A Report on the
International Conference on Metals and Materials Research (ICMR 2016)
June 20-22, 2016, IISc, Bangalore

The International Conference on Metals and Materials Research (ICMR-2016) was organized by the Bangalore Chapter and the Metal Sciences Division of the Indian Institute of Metals (IIM), and the Electron Microscope Society of India (EMSI) in collaboration with the Department of Materials Engineering, Indian Institute of Science, Bangalore, during June 20-22, 2016 at the Indian Institute of Science, Bangalore. The past two decades have witnessed extraordinary developments in the discovery of new metallic structures and materials. Thus materials research has always been found to be a fascinating field, as it continues to unravel the mystery of the existence of exotic materials, their novel structures and unique processing techniques leading to the possibilities for technological advancements. In view of increasing interest on the cutting edge researches on materials, an international conference, as suggested by several distinguished researchers in the country and abroad was organized to coincide with the celebration of the 75th birth anniversary of Professor S. Ranganathan (IISc, Bangalore).

The inauguration of the conference began with the welcome address of T.A Abinandanan, Chairman of Materials Engineering, IISc, Bangalore. He indicated how ICMR-2016 was initiated by the students, collaborators and well-wishers of Professor S. Ranganathan on his 75th birth anniversary to celebrate the growth of materials research by organizing a felicitation function to honor him for his seminal contributions to the research and education of metallurgy and materials science & engineering. V.S. Raja (IIT, Bombay), Chairman of ICMR-2016, highlighted the theme of the conference and urged the delegates to actively participate in the conference so that it could lead to a scientifically meaningful, enjoyable and beneficial meeting. Anurag Kumar, Director of IISc, Bangalore inaugurated the conference and introduced C.N.R. Rao, Linus Pauling Professor (JNCSAR, Bangalore), who delivered the inaugural lecture. S. Subramaniam (IISc, Bangalore) thanked all the delegates and acknowledged the support of the various organizations on behalf of the organizing committee.

In the evening of the first day, a felicitation function and Banquet was organized in *Le Meridien* Hotel to honor Professor S. Ranganathan. It was well attended by dignitaries, delegates and guests. During the function, the overall appreciation for Professor Ranganthan's outstanding contributions to materials research starting from grain boundary engineering, field ion microscopy, structural metallurgy, quasicrystals, metallic glasses, high entropy alloys and archaeo-metallurgy were well articulated by several distinguished luminaries and guests. It is also very clear that he has been an inspiration and role model to many present eminent metallurgists and materials scientists. His profound impact on the national and international scientific scenarios was well recorded. The reminiscences of the dignitaries and distinguished scientists from India and abroad during the felicitation function mesmerized the delegates and was also motivating for participants, especially young researchers and students. In the evening of the second day (June 21, 2016), an excellent dance performance by distinguished artist, Ms. Sobhana, recipient of prestigious Padmasri award, and her group left a permanent and memorable impression on the delegates.

In addition to an inaugural lecture, there were 6 plenary talks and 67 invited oral presentations by eminent scientists and 49 poster presentations by senior research scholars and young researchers. There were 175 participants out of whom 22 overseas participants came from various parts of the globe, such as Australia, Canada , China, Germany, Japan, Singapore, Sweden, Taiwan, UK and USA. The Indian delegates were from IITs, NITs, IISc~~, NIAS~~ and central and state universities as well as from the R&D labs such as DRDO, BARC, IGCAR and CSIR-NML & CGCRI and industries such as GE, Boeing and JSW. The conference covered a wide spectrum of materials with a special

focus on the topics of alloy design, advanced steels, archaeo-metallurgy, atomic resolution microscopy, grain boundaries and interfaces, bulk metallic glasses, quasicrystals, nanomaterials and high entropy alloys. The details of the conference are available at the website:www.icmr2016.net. Some of the important technical issues discussed during the conference are highlighted here in various subsections.

1. Nano- and bio-materials

In his inaugural address, C.N.R. Rao (JNCASR, Bangalore) elaborated on the synthesis of and developments in graphene and graphene like materials such as MoS_2, WS_2, GaS and BN. He presented interesting results on few-layer metal chalcogenides and BN. It was shown that transistors and devices could be successfully fabricated using many of the few-layers inorganic materials. A new graphene like material such as $B_xC_yN_z$ with high surface area and novel gas adsorptive properties was mentioned. Bikramjit Basu (IISc, Bangalore) discussed a new paradigm for development of multifunctional bioceramics and external field stimulated cell with the appropriate demonstration of a model system. Chandan Srivastava (IISc, Bangalore) elaborated biomedical imaging using fluorescent $CoFe_2O_4$-ZnO core shell nanoparticles and its underlying mechanisms.

