MEETING REPORT

METALLO 2007*

A four-day international conference on the theme of metals and alloys, METALLO 2007, was organized to discuss the past, present and future of metals and alloys and their applications in diverse engineering fields. The conference showcased the latest global trends in metals and alloys research, education and industry. In particular, the latest developments, strategies and material requirements for a range of applications in various sectors were highlighted, e.g. in construction, automotive, aerospace, railways, space, nuclear, defence, chemical, petrochemical, biomedical and process industries. The target audience included academicians, engineers, scientists, young researchers and policy makers drawn globally from the industry, R&D and education sectors. The conference honoured T. R. Anantharaman, whose eightieth birthday was being celebrated in 2007. A citation of honour was read out for Anantharaman during the inaugural function.

Different aspects of research related to production of metals and alloys, structure and properties of metallic alloys at nanoscale as well as various diverse applications were discussed by 31 invited speakers. The workshop was attended by close to 250 delegates from USA, Canada, UK, Australia, Germany as well as various Indian institutions. Besides invited talks, the meeting had a poster presentation by active researchers, including senior Ph D students. Altogether 25 posters were presented under 11 different sessions with those on microstructural and phase evolution, mechanical properties, powder metallurgy and sintering, nanomaterials, corrosion and oxidation and modelling on 8 December, and sessions on material processing, application and process overview, characterization, steels and intermetallics and electronic materials on 9 December.

T. Ramasami (Secretary, Department of Science and Technology, New Delhi) delivered the inaugural lecture on 'An insight into the world of metals and alloys'. He emphasized the important role that metals and alloys would play in the coming years for India's overall development.

On 8 December 2007 there were four speakers in the first session of the conference, entitled 'Metals and alloys: Fundamentals and applications'. The first talk was delivered by Reiner Kirchheim (Institut für Materialphysik, Univeristy of Goettingen, Germany) on 'A new way of describing the interaction of solute atoms and defects'. He presented a coherent method which could explain segregation of solutes at interfaces. The results of the presented treatment were compared with those stemming from experiments, statistical mechanics or computer simulations. It was explained how various phenomena and models, like solid solution softening, hydrogen-enhanced local plasticity, brittleness of hydrides, and superabundant vacancies could be interpreted on the basis of thermodynamics as caused by changing the defect energy by solute segregation. This was followed by a lecture by P. Rama Rao (International Advanced Research Centre for Power Metallurgy and New Materials (ARCI), Hyderabad) on 'Low stress creep of zirconium and its alloys, zircaloy 2 and Zr-2.5Nb', in which he highlighted the importance of microstructural control on properties. In particular, he discussed the low stress creep behaviour of zirconium, zircloy-2 and Zr-2.5Nb alloy. Zircaloy-2 has 1.5 wt% Sn as a major alloying element along with Fe, Ni and Cr, each around 0.1 wt%. The microstructural changes observed during low stress creep leading to significantly enhanced creep rates for the $\alpha + \beta_2$ structure were rationalized in terms of the relative stability of the β_1 and β_2 phases. P. Ramachandra Rao (ARCI, Hyderabad) delivered an interesting lecture on 'Biomimetic synthesis of materials', in which he mentioned that several interesting practical applications of engineering materials were developed using clues from nature. Rao's talk briefly summarized some of the observations made and results obtained by his collaborator (Arvind Sinha) at NML, Jamshedpur. Subhash Mahajan (Arizona State University, USA) enlightened the audience on 'Physical metallurgy in microelectronics: Past, present and future' by providing examples to show the impact of physical metallