, S.R. Atchuta, M. Sreekanth, B.V. Sarada, T.N. Rao and S. Sakthivel, A non-Vacuum Dip coated SiO2 Interface Layer for Fabricating GIGS Solar Cells on Stainless Steel Foil Substrates, Solar Energy, Vol. 214, p 471 - 477, 2021

135. N. Manjula, M.B. Suresh and S. Bathulapalli, Effect of Na doping on Structural, Optical, and Dielectric Properties of SnSe Polycrystals, Journal of Materials Science-Materials in Electronics, Vol. 32 (4), p 4347-4362, 2021

136. K. Madhuri, P.K. Kannan, B.S. Yadav, S. Chaudhari, S.R. Dhage, and S.R. Dey, Investigation on Effects of Precursor Pre-Heat Treatments on CIGS Formation using Spin-Coated CIG Precursor, Journal of Materials Science-Materials in Electronics, Vol. 32(2), p 1521-1527, 2021

137. K.M. Reddy, X.S. Zou, Y.X. Hu, H.B. Zhang, T.N. Rao and J. Joardar, Influence of Heating Rate on Formation of Nanostructured Tungsten Carbides during Thermo-Chemical Processing, Advanced Powder Technology, Vol.32, p 121-130, 2021

138. K. Geethasree, A.M. Zafir, P. Sudarshan Phani, R. Sarkar, V.V.S. Prasad and G. Brahma Raju, Influence of Ti and Zr Alloying Elements on Microstructure and Micromechanical Properties of Near-Eutectic Nb-18.7Si Alloy, Materials Characterization, Vol. 171, Article No. 110723, 2021

139. M.K. Gupta, D. Dinakar, I.M. Chhabra, S. Jha and M.B. Suresh, Experimental Investigation and Machine Parameter Optimization for Nano Finishing of Fused Silica using Magnetorheological Finishing Process, OPTIK, Vol.226, Article No. 165908, 2021

140. V.S. Katta, A. Das, K.R. Dileep, G. Cilaveni, S. Pulipaka, V. Ganapathy, R. Easwaramoorthi, P.Praveen, S. Asthana, D. Melepurath and S.S.K. Raavi, Vacancies Induced Enhancement in Neodymium doped Titania Photoanodes based Sensitized Solar Cells and Photo-electrochemical Cells, Solar Energy Materials and Solar Cells, Vol. 220, Article No. 110843, 2021

141. R.B. Mane, R. Vijay, B.B. Panigrahi and D. Chakravarty, High Temperature Decomposition Kinetics of Ti3GeC2 MAX Phase, Materials Letters, Vol. 282, Article No. 128853, 2021

142. Y. Madhavi, L. Rama Krishna and N. Narasaiah, Corrosion-Fatigue Behavior of Micro-Arc Oxidation Coated 6061-T6 Al Alloy, International Journal of Fatigue, Vol.142, Article No. 105965, 2021

143. K. Hembram, T.N.Rao, R.S. Srinivasa and A.R. Kulkarni, CaO doped ZnO-Bi2O3 Varistors: Grain Growth Mechanism, Structure and Electrical Properties, Ceramics International, Vol.47(1), p 1229-1237, 2021

144. G. Shubham, S.M. Muthu, N. Arivazhagan, K.V.P. Prabhakar and M. Arivarasu, Comparative Studies on the Metallurgical and Mechanical Behaviour of Co2 Laser Beam and Pulsed Current Gas Tungsten Arc Welded Stainless Steel, Lasers in Engineering, Vol.48(1-3), p 107-120, 2021

145. S. Mubina, M. Ilaiyaraja, A.K. Khanra and B.P. Saha, Fabrication and Microstructure Analysis of Continuous C Fibers Reinforced SiC-Cnfs Hybrid Composite Tubes, Materials And Manufacturing Processes, Vol.36(3), p 292-300, 2021

146. M. Murugesan, V. Krishnamurthy, N. Hebalkar, M. Devanesan, P. Nagamony, M. Palaniappan, S. Krishnaswamy and A.H. Yuan, Nano-Hydroxyapatite (HAp) and Hydroxyapatite/Platinum (HAp/Pt) Core Shell Nanorods: Development, Structural Study, and their Catalytic Activity, Canadian Journal of Chemical Engineering, Vol. 99(1), p 268 - 280 , 2021

147. S.Loganathan, S. Santhanakrishnan, R. Bathe and M. Arunachalam, Physiochemical Characteristics: A Robust Tool to Overcome Teeth Heterogeneity on Predicting Laser Ablation Profile, Journal of Biomedical Materials Research Part B-Applied Biomaterials Vol. 109(4), p 486-495, 2021

148. S. Mubina, P.Sudharshan Phani, A.K. Khanra and B.P. Saha, A Nanoindentation based Study to Evaluate the Effect of Carbon Nanofibers on the Mechanical Properties of SiC Composites, Composite Interfaces Vol.28(4), p 363-380, 2021

149. K. Nanaji, Tata N. Rao, U. V. Varadaraju and S. Anandan, Investigating the Dual Role of Potassium Hydroxide as Pore Inducing Agent as well as a Catalyst to Obtain Graphene-like Carbon Sheets for Supercapacitors with Ultra-Fast Rate Capability, Renewable Energy, Vol. 172, p 502-513, 2021

150. K. Nanaji, P.V. Srinivas, S. Anandan, M. Pramanik, K. Narayanan, R. Balasubramaniam and Tata N. Rao, Petroleum Coke as an Efficient Single Carbon Source for High Energy and High Power Lithium-Ion Capacitors, Energy and Fuels, Vol. 35, p 9010-9016, 2021

151. M. Nagini, R. Vijay, K.S. Satya Prasad, A.V. Reddy and G. Sundararajan, Role of Microstructure and Temperature on the Tensile Fracture Behaviour of Oxide Dispersion Strengthened 18Cr Ferritic Steel, Metallurgical and Materials Transactions A-Physical Metallurgy and Materials Science, Vol. 52 A, p. 1826-1835, 2021.

152. M. Sreekanth, P. Misra, B. Divya, T.N.Rao and B.V. Sarada, Control over MoSe2 Formation with Vacuum-Assisted Selenization of One-Step Electrodeposited Cu-In-Ga-Se Precursor Layers, Environmental Science and Pollution Research, Vol. 28 (12), p 15123-15129 , 2021

153. Rahul B. Mane, Ramakrishna Sahoo, B. S. K. Reddy, R. Vijay, Bharat B. Panigrahi, Pramod H. Borse and D. Chakravarty, Doping-Induced Coloration in Titania, Journal of the American Ceramic Society, Vol. 104, p 2932-2936, 2021

154. R. Jayasree, Rahul B. Mane, R. Vijay and D. Chakravarty, Effect of Process Control Agents on Mechanically Alloyed Al0.3CoCrFeNi, Materials Letters, Vol 292, Article No. 129618, 2021.

155. S.H. Adsul, U.D. Bagale, S.H. Sonawane and R. Subasri, Release Rate Kinetics of Corrosion Inhibitor Loaded Halloysite Nanotube-based Anticorrosion Coatings on Magnesium Alloy AZ91D, Journal of Magnesium and Alloys, Vol.9 p 202-215, 2021

156. K.Tabassum, D.S. Reddy, Vivek R. Singh, R. Subasri and P. Garg, Sol-gel Nano-Composite Coatings for Preventing Biofilm Formation on Contact Lens Cases, Translational Vision Science and Technology, Vol 10 (1) Article No. 4, 2021.

157. S. Ganesh, P. Sai Karthik, M. Ramakrishna, A.V. Reddy, S.B. Chandrasekhar and R. Vijay, Ultra-High Strength Oxide Dispersion Strengthened Austenitic Steel, Materials Science and Engineering A, Vol.814, Article No. 141192, 2021

158. R. K. Dileep, M. K. Rajbhar, A. Ashina, E. Ramasamy, S. Mallick, T. N. Rao and V. Ganapathy, A Facile Co-Precipitation Method for Synthesis of Zn Doped BaSnO3 Nanoparticles for Photovoltaic Application, Materials Chemistry and Physics Vol. 258, Article No. 123939, 2021.

159. A. Ashina, B. Ramyakrishna, E. Ramasamy, N. Chundi, S. Sakthivel and V.Ganapathy, Dip coated SnO2 Film as Electron Transport Layer for Low-Temperature Processed Planar Perovskite Solar Cells, Applied Surface Science Advances Vol. 4, Article No.100066, 2021.

160. V. N. Rao, P. Ravi, M. Sathish, M. Vijayakumar, M. Sakar, Mani Karthik, S. Balakumar, K. R. Reddy, N. P. Shetti, M. V. Shankar and T.M. Aminabhavi, Metal Chalcogenide-based Core/Shell Photocatalysts for Solar Hydrogen Production: Recent Advances, Properties and Technology Challenges, Journal of Hazardous Materials, Vol. 415, p. 125588-125609, 2021.

161. D.Lal, P. Kumar, Ravi Bathe, S. Sampath and V. Jayaram, Effect of Microstructure on Fracture Behavior of Freestanding Plasma Sprayed 7 wt.% Y2O3 Stabilized ZrO2, Journal of the European Ceramic Society, Vol. 41 (7), p 4294-4301, 2021

162. J.A.Prithi, R. edarajan, G.Ranga Rao and N.Rajalakshmi, Functionalization of Carbons for Pt Electrocatalyst in PEMFC, International Journal of Hydrogen Energy, Vol 46, p 17871-17885, 2021

163. Puneet C, K. Valleti and A. Venu Gopal, Low Friction Coefficient Nanocomposite Cralsin/Gradient-Cralsicn Coatings for High Speed/Dry Machining Applications, Journal of Manufacturing Science and Engineering, Vol. 143 (8), Article No. 081013, 2021

164. Naveen M. Chavan, P.S. Phani, M. Ramakrishna, L. Venkatesh, P. Pant and G. Sundararajan, Role of Stacking Fault Energy(SFE) on the High Strain Rate Deformation of Cold Sprayed Cu and Cu-Al Alloy Coatings, Materials Science and Engineering A- Vol. Vol.814, Article No. 141242, 2021

165. A. Sharma, M. Krishnan, G. Gurudatta, S. Seema, Papiya Biswas, R. Johnson, K.M. Abraham and S.R. Iyer, In Vitro Evaluation of Magnesium Aluminate [MgAl2O4] Spinel Ceramic based Polyphasic Composite Scaffold for Craniofacial Bone Tissue Engineering, Ceramics International, Vol. 47, p. 13678–13692, 2021

166. M. Swathi , Papiya Biswas, P. Barick, S. Kumari, B. P. Saha and Roy Johnson, Comparative Study on Compaction and Sintering Behavior of Spray and Freeze Granulated Magnesium Aluminate Spinel Powder, Transactions of Indian Ceramic Society, Vol. 80, p. 110-117, 2021

167. S.R. Dey, Ch.L. P. Pavithra, R.K.S.K.Janardhana; K. Madhav Reddy; M. Chandrasekhar, Joydip Joardar, B. V. Sarada; R. R. Tamboli, Y.Hu, Y.Zhang and X. Wang, An Advancement in the Synthesis of Unique Soft Magnetic Co-Cu-Fe-Ni-Zn High Entropy Alloy Thin Films, Scientific Reports,Vol.11, Article No. 8836, 2021

168. R. Sahoo, M. Singh and Tata N. Rao, A Review on the Current Progress and Challenges of 2D Layered Transition Metal Dichalcogenides (TMDs) as Li/Na-Ion Battery Anode., ChemElectroChem 2021 (In Press)

169. K. Pradeep Prem Kumar and R. Subasri, Improving the Corrosion Resistance of Mg Alloy AZ31 by a Duplex Anodized and Sol-gel Coating, Materials Performance and Characterization. (In Press)

170. R. Senthil Kumar, K.H. Sai Priyanka, A.K. Khanra, R. Johnson, A Novel Approach of Synthesizing Nano Y2O3 Powders for the Fabrication of Submicron IR Transparent Ceramics, Ceramics International (In Press)

171. M. Vijayakumar, G. Elsa, A. Nirogi, R. Navaneethan, A. B. Sankar and Mani Karthik, MXenes and their Composites for Hybrid Capacitors and Supercapacitors: A Critical Review, Emergent Materials, 2021 (In Press)

172. R. Sharma, S. Pradhan and R.N. Bathe, Design and Fabrication of Honeycomb Micro-Texture using Femtosecond Laser Machine, Materials and Manufacturing Processes, 2021 (In Press)

173. P.Barick and B.P.Saha, Effect of Boron Nitride Addition on Densification, Microstructure, Mechanical, Thermal and Dielectric Properties of β-SiAlON Ceramic, Journal of Materials Engineering and Performance, 2021 (In Press)

174. N. Rajalakshmi and R. Gopalan, Recent Trends in Science and Technology of Hydrogen and Polymer Electrolyte Membrane Fuel Cells, Transactions of the Indian National Academy of Engineering (In Press)

175. P. Sreeraj, Raman Vedarajan, N.Rajalakshmi and V.Ramadesigan, Screening of Recycled Membrane with Crystallinity as a Fundamental Property, International Journal of Hydrogen Energy (In Press)

176. P.Sudharshan Phani, W.C. Oliver and G.M. Pharr, Measurement of Hardness and Elastic Modulus by Load and Depth Sensing Indentation: Improvements to the Technique based on Continuous Stiffness Measurement, Journal of Materials Research , 2021 (In Press)

177. E.M. Rossi, P. S. Phani, R. Guillemet, J. Cholet, D. Jussey, W.C. Oliver and M. Sebastiani, A Novel Nanoindentation Protocol to Characterize Surface Free Energy of Superhydrophobic Nanopatterned Materials, Journal of Materials Research, 2021 (In Press)

178. M. Aqeel, S.M. Shariff, J.P. Gautam and G .Padmanabham, Liquation Cracking in Inconel 617 Alloy by Laser and Laser-Arc Hybrid Welding, Materials and Manufacturing Processes, 2021 (In Press)

179. R. Jarugula, K. Suresh, R. Jeyaraam, S.G.S. Raman and G. Sundararajan, On the Understanding of Microstructural Evolution during Hot Deformation of n-ODS-18Cr Ferritic Steel Containing Heterogeneous Microstructure, Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing, Vol. 800, 2021 (In Press)

Conference Proceedings

1. C. Keerthana, A.M. Hebbale, B.S. Patil and M.A. Prasad, Neuro-Fuzzy Modeling and Wear Rate Predictions of Microwave Clads, Proceedings of 1st International Conference on Advanced Lightweight Materials and Structures (ICALMS) in Advances in Lightweight Materials and Structures, Vol. 8, p 541-550, 2020
2. S.Pradhan, S. Indraneel, R.Sharma D.K. Bagal and R.N. Bathe, Optimization of Machinability Criteria During Dry Machining of Ti-2 with Micro-Groove Cutting Tool using WASPAS Approach, Proceeding of 2nd International Conference on Processing and Characterization of Materials (ICPCM) in Materials Today-Proceedings, Vol. 33, p 5306-5312, 2020
3. R. Sharma, S. Pradhan and R.N. Bathe, Design and Fabrication of Spiral Triangular Micro Texture on Chemical Vapor Deposition coated Cutting Insert using Femtosecond Laser Machine, Proceedings of International Conference on Aspects of Materials Science and Engineering (ICAMSE) in Materials Today-Proceedings, Vol. 28, p 1439-1444, 2020
4. A. Kumar, K. Kumari, D. Sivaprahasam and A.D. Thakur, Thermoelectric Properties in Spark Plasma Sintered La0.7Sr0.3Mn0.5Co0.5O3, Proceedings of 3rd International Conference on Condensed Matter and Applied Physics (ICC-2019) in AIP Conference Proceedings, Vol. 2220, Article No.120001, 2020
5. K.S.K .Reddy, M. Kannan, R. Karthikeyan, A. Sripad and P.K. Jain, Investigation of Thermal and Mechanical Properties of Al7020/SiC/Graphite Hybrid Metal Matrix Composites, Proceedings of 10th International Conference of Materials Processing and Characterization (ICMPC) in Materials Today-Proceedings, Vol. 26, p 2746-2753, 2020
6. H. Gupta, S. Chakrabarti, S. Mothkuri, B. Padya, T.N. Rao and P.K. Jain, High Performance Supercapacitor based on 2D-MoS2Nanostructures, Proceedings of International Conference on Nano Science and Engineering Application (ICONSEA) in Materials Today-Proceedings, Vol. 26, p 20-24, 2020
7. B. Padya, N. Ravikiran, R. Kali, N. Narasaiah, P.K. Jain and T.N. Rao, Multifunctional Surface-Modified Ultrathin Graphene Flakes for Thermal and Electrochemical Energy Storage Application, Proceedings of ICONSEA in Materials Today-Proceedings, Vol. 26, p 52-57, 2020
8. M. Sagar, S. Chakrabarti, H. Gupta, B. Padya, T.N. Rao and P.K. Jain, Synthesis of MnO2Nano-Flakes for High Performance Supercapacitor Application, Proceedings of ICONSEA in Materials Today-Proceedings, Vol. 26, p 142-147, 2020
9. K. Madhuri, P.K. Kannan, S. Chaudhari, S.R. Dhage and S.R. Dey, Effect of Annealing Time and Heat Flux on Solvothermal Synthesis of CIGS Nanoparticles, Proceedings of International Symposium on Functional Materials (ISFM) - Energy and Biomedical Applications in Materials Today-Proceedings, Vol. 21, p 1882-1887, 2020
10. P. Misra, M. Sreekanth, T.N. Rao and B.V. Sarada, A Multi-Layer Cu:Ga/In Sputtered Precursor to Improve Structural Properties of CIGS Absorber Layer, Proceedings of 3rd International Conference on Solar Energy Photovoltaics (ICSPE) in Materials Today Proceedings, Vol.39, p 2037-2041, 2021
11. A. H. V. Pavan, K. Sowmya, B. R. Chandra, M. Swamy, R. Vijay and Kulvir Singh, Characterization and Mechanical Behavior of Mechanically Milled and Hot Extruded Oxide Dispersion Strengthened Steel, Proceedings of the International Conference and Exposition on Mechanical, Material and Manufacturing Technology (ICE3MT2020) in Materials Today Proceedings, Vol. 38, p 2687-2694, 2021

Books

1. A chapter on Advanced Nanocatalysts for Fuel-Cell Technologies, authored by Raman Vedarajan, J. Prithi and N. Rajalakshmi, in the book on Nanomaterials for Sustainable Energy and Environmental Remediation, (ed.) Mu. Naushad, R. Saravanan and Kumar Raju, ISBN: 978-0-12-819355-6, Elsevier Publications, Materials Today, p 165-192, 2020
2. 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, ISBN: 978-0-12-816770., Elsevier, Vol.1, p 399-412, 2020
3. A chapter on Cost-Efficient Solar Receiver Tube, authored by S. R. Atchuta, B. Mallikarjun, M. S. Prasad and S. Sakthivel in the book on Solar Energy Research Institute for India and the United States (SERIIUS) - Lessons and Results from a Binational Consortium, Springer Lecture notes in Energy, ISBN: 978-3-030-33184-9., Vol. 39, p 112-115, 2020.
4. A chapter on Sustainable Photovoltaics, authored by David Ginley, Joel Ager, Rakesh Agrawal, Sanjay R. Dhage, B.V. Sarada, et. al in the book on Solar Energy Research Institute for India and the United States (SERIIUS) - Lessons and Results from a Binational Consortium, Springer Lecture notes in Energy, ISBN: 978-3-030-33184-9., Vol. 39, p 25-85, 2020
5. A chapter on Multiscale Concentrated Solar Power authored by D. Ginley, R. Aswathi, S.R. Atchuta, B. Basu, S. Basu, J.M. Christain, M. Shiva Prasad, S. Sakthivel et.al in the book on Solar Energy Research Institute for India and the United States (SERIIUS) - Lessons and Results from a Binational Consortium, Springer Lecture notes in Energy, ISBN: 978-3-030-33184-9., Vol. 39, p 87 -132, 2020
6. 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. ISBN: 978-3-319-73255-8, Vol. 1, p 1413-1442, 2020
7. 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 Composites (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature. ISBN: 978-3-319-73255-8, p 1335-1368, 2020
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9. A chapter on Processing of Infrared Transparent Magnesium Aluminate Spinel: An Overview, authored by Papiya Biswas, Roy Johnson, Y.R. Mahajan and G. Padmanabham, in the Handbook of Advanced Ceramics and Composites, (ed.) Y.R. Mahajan and Roy Johnson, Springer Nature, ISBN: 978-3-319-73255-8, Vol. 1, p 495-531, 2020
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14. A chapter on Transparent Ceramics for Ballistic Armor Applications, authored by Senthil Kumar Rajendran, Papiya Biswas, Roy Johnson, and Y. R. Mahajan in the Handbook of Advanced Ceramics and Composites, (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature, ISBN: 978-3-319-73255-8, Vol.1, p 435-457, 2020
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16. A chapter on New Generation Ceramic Coatings for High-Temperature Applications by Liquid Feedstock Plasma Spraying, S.V. Joshi, N. Markocsan, P. Nylén, G. Sivakumar, in the 'Handbook of Advanced Ceramics and Composites' (ed.) Y. R. Mahajan and Roy Johnson, Springer Nature, ISBN: 978-3-319-73255-8, Vol.1, p 1371-1412, 2020
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18. A chapter on Recent Developments in Hydrogen Fuel Cell - Strengths and Weakness authored by N. Rajalakshmi, R. Balaji, S. Ramakrishnan in the Sustainable Fuel Technologies Handbook (ed.) Suman Dutta and C.M. Hussain, ISBN : 978-0-12-822989-7, Academic press, Elsevier Publications, p 431-456,2021
19. 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, Vol.3 Applications and Development, (ed) M. Aliofkhazraei, Nasar Ali, M. Chipara, N.B. Laidhani, Jeff Th. M. De Hosson, Elsevier Publishers. ISBN: 978-0-444-63237-1, p 425-447, 2021
20. A chapter on A Review of Machinability Aspects of Difficult-to-Cut Materials using Microtexture Patterns authored by R. Sharma, S. Pradhan, and Ravi N. Bathe, in the book on Advanced Manufacturing and Processing Technology (ed.) Chander Prakash, Sunpreet Singh, J. Paulo Davim, eBook ISBN 9780429298042, CRC Press, Chapter-3, 2021 (In Press)
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Other Technical Articles Published via Print, Digital or Electronic Media