2. Metallic Glasses, quasicrystals and metastable alloys

A.L. Greer (Cambridge, UK) elaborated the optimizing principles for improvement of toughness of metallic glasses. The lack of tensile ductility is a major concern in using a metallic glass in spite of it being a high strength material. Controlled annealing of single phase monolithic metallic glasses was shown to lead to a higher-energy rejuvenated state with improved ductility which could be retained. It was demonstrated that anisotropy could be induced for potential applications. A. Inoue (Japan) described the development of nonequilibrium metallic engineering materials including bulk metallic glassy alloys and nanocrystalline alloys in various alloy systems by an effective combination of appropriate alloy components, unique preparation techniques and optimum preparation conditions. He presented the developmental history, structural features, fundamental properties, engineering characteristics, applications and future prospects of Al- and Cu-based metastable alloys. R.S. Tiwari (BHU) demonstrated phase separation in a Ce-Al(Ga) metallic glass identifying two amorphous phases, which was attributed to the addition of Ga. G.K. Dey (BARC, Mumbai) investigated solidification behavior of alloys through study of glass/crystal composites and pointed out the local solidification condition from this observation. Bhaskar Majumdar (DMRL, Hyderabad) presented the possible development of metallic glass composites for magnetic and structural applications in defense industries. Alok Singh (NIMS, Japan) investigated the effect of quasicrystalline (QC) phase precipitates on the microstructure and mechanical properties of Mg base alloys. Using advanced TEM techniques, Mg-Zn-Re alloys with desirable microstructure were developed through appropriate processing techniques. It was shown that QC phase modified the microstructure and texture by affecting the dynamic recrystallization during wrought processing. N.K. Mukhopadhyay (IIT, BHU) established the inverse Hall-Petch behavior in nanostructured quasicrystalline and crystalline intermetallics and attributed it to grain boundary sliding phenomena. T.P. Yadav (BHU) showed phase transformations in Al-based quasicrystals during mechanical milling.

3. Iron &Steel Technology

S. Banerjee (BARC, Mumbai) discussed the evolution of microstructures in laser processed grey cast iron and showed that in the heat affected zone pearlite matrix transforms into austenite without any significant dissolution of graphite flakes, whereas the fusion zone is characterized by complete dissolution of graphite flakes and the formation of dendrites of supersaturated austenite. The transformation paths in different regions were discussed in terms of thermodynamics and kinetics of the competing processes. S. Seetharaman (RIT, Sweden) discussed the history of iron and steel making in Sweden and showed that in 1990s, Sweden developed Wilberg process and Kaldo process for newer steel technology, though currently the steel making scenario is dominated by China. However he claimed that Sweden is still holding a leading position with constant research support by

Swedish Steel Producers Association. S. Mishra (Indian Steel Association, New Delhi) elaborated in detail the changes in steel and its processing in the last fifty years. It was pointed out that the introduction of microalloying and thermomechanical processing revolutionized the art of steel processing. He cited examples of a variety of steel products developed in the country. S. Manjini (JSW, India) studied thermo-mechanical simulation of austenite recrystallization and softening during hot rolling of line pipe steel. A three dimensional empirical model was developed to determine the accumulated strain energy and softening at the end of the hot rolling process. K. Nagata (Tokyo Inst. Tech., Japan) revealed the thermodynamic mechanisms for the presence of oversaturated oxygen in the steel in the era of pre-modern iron making and steel making and presented evidence from old nails used in wooden shrines and temples in Japan. U.K. Mudali (IGCAR, Kalpakkam) highlighted the recent developments of high nitrogen stainless steel for construction engineering components of fast breeder reactor and associated reprocessing plants. V.A. Ravi (California Polytech., USA) presented some interesting results on pack aluminizing of austenitic stainless steels. N.N. Viswanathan (IIT, Bombay) presented a new way of understanding and quantifying sintering kinetics of iron ore pellets using optical dilatometer.