1. Dr. S. Kavitha, 'Magnetocaloric Materials for Hyperthermia: An Alternative to Magnetic Hyperthermia and Radiation Therapy', SRUJAN - ARCI Hindi Magazine: 2019-20, Vol. 3, p 06-07, 2021
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5. K. Swati, Priya Anish Mathews and Sanjay Bhardwaj, 'National Biodiversity Authority and Patent: Brief Overview', SRUJAN - ARCI Hindi Magazine: 2019-20, Vol. 3, p 16-17, 2021
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32. Dr. R. Prakash, New anode material could produce efficient lithium-ion batteries for electric vehicles on December 03, 2020

33. Dr. B. V. Sarada, P. Samhita, Dr. K. Nanaji, M. Sreekanth, S. K. Martha and Dr. T. Narasinga Rao, Scientists Develop High Performance Hybrid Supercapacitors with Novel Electrode Materials on December 16, 2020

34. Dr. G. Padmanabham, Rise all: Need a strong AM system on February 01, 2021

Contribution to Professional Societies / Bodies as Office Bearers

S.No.	Name	Contribution/Role
1.	Dr. Sanjay Bhardwaj	Elected as Chairman, Indian Institute of Chemical Engineers – Hyderabad Regional Centre (IIChE – HRC) for 2020-2021
		Chairman, Organizing Committee, online panel discussion titled "Best Practices of Safety Management in Chemical Industry" on May 31, 2020 organized by IIChE – HRC at Hyderabad
		Chairman, Organizing Committee, 13th M.P. Chary Memorial Lecture on "Green Energy, Clean Energy – Challenges and Opportunities" on August 20, 2020 by Dr. Sanjeev S. Katti, Director General, ONGC Energy Centre organized by IIChE – HRC at Hyderabad
2.	Dr. R. Gopalan	Member Research Advisory Board (Under Ministry of Heavy Industry) - International Centre for Automotive Technology, 2020
		Member Publication Committee - Indian National Academy of Engineering (INAE), 2020
		Member of Sectional Committee-VIII : Mining, Metallurgical and Materials Engineering, Indian National Academy of Engineering (INAE), 2020
		International Advisory Committee Member for Rare Earth Magnets (REPM 2020-21)
		Member- Board of Studies, PSG College of Technology, Coimbatore, 2020
		Member- Board of Research , Hindustan Institute of Science & Technology , Chennai, 2020
		Member, Steering Committee on Energy Storage - TIFAC, New Delhi
		Member Invitee – "The Consultative Group on Future Transportation System"- PSA Office, Govt. of India, 2020
		Research Advisory Committee Member, ICAT-New Delhi
		Board of Members, ASPIRE, ICAT, 2020
		Executive Member – Indian Society for Analytical Scientists (ISAS) 2020

Awards and Honours

1. **Dr. Nitin P. Wasekar** was awarded the 'Best Reviewer Award for 2020' by Transactions of Indian Institute of Metals Springer.

2. **Dr. K. Nanaji** was awarded the 'Institute Research Award' by IIT Madras for the year 2019-2020 for excellence in research work

3. **Dr. R. Gopalan** was awarded the 'The Honorary Fellow of the Indian Society for Analytical Scientists' (2020) by the Indian Society Analytical Scientists.

4. **Dr. R. Gopalan** was awarded the 'IIM Honorary Fellow' (2020) by the Indian Institute of Metals (IIM).

5. **Dr. R. Gopalan** was awarded the 'Distinguished INAE-AICTE Visiting Professorship' (2020) by Indian National Academy of Engineering (INAE), 2020.

6. **Dr. R. Gopalan** was Elected the Fellow of Electron Microscope Society of India 2020.

7. **Dr. K. Nanaji** was awarded the 'Prof Werner Prize' for the best Ph. D thesis in Chemistry for the year 2020 during the 57th convocation of IIT Madras during November 2020

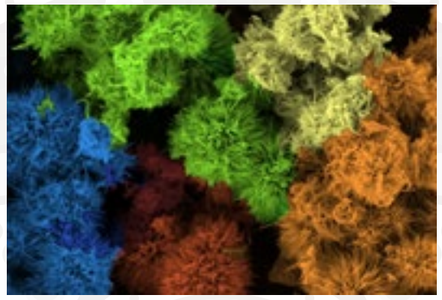
8. **Dr. Sanjay R. Dhage** has been conferred the 'Award of Outstanding Researcher in Solar Energy Materials' at '6th Venus International Science and Technology Award (VISTA- 2020)' on January 09, 2021

9. **Ms. S. Mamatha** (Dr. Roy Johnson) received the 'Best Paper Award' for presenting a paper on '3D Printing of Ceramics – An Emerging Technology' at the 'Science Technology and Innovation Talks (STIN-2021) by Young Research Scholars' held as a part of 'National Science Day Celebrations' organized by ARCI, Hyderabad during February 25-26, 2021.

10. **Mr. B. Lavakumar** (Dr. Nitin P. Wasekar) received the 'Best Paper Award' for presenting a paper on 'Microstructural Gradient Coatings For Improved Contact Resistance' at the 'Science Technology and Innovation Talks (STIN-2021) by Young Research Scholars' held as a part of 'National Science Day Celebrations' organized by ARCI, Hyderabad during February 25-26, 2021.

11. **Mr. Brijesh Singh Yadav's** (Dr. Sanjay R. Dhage) popular science story on 'Pintable Solar Cell Thinner than Hair' has been selected for the 'Augmenting Writing Skills for Articulating Research (AWSAR) Award' of the Department of Science and Technology (DST) on February 28, 2021.

12. **Mr. N. Ravikiran** (Dr. P. K. Jain) participated in the 2020 Terasaki Media Contest organized by Terasaki Institute, Los Angeles, USA and received Runner-up prize (USD 500) in the Broad Science Category for SEM image of modified Nano Urchin.



SEM image of modified Nano Urchin

13. **Dr. G. Padmanabham** was awarded the 'INAE Distinguished Visiting Professorship (July 2021 – June 2022)' at University of Hyderabad on March 09, 2021.

PERSONNEL

(as on March 31, 2021)

DIRECTOR

Dr. G. Padmanabham

REGIONAL DIRECTOR

Dr. Raghavan Gopalan

ASSOCIATE DIRECTORS

Dr. Tata Narasinga Rao
Dr. Roy Johnson

SCIENTISTS

D. Srinivasa Rao, Scientist 'G'
Dr. G. Ravi Chandra, Scientist 'G'
Dr. Pawan Kumar Jain, Scientist 'G'
Dr. R. Vijay, Scientist 'G'
Dr. R. Subasri, Scientist 'G'
V. Balaji Rao, Scientist 'G'
Dr. Bhaskar Prasad Saha, Scientist 'F'
Dr. Pramod H. Borse, Scientist 'F'
Dr. L. Rama Krishna, Scientist 'F'
Dr. Y. Srinivasa Rao, Scientist 'F'
Dr. Sanjay Bhardwaj, Scientist 'F'
Dr. S. Sakthivel, Scientist 'F'
Dr. N. Ravi, Scientist 'F'
Dr. I. Ganesh, Scientist 'F'
Dr. Joydip Joardar, Scientist 'F'
Dr. Malobika Karanjai, Scientist 'F'
Dr. Ravi N. Bathe, Scientist 'F'
Dr. G. Siva Kumar, Scientist 'F'
Dr. R. Prakash, Scientist 'F'
Dr. S. M. Shariff, Scientist 'F'
Dr. D. Siva Prahasam, Scientist 'F'
Dr. B. V. Sarada, Scientist 'F'
K. V. Phani Prabhakar, Scientist 'F'
Dr. T. Mohan, Senior Scientist *
Dr. Neha Y. Hebalkar, Scientist 'F'
Dr. S. B. Chandrasekhar, Scientist 'F'
Dr. K. Suresh, Scientist 'E'
Dr. P. Sudharshan Phani, Scientist 'E'
Dr. Sanjay R. Dhage, Scientist 'E'
Dr. Nitin P. Wasekar, Scientist 'E'
Dr. Dibyendu Chakravarty, Scientist 'E'
Dr. Kaliyan Hembram, Scientist 'E'
Dr. K. Murugan, Scientist 'E'
Dr. Dulal Chandra Jana, Scientist 'E'
Dr. K. Ramya, Senior Scientist
Dr. Srinivasan Anandan, Scientist 'E'
Ms. S. Nirmala, Scientist 'E'
Dr. P. Suresh Babu, Scientist 'E'
Dr. Krishna Valleti, Scientist 'E'

DISTINGUISHED ARCI CHAIR

Prof. P. Rama Rao

DISTINGUISHED EMERITUS SCIENTIST

Prof. G. Sundararajan

Dr. M. Buchi Suresh, Scientist 'E'
Manish Tak, Scientist 'E'
Dr. Papiya Biswas, Scientist 'E'
Dr. Gururaj Telasang, Scientist 'E'
Dr. R. Easwaramoorthi, Scientist 'E'
R. Senthil K umar, Scientist 'E'
Dr. S. Kumar, Scientist 'E'
Ms. Priya Anish Mathews, Scientist 'E'
Dr. Prasenjit Barick, Scientist 'E'
Dr. Naveen Manhar Chavan, Scientist 'E'
M. Ramakrishna, Scientist 'E'
Balaji Padya, Scientist 'E'
S. Sudhakara Sarma, Scientist 'E'
R. Vijaya Chandar, Scientist 'D'
Dr. Pandu Ramavath, Scientist 'D'
Ms. J. Revathi, Scientist 'D'
Arun Seetharaman, Scientist 'D'
Dr. M. B. Sahana, Senior Scientist
Dr. D. Prabhu, Scientist 'D'
Dr. R. Balaji, Senior Scientist
Dr. Raman Vedarajan, Scientist
Dr. Shiv Prakash Singh, Scientist
Dr. V. Ganapathy, Scientist
Dr. Bijoy Kumar Das, Scientist
Dr. Srikanti Kavitha, Scientist
Shri S. Ramakrishnan, Scientist
Shri Vallabharao Rikka, Scientist
Dr. L. Venkatesh, Scientist 'C'
Ms. K. Divya, Scientist 'C'
Dr. K. Nanaji, Scientist
Dr. Ravi Gautam, Scientist
Dr. J.A. Prtihi, Scientist
Amit Das, Scientist 'B'

TECHNICAL OFFICERS

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

TECHNICAL ASSISTANT

J. Shyam Rao, Technical Assistant 'A'
Gugulothu Murthy, Technical Assistant 'A'

TECHNICIANS

D. Krishna Sagar, Technician 'E'
K. V. B. Vasantha Rayudu, Technician 'E'
G. Venkata Rao, Technician 'E'
E. Konda, Technician 'E'
A. Sathyanarayana, Technician 'E'
B. Venkanna, Technician 'E'
G. Venkat Reddy, Technician 'D'
P. Anjaiah, Technician 'D'
A. Ramesh, Technician 'D'
D. Kutumba Rao, Technician 'D'
B. Subramanyeswara Rao, Technician 'D'
Kona Vigneswara Rao, Technician 'D'
A. JayaKumaran Thampi, Technician 'D'
B. Hemanth Kumar, Technician 'D'
A. Praveen Kumar, Technician 'D'
K. Satyanarayana Reddy, Technician 'D'
D. P. Surya Prakash Rao, Technician 'D'
Kurra Venkata Ramana, Technician 'D'
Govinda Kumar, Technician 'D'
A. Janga Reddy, Technician 'D'
A. Jagan, Technician 'D'
Sushanta Mukhopadhyay, Technician 'D'
M. Satyanand, Technician 'D'
P. Suri Babu, Technician 'C'
G. Anjan Babu, Technician 'C'
Shaik Ahmed, Technician 'C'
K. Ashok, Technician 'C'
E. Yadagiri, Technician 'C'
I. Prabhu, Technician 'C'
Ch. Jangaiah, Technician 'C'
S. Narsing Rao, Technician 'B'
Mothe Lingaiah, Technician 'B'
Aan Singh, Technician 'A'
Gaje Singh, Technician 'A'
Kadiri Sai Charan, Technician 'A'
Sushant Nayak, Technician 'A'