4. Alloy development and materials processing

K. Chattopadhyay (IISc, Bangalore) indicated various pathways for developing high temperature alloys, including Ni-based complex intermetallic ternary eutectics and new class of Co-based super alloys. It was claimed that these classes of materials could substitute the conventional Ni-base super alloys. He also highlighted possible development of high temperature Al-alloys by suitably exploiting ordered structures, complex chemistry and microstructure. Baldev Raj (NIAS, Bangalore) brought out the importance of interdisciplinary measurements in a spectrum of applications related to frontier technologies. He further elaborated with examples how accuracy in measurements was crucial for applications involving nuclear reactors, nuclear recycle plants, fighter aircrafts, space launch vehicles, submarines, missiles, fossil power plants, chemical industry and manufacturing industry requiring high precision components. N. Eswara Prasad (DMSRDE, Kanpur) presented the development and the current trend in Al-Li alloys for aerospace applications. He lucidly discussed the 1st and 2nd generation of Al-Li alloys and then the 3rd generation alloys which hold promise for aerospace applications. Samir Kamat (DMRL, Hyderabad) discussed the various futuristic materials for defence applications and also the challenges for meeting the technical requirements in harsh environments.

Fuxio Yu (Northeaster Univ., China) investigated the solidification microstructure and temperature field during normal casting of Al-3Fe alloys and established the correlations among them. S.N. Ojha (IIT-BHU, Varanasi) described the emerging trends in processing of advanced metallic materials. The enhanced mechanical properties of some monolithic Al-alloys and their composites synthesized by spray deposition techniques were presented. Ravi Ravindran (Ryerson Univ., Canada) presented a procedure for in-situ tracking of defects and an analysis of phase evolution in light alloys of magnesium and aluminum using neutron diffraction techniques. This approach revealed the solidification characteristics with inoculants and solute additions resulting in better castability. Subodh Kumar (IISc, Bangalore) discussed the development of an Al alloy for aerospace application at higher temperatures by adding a small amount of Sc and Mg to 2219 Al alloy and also suitably processing it. The salient feature of microstructure responsible for high strength at each stage was identified. S.C Sharma (VSSC, Trivandrum) discussed the production of Hf metal for Indian space programme. In collaboration with C-Met, Hyderabad the Hf sponge production plant was established based on the solvent extraction method. The indigenous Hf sponge was further processed through electron beam melting to obtain Hf metal ingot and used for producing Nb based alloys for space applications. S. Subramaniam (IISc, Banglore) described microbially assisted processes in mineral processing elaborated on the use of microorganisms and their direct derivatives in mineral processing, hydrometallurgy bioremediation of mineral industry discharge.

5. Computational Materials Science

S. Lele (IIT-BHU, Varanasi) presented the concept based on cluster expansion and cluster variation methods (CE-CVM) for obtaining accurate analytical formulations for configurational enthalpy and entropy of solution phases. The approach developed by them eliminates the requirement of solving the transcendental systems of equilibrium equations and considerably reduces the computational burden, making it comparable to the standard Calphad methods, without losing the description of SRO. Pradip (TRDDC, Pune) described the importance of integrated computational materials engineering (ICME) framework for developing engineering materials and products. Satyam Sahay (John Deere, Pune) emphasized the industrial realization of integrated computational materials engineering framework which was envisaged to create value in terms of accelerated product design cycle and overall cost reduction by integrating design, materials, manufacturing and product performance competencies within a computational environment. G. Phanikumar (IIT, Madras) discussed the challenges and opportunities for the metallurgical community in the era of ICME. M. Gururajan (IIT, Bombay) shared some computer experiments on phase field modeling of anisotropic precipitate morphologies. R. Sankarasubramanian (DMRL, Hyderabad) studied disorder trapping during solidification of nickel aluminides. U.V. Waghmare (JNCASR, Bangalore) presented theoretical analysis on the prediction of robust non-centrosymmetric topological Dirac semi-metallic state in ternary half-Heusler compounds such as LiMgBi model system. His work appears to open up tremendous possibilities of producing epitaxial heterostructures and interfaces that involve chirality, polarity, topology and correlations. T.A. Abinandanan (IISc, Bangalore) investigated morphological instabilities in cylindrical pores using phase field modeling by taking into account atomic transport through surface diffusion. The salient features of the model and the implications of the stability of films and membranes with continuous pores were discussed.