SENIOR FINANCE & ADMINISTRATIVE OFFICER

G. Ravi Shankar

SENIOR STAFF OFFICER TO DIRECTOR

P. Nagendra Rao

SENIOR STORES & PURCHASE OFFICER

N. Srinivas

ADMINISTRATIVE & PERSONNEL OFFICER

A. Srinivas

FINANCE & ACCOUNTS OFFICER

G. M. Rajkumar

FINANCE & ACCOUNTS OFFICER (PROJECTS)

Anirban Bhattacharjee

COMMUNICATIONS AND PUBLIC RELATIONS OFFICER

N. Aparna Rao

SECURITY, FIRE & SAFETY OFFICER

D. Ramesh

OFFICERS

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

ASSISTANTS

Ms. Rajalakshmi Nair, Assistant 'B' (MACP)
Ms. K. Madhura Vani, Assistant 'B'
Narendra Kumar Bhakta, Assistant 'B'
J. Bansilal, Junior Assistant (MACP)
Boorgu Venkatesham, Assistant 'A'
Ramavathu Ranga Naik, Assistant 'A'
Pokalkar Sai Kishore, Assistant 'A'
Sudheendra, Assistant 'A'

P. Siva Prasad Reddy, Assistant 'A'
Ch. Venugopal, Assistant 'A'
Edunuri Ramesh, Assistant 'A'
A. Balraj, Assistant 'A'
K. Prashanth, Assistant 'A'
P. Prasad Babu, Assistant 'A'
Thati Thoti T Koteswar Rao, Assistant 'A'
Pakanati Ashoka Reddy, Assistant 'A'
Nalamasa Sampathkumar, Assistant 'A'
Ramavath Sunil Naik, Assistant 'A'

JUNIOR TRANSLATION OFFICER

Dr. Rambha Singh

DRIVERS

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

LAB ASSISTANTS

Roop Singh, Lab Assistant 'D'
Hussain Ali Khan, Lab Assistant 'D'

CONSULTANTS

Dr. V. Chandrasekharan
Dr. Uma (Medical Doctor)
S. N. Nautiyal
G. Ramesh Reddy
P. Sampath Kumar
D. Manikya Prabhu

PROJECT SCIENTISTS (TRC)

Dr. Mani Karthik, Project Scientist 'E'
Dr. Manjusha Battabyal, Project Scientist 'D'
Dr. Mandati Sreekanth, Project Scientist 'C'
Dr. Prashant Misra, Project Scientist 'C'
Kumari Konda, Project Scientist 'B'
Dr. K. Harigopi, Project Scientist 'B'
P. Sai Karthik, Project Scientist 'B'
Puppala Laxman Mani Kanta, Project Scientist 'B'
A. Srinivas Rao, Project Scientist 'B'
G. Vijaya Ragavan, Project Scientist 'B'
Muni Bhaskar Siva Kumar, Project Scientist 'B'
S. Vasu, Project Scientist 'B'
V. V. N. Phani Kumar, Project Scientist 'B'
Mahender Peddi, Project Scientist 'B'
Bheesetti Gowreeswari, Project Scientist 'B'
V. Tarun Kumar, Project Scientist 'B'
P. Vijaya Durga, Project Scientist 'B'
Minati Tiadi, Project Scientist 'B'
S. Ganesh, Project Scientist 'B'

PROJECT TECHNICAL ASSISTANT (TRC)

V. Sai Krishna
R. Vasudevan
N. Kannadasan
Debendra Nath Kar
Shaik Nagur Baba
Golu Kumar Jha
Krishna Kumar Pathak
K. Velmurgan
K. Shanmugam
T. P. Sarangan
A. Sivaraj

TRC: Technical Research Centre on 'Alternate Energy Materials and Systems'

Financial Report

M. BHASKARA RAO & CO.
CHARTERED ACCOUNTANTS
5-D, FIFTH FLOOR, "KAUTILYA
6-3-652, SOMAJIGUDA,
Hyderabad - 500 004
Email : mbr_co @ mbrc.co.in

Date: 23/09/2021

To

Members of Governing Council
International Advanced Research Centre for
Powder Metallurgy and New Materials (ARCI)
Hyderabad - 500 005.

INDEPENDENT AUDITORS' REPORT

Opinion

We have audited the accompanying financial statements of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad ("the Entity"), which comprise the Balance Sheet as at March 31, 2021, and the Income and Expenditure Account and Receipts and Payments Account for the year then ended, and notes to the financial statements, including a summary of significant accounting policies and explanatory notes of:

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

In our opinion, 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, 2021, of its financial performance and of its cash flows for the year then ended in accordance the Accounting Standards issued by the Institute of Chartered Accountants of India (ICAI).

Basis for Opinion

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

Emphasis of Matter

We draw attention to:

Note 3 to the Schedule 26 to the Financial Statements of the Consolidated Fund and Note 3 to the Schedule 26 to the Financial Statements of Operational Fund regarding delays in recording in the payments made through banking channels in the books of accounts and regarding certain unreconciled items appearing in the Bank Reconciliation Statements.

Responsibilities of Management for the Financial Statements

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

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

The above Governing Council is also responsible for overseeing the company's financial reporting process.

Auditor's Responsibilities for the Audit of the Financial Statements

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

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

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

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

Other Matters

As per the information and explanations furnished to us, the Society has not carried out physical verification of fixed assets pertaining to Operational Fund and Sponsor Fund as on March 31,2021. Considering the size of the Society and the nature of the assets, the Society should conduct physical verification of all fixed assets at periodical intervals, preferably on an annual basis.

Report on Other Matters

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

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

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

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
ARC INTERNATIONAL FUND (OPERATIONAL) BALANCE SHEET AS AT 31.03.2021

(Amount in Rs.)

GRANTS-IN-AID: FUND AND LIABILITIES	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
GRANTS- IN- AID	1	1,23,33,80,280.21	1,32,42,37,747.49
RESERVES AND SURPLUS	2	13,24,77,417.89	8,09,09,471.89
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	38,05,01,007.06	36,74,00,313.53
TOTAL		**1,74,63,58,705.16**	**1,77,25,47,532.91**
ASSETS			
FIXED ASSETS	8	1,21,33,39,856.81	1,26,38,31,878.55
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUND	9	0.00	0.00
INVESTMENTS - OTHERS	10	0.00	0.00
CURRENT ASSETS, LOANS, ADVANCES ETC.	11	53,30,18,848.35	50,87,15,654.36
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)		0	0
TOTAL		**1,74,63,58,705.16**	**1,77,25,47,532.91**
BACKGROUND INFORMATION & 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

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

Sd/-
G. M. Raj Kumar
Finance and Accounts Officer

Sd/-
D. Srinivasa Rao
OSD (Admin, Finance & Stores)

Sd/-
Dr. Tata Narasinga Rao
Director (Additional Charge)

Date: 23-09-2021
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INCOME AND EXPENDITURE ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2021

(Amount in Rs.)

	SCHEDULE		CURRENT YEAR		PREVIOUS YEAR
INCOME					
Income from Sales/Services	12		0.00		0.00
Grants/Subsidies	13		50,06,00,000.00		40,41,99,000.00
Fees/Subscriptions	14		0.00		98,766.95
Income from Investments (Income on Investments from earmarked/endowment funds)	15		0.00		0.00
Income from Royalty, Publications etc.	16		0.00		0.00
Interest Earned	17		2,52,77,300.39		2,75,80,776.89
Other Income	18		1,73,67,121.06		2,42,63,025.38
Increase/(decrease) in stock of finished goods and work-in-progress	19		0.00		0.00
TOTAL (A)			**54,32,44,421.45**		**45,61,41,569.22**
EXPENDITURE					
Establishment Expenses	20		38,35,83,395.21		32,61,63,672.37
Other Expenses	21		16,98,98,612.52		18,05,22,937.65
Expenditure on Grants/Subsidies	22		1,37,700.00		0.00
Interest	23		46,94,641.00		87,03,670.00
Depreciation (Net Total at the year-end: corresponding to Schedule 8)			18,67,87,540.00		14,99,27,557.17
TOTAL (B)			**74,51,01,888.73**		**66,53,17,837.19**
Balance being excess of Income over Expenditure (A-B) Transfer to Special Reserve [specify each] Transfer to/from General Reserve			-20,18,57,467.28		-20,91,76,267.97
BALANCE being Excess of Expenditure over Income - Transfer to Grants-in-Aid			**-20,18,57,467.28**		**-20,91,76,267.97**
BACKGROUND INFORMATION AND 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

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

Sd/-
G. M. Raj Kumar
Finance and Accounts Officer

Sd/-
D. Srinivasa Rao
OSD (Admin, Finance & Stores)

Sd/-
Dr. Tata Narasinga Rao
Director (Additional Charge)

Date: 23-09-2021
Place: Hyderabad

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

BALAPUR POST. HYDERABAD

ARCI (OPERATIONAL) FUND

SCHEDULE – 24 BACKGROUND INFORMATION & SIGNIFICANT ACCOUNTING POLICIES

1. **Operation Fund of ARC – International (OP Fund of ARCI)** is the main fund of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI/Society).

   Grants received from Department of Science and Technology (DST), Ministry of Science and Technology, Government of India (GOI) are recognized in the financial statements of OP Fund of ARCI as Income of the Society if these grants are for meeting operational expenses of the Society and as part of Corpus, if utilized for the purposes of capital expenses. These Grants are allocated by GOI in the form of annual budgets under Plan Funds to DST. DST draws the funds from GOI and forwards the same to ARCI. The funds released by DST are in the form of Grants in Aid.

   Other Funds of the Society are Technology Development & Transfer Fund (TDT) and Sponsored Project Fund (SP Funds).

2. **Basis of preparation of financial statements:**

   Financial statements of OP Fund of ARCI, Hyderabad, have been prepared on historical cost convention and on accrual basis unless otherwise stated.

   Significant Accounting Polices:

   (A) Grants:

   Grants are recognized on receipt basis.

   Grants received from DST and earmarked for special / specific projects are grouped under Sponsored Project Fund.

   (B) Reserves & Surpluses:

   Fifty percent of Net Surplus / Deficit in Technology Demonstration & Transfer Fund (TDT Fund) is transferred to OP Fund of ARCI and is recognized under Reserves ad Surplus. Balance Fifty percent is retained 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.

   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.

4. **Interest Income:**

   Interest income from bank balances/deposit is recognized on time proportionate basis.

5. **Research and Development (R&D) Expenditure:**

   R&D expenditure including cost of raw materials, consumables, other inputs and services etc. is charged off as revenue expenditure. Raw materials, consumables, stores spares and other inputs are procured on need basis and issued to indenting departments soon after they are received. Hence values of closing stock of these materials is not recognized in the accounts.

6. **Foreign Exchange Transactions:**

   Foreign exchange transactions during the year are recorded at the exchange rate prevailing on the date of transactions.

7. **Retirement Benefits:**

   Contributions of Society's share of 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. 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 as per the actuarial reports shared to the Society by LIC.

8. **Margin Money Deposits:**

   Society places one hundred percent of its funds as Margin Money Deposits with Banks towards Letters of Credit issued to the vendors of the Society. These are grouped under Loans and Advances- Advances Recoverable in Cash/Kind.

Sd/-	Sd/-	Sd/-
G. M. Raj Kumar	**D. Srinivasa Rao**	**Dr. Tata Narasinga Rao**
Finance and Accounts Officer	OSD (Admin, Finance & Stores)	Director (Additional Charge)

AS PER OUR REPORT OF EVEN DATE

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

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

Date: 23-09-2021
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. 50,06,00,000/ towards revenue and Rs: 11,10,00,000/- as capital grant-in-aid under Plan (Previous year Rs. 40,41,99,000/ and Rs. 11,59,14,000/- towards revenue and capital respectively under Plan grant-in-aid). Under Non-Plan, Grant-in-aid sanctioned was nil.

2. Capital Work in Progress

   Rs. 27,75,92,622/- representing pilot scale R&D facility with process equipments for fabrication of CIGS thin-film solar cells with the objective of improving the existing manufacturing processes, developing new non-vacuum based process technologies. The said equipment consisted three main processing equipments out of which process qualification was not completed for one of the processing equipment by the supplier. This resulted in the equipment being shown under Capital work in progress pending capitalization up to previous year ending as on March 31, 2020.

   The said equipment became fully operational after modifications. Society commenced utilizing the complete facility on trial basis in September 2020. Based on successful trials, the machinery was capitalized with effect from March 26, 2021. The performance levels of the equipment were also found to be beyond the benchmark. Considering the same, management is of the view that the same is not required for impairment testing of the carrying value of the said asset as on March 31,2021.

3. Rs. 1,07,55,538/- as at March 31,2021 as stated in Schedule 8 to the financial statements – pending capitalization for more than three years. Management identified certain deficiencies while installing these equipments. The process of resolving the deficiencies is going on. In the opinion of the management of the Society, all these capital works are capable of being used for the purpose for which these assets were procured. The management, at present, is of the opinion that these capital works do neither require any impairment nor provisioning.

4. Accounting for payments made through bank and reconciliation of balances as per bank statements with the books of account:

   a. Accounting for payments made through bank:

   Due to the lockdown and other restrictions imposed by the Government authorities and prevailing conditions related to COVID 2019 pandemic situation during 2020 – 2021, together with information system related checks and controls, certain payments effected through banking channels could not be recorded on the date of said transactions. These were recorded with delay, after resolving / complying with information system related checks and controls. Management confirms that all the payments were affected only after obtaining prior approvals from the respective competent authorities and recognized in the books of accounts as on March 31, 2021.

   b. Reconciliation of bank balances:

   Balances with banks are subject to reconciliation with the following unidentified aggregate amounts, which were pending for a period in excess of one month as at March 31, 2021:

   Unidentified Credits by Banks aggregating to Rs. 3,83,365/-

   Unidentified Debits by Banks aggregating to Rs. Rs. 5,79,603/-

   Management of the Society initiated process for resolving these matters and recording the requisite accounting entries in the books of accounts.