6. Phase Stability& crystallography

Indranil Manna (IIT Kanpur) discussed the size dependent polymorphic phase transformation in early transition metals induced by mechanical attrition. The polymorphic/ allotropic transformations (bcc/hcp→fcc) were demonstrated in Nb, Ti and Zr alloys and the structural instability was attributed to the negative hydrostatic pressure arising out of nanocrystallization or grain refinement. Wenzhang Zhang (Tsinghua Univ., China) proposed an integrated approach for understanding the morphologies of precipitates and its application to light metals. This theory was applied to Ti and Mg alloys to analyze the faceted interface of two phases irrespective of their orientation, unit cell size and structures. Chuang Dong (Dalian Inst. Tech., China) proposed the structures of several industrial alloys in terms of the building blocks i.e., cluster-plus-glue atom configuration. It was claimed that such local units could provide insight to the correlation between the composition and the properties and it was demonstrated in case of low Young's modulus Ti base, Zr base alloys, stainless steel, Ni-base super alloys and high entropy alloys. John Rodgers (Nanoholdings, USA) introduced the scheme for materials selection for extreme environments using property correlations and systematics with application to intermetallics and ceramic coatings. Mathematical methods such as correlations, systematics and estimations were applied in the present context. Anandh Subramaniam (IIT, Kanpur) proposed mechanisms for stabilization of coherent precipitates in nanoscale thin films in Cu-2wt%Fe system. A phase diagram showing the stability regions of the coherent and semi-coherent states of the precipitate was proposed. R.K. Mandal (IIT, BHU) proposed a generalized form of Miller-Bravais indexing scheme for the hexagonal system beyond its classical form. A critical appraisal in terms of four dimensional approaches was provided. R. Prasad (IIT, Delhi) discussed some misconceptions in the models of crystal dislocations. He pointed out that the extra half plane in edge dislocations was not unique and more over helicoidal planes were associated not only with screw dislocations (which is an accepted fact) but also with edge dislocations. Sharada Srinivasan (NIAS, Bangalore) studied Iron Age high tin bronzes (with various Sn contents) from Tamil Nadu and compared them with those from South East Asia. The Indian influence in developing the Asian and South East Asian high tin bronzes was emphasized.

7. High Entropy Alloys

While discussing physical metallurgy of high entropy alloys, J.W. Yeh (National Tsing Hua Univ., Taiwan) discussed four core effects i.e., high entropy, sluggish diffusion, severe lattice distortion and cocktail effects held to be responsible for exhibiting unique properties compared to conventional alloys. Rajarshi Banerjee (Univ. of North Texas, USA) studied a combinatorial assessment of laser deposited $Al_xCrCuFeNi$ ($0<x<1.5$) HEAs using composition, microstructure, mechanical and magnetic properties and developed a graded alloys. It was claimed that such graded alloys are highly attractive candidates for investigating the influence of compositional changes on microstructural evolution and concurrent physical and mechanical properties in HEAs. B.S. Murty (IIT, Madras) pointed out the challenges and opportunities in high entropy alloy research in general. Processing of the alloys for useful applications due to their unusual properties was suggested for full exploitation of these newly developed materials. S. Raju (IGCAR, Kalpakkam) elaborated the concept of entropy and entropic stabilization of alloy phases. The approach proposed here was relevant to understand the stability of the phases including high entropy alloys. N. Balasubramanian (Bangalore) investigated strength of ultrafine-grained high entropy alloys in CoCrFeNiMn subjected to severe plastic deformation (SPD) and illustrated how ultrafine-grain size and unique features of grain boundaries resulting from severe plastic deformation could be utilized to enhance the mechanical properties of high entropy alloys. M. Phaniraj (Seoul National Univ., South Korea) investigated hydrogen embrittlement phenomena in Cr-Mn-N austenitic stainless steels and high entropy alloys. The micro-mechanisms for embrittlement phenomena were discussed.