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

Sd/-	Sd/-	Sd/-
G. M. Raj Kumar	**D. Srinivasa Rao**	**Dr. Tata Narasinga Rao**
Finance and Accounts Officer	OSD (Admin, Finance & Stores)	Director (Additional Charge)

AS PER OUR REPORT OF EVEN DATE

Sd/-
V.K.Muralidhar
Partner, Membership No. 201570
for **M/s. M.Bhaskara Rao & Co**
Chartered Accountants
Firm Registration No. 000459S

Date: 23-09-2021
Place: Hyderabad

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
RECEIPTS AND PAYMENT ACCOUNT OF ARC INTERNATIONAL FUND (OPERATIONAL) FOR THE YEAR ENDED 31.03.2021

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
I. **Opening Balances**			I. **Expenses**		
a. Cash in hand	30,126.00	25,800.00	a. Establishment expenses	37,28,58,710.00	29,70,55,121.00
b. Bank Balances			b. Other expenses	16,77,51,528.32	16,59,30,822.00
i) In Current accounts	0.00	0.00			
ii) In Deposit accounts	1,00,00,000.00	7,00,00,000.00	**Total: Expenses**	**54,06,10,238.32**	**46,29,85,943.00**
iii) Savings accounts	1,17,26,553.17	80,23,632.22			
Total: Opening Balances	**2,17,56,679.17**	**7,80,49,432.22**			
II. **Grants Received**			II. **Payments made against various projects**		
a. From Government of India	61,16,00,000.00	52,01,13,000.00			
b. From State Governments	0.00	0.00	Payments made against various projects	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	**61,16,00,000.00**	**52,01,13,000.00**	**Total: Payments made Against Projects**	**0.00**	**0.00**
III. **Income on Investments From**			III. **Investments and deposits made**		
a. Earmarked/Endowment Funds	0.00	0.00	a. Out of Earmarked/Endowment funds	0.00	0.00
b. Own funds (other investments)	0.00	0.00	b. Out of own funds (investments-others)	0.00	0.00
Total: Income on Investment	**0.00**	**0.00**	**Total: Investments and Deposits**	**0.00**	**0.00**
IV. **Interest Received**			IV. **Expenditure on Fixed Assets & Capital Work-in-Progress**		
a. On bank deposits	45,65,873.00	85,63,318.00			
b. Interest from sponsored projects	0.00	0.00			
c. Loans, Advances to staff etc.	1,44,591.00	1,40,352.00	a. Purchase of fixed assets	5,02,73,075.80	16,25,14,493.14
Total: Interest Received	**47,10,464.00**	**87,03,670.00**	**Total: Expenditure on Fixed Assets & Capital WIP**	**5,02,73,075.80**	**16,25,14,493.14**
V. **Other Income**	5,78,83,420.06	3,96,07,861.11	V. **Refund of surplus money/loans**		
			a. To Government of India	0.00	0.00
			b. To State Government	0.00	0.00
			c. To other providers of funds	0.00	0.00

(Amount in Rs.)

RECEIPTS	CURRENT YEAR	PREVIOUS YEAR	PAYMENTS	CURRENT YEAR	PREVIOUS YEAR
VI. **Amount Borrowed**	0.00	0.00	VI. **Finance charges (Interest)**	0.00	0.00
VII. **Any Other Receipts**			VII. **Other Payments**		
a) EMD & Security Deposits	0.00	62,53,429.00	(a) Interest - DST	87,03,670.00	80,26,234.00
b) Sales of Fixed Assets	0.00	22,81,609.98	(b) Security Deposit- Supplier	1,00,000.00	0.00
c) Advances from Suppliers- Buildings	0.00	2,74,347.00	(c) Earnest Money Deposit-Supplier	52,93,500.00	0.00
d) Tax Deduction at Source & GST Deductions	4,23,194.90	0.00	(d) TDS	1,06,925.00	0.00
Total : Any Other Receipts	**4,23,194.90**	**88,09,385.98**	**Total : Other Payments**	**1,42,04,095.00**	**80,26,234.00**
			VIII. **Closing Balances**		
			a) Cash in hand	32,692.00	30,126.00
			b) Bank balances		
			i) In Current accounts	0.00	0.00
			ii) In Deposit accounts	5,70,00,000.00	1,00,00,000.00
			iii) In Savings accounts	3,42,53,657.01	1,17,26,553.17
			Total : Closing Balances	**9,12,86,349.01**	**2,17,56,679.17**
TOTAL	**69,63,73,758.13**	**65,52,83,349.31**	**TOTAL**	**69,63,73,758.13**	**65,52,83,349.31**

Sd/-
D. Srinivasa Rao
OSD (Admin, Finance & Stores)

Sd/-
Dr. Tata Narasinga Rao
Director (Additional Charge)

Sd/-
G. M. Raj Kumar
Finance and Accounts Officer

Date: 23-09-2021
Place: Hyderabad

AS PER OUR REPORT OF EVEN DATE

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

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

OUR COLLABORATORS

FOREIGN

- Applied Materials, USA
- Belarusian State University of Informatics and Radio Electronics
- Ballard Power Systems Inc., USA
- Bromine Compounds Ltd., Israel
- Corning Incorporated, USA
- DesignTech Systems Limited
- Deakin University, Australia
- Fraunhofer Institutions, Germany
- Industrial Materials Institute of National Research Council of Canada (NRC-IMI), Canada
- Institute for Problems of Materials Science (IPMS), Ukraine
- International Centre for Electron Beam Technologies, Ukraine
- Li-ion Technologies Limited, Russia
- MPA Industrie, France
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- SLM Solutions Singapore Pvt. Ltd.
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- Techno Takatsuki Co. Ltd., Japan
- Zoz GmbH, Germany

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- 3 Amplify Cleantech Solutions Pvt. Ltd.
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- Andhra Pradesh Mineral Development Corporation Ltd.
- Bharat Electronics Limited
- Bharat Heavy Electricals Limited
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- Central Scientific Instruments Organization
- Central Institute of Plastics Engineering and Technology
- Carborundum Universal Limited
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- Devise Electronics Pvt. Ltd.
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- GE India Industrial Pvt. Ltd.
- Green Era Energy India Pvt. Ltd.
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- Hindustan Petroleum Corporation Limited
- Hyderabad Electroplating Works
- Helious Clean Green Energy
- Indian Institute of Chemical Technology
- Indian Airforce
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- Indian Institute of Technology-Kharagpur
- Indian Institute of Technology-Hyderabad
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- Innoven Chem LLP
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- Las Engineers and Consultants Pvt. Ltd.
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- Phasetron Engineers India (P) Limited
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- Sai Surface Coating Technologies
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- Tata Steel Limited
- TVS Lucas
- TVS Motor Company Limited
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- Temperate Technologies Pvt. Ltd.
- University of Hyderabad
- Wissenkraft Labs Pvt. Ltd.

ए आर सी आई
ARCI

EDITORIAL BOARD

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ARCI

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