8. Advanced characterization techniques

C. Barry Carter (Univ. of Connecticut, USA) shared his experience while studying defects using transmission electron microscopy. He pointed out that data handling while recording the data with high resolution and precision is a challenge. He discussed the defect process occurring during lithiation using *operando* and video techniques in the TEM and considered the future 4D studies of these defect processes. Hamish Fraser (Ohio State Univ., USA) demonstrated the formation mechanisms of various forms of ultrafine α microstructures in metastable β-Ti alloys with the help of aberration corrected high resolution electron microscopy technique. S.G. Srinivasan (Univ. of North Texas, USA) discussed phase transition and anomalous diffusion in metastable β-Ti-Mo alloy. Using *ab-initio* methods, a prototypical Ti-Mo system was studied to understand the effect of Mo distribution on the phase transformation mechanisms. V. Jayaram (IISc, Bangalore) elaborated on the surface mechanical and structural characterization techniques to understand the domains of tribology in automotive engines. He demonstrated the critical role of high resolution characterization techniques such as FIB, AFM and TEM for elucidating the mechanisms of material removal and in formulating models of wear in different ranges of pressure. Joysurya Basu (IITBHU) investigated the atomistic origin of electrochemical activity in transverse compositionally graded Li $(Ni,Mn)_xO_y$ cathodes using high resolution electron microscopy technique. K.G. Pradeep (Univ. Aachen, Germany) discussed atomic scale study of Cu clustering and pseudo-homogeneous nanocrystallization in Fe-Si based soft magnetic amorphous alloys using atom probe tomography technique. Ranjan Datta (JNCSAR, Bangalore) discussed nanoscale quantitative magnetic information and optical band gap by high resolution electron energy spectroscopy in an aberration corrected transmission electron microscope. P. Ghosal (DMRL, Hyderabad) presented advanced characterization techniques, like FIB, TEM-PED-OIM and EBSD for materials for high temperature application. Rahul Mitra (IIT Kharagpur) elaborated microstructural evolution and structure-property relationship of mushy state rolled in-situ Al-4.5Cu-5TiB2 composites. Gouthama (IIT Kanpur) discussed self-accommodation in nanocrystalline NiTi shape memory alloys. It is interesting to note that self-accommodation among variants occurs by the collective displacement of atoms from one crystal structure to another one without any macroscopic changes. D. Srivastava (BARC, Mumbai) highlighted orientation sensitive deformation in Zr alloys with some interesting experimental data and modeling results. The various operating mechanisms were identified from their studies.

9. Surface & grain boundary engineering

Satyam Suwas (IISc, Bangalore) discussed recent trends in grain boundary engineering and its importance for developing desirable strength and ductility. He demonstrated that in case of a particular grade of steel, grain boundary engineered samples exhibited higher ductility compared to the conventionally processed samples. M.J.N.V. Prasad (IIT, Bombay) demonstrated the abnormal grain growth and mechanical behavior of elctrodeposited nanocrystalline Ni and its alloys. The abnormal grain population was found to be non-faceted in nature and of largely {100} facetted orientation with high fraction of ∑3 CSL boundaries. N.P Gurao (IIT Kanpur) revealed the influence of crystallographic texture on twinning during cyclic loading in stainless steel and commercially pure titanium. V.K. Vasudevan (Univ. Cincinnati, USA) studied bulk and surface grain boundary engineering for improved resistance to corrosion and stress corrosion cracking (SCC) resistance of nuclear alloys. A clear correlation and mechanistic understanding relating the grain boundary character, sensitization, carbide precipitation and susceptibility to corrosion and stress corrosion cracking was observed. V.S. Raja (IIT Bombay) showed that 7010 Al alloys could be made more resistant to stress corrosion cracking through an engineered microstructure. Thus, it is important to develop the suitable microstructure through proper processing techniques. Chris Berndt (Swinburne Univ., Australia) investigated plasma sprayed yttria stabilized zirconia coatings and established the microstructure-property relationship. A physical model was developed to optimize the plasma spraying process leading to cheaper coatings of enhanced consistency, quality and durability for defense and commercial air fleets. S.R. Bakshi (IIT Madras) described the reactive spark plasma sintering process for synthesis of nanocrystalline ultra high temperature ceramic based nanocomposites and showed it to be an effective tool to obtain compact products. Dheepa Srinivasan (GE Power, Bangalore) discussed advanced materials technologies for structural component repair in gas turbine components including welding, coatings and additive manufacturing. Larsen Miller parameter type of approach was shown to provide a good estimate of the residual life of coatings and also for exploring the possibility of extension of service life of coatings and components. M.S.M. Saifullah (Inst. Materials Res. & Engg., Singapore) discussed a process involving nano-imprint lithography which can be potentially incorporated during metal working process to impart hydrophobic and potentially superhydrophobic behavior without altering chemical purity of the metal. This kind surface appears to have potential for corrosion resistant applications.

In conclusion, it was realized that the discussions among the delegates during oral & poster sessions and also beyond the technical sessions were highly intense. It is hoped that better understanding and insight on the subjects will be developed. It was also felt that the contacts and interaction initiated during ICMR 2016 will lead to effective collaboration among the delegates for higher learning and future research activities. Finally, the delegates expressed their best wishes to Professor S. Ranganathan for his active research and healthy life and also acknowledged their gratefulness to the organizing committee of ICMR for organizing this conference in the honor of Prof. S. Ranganathan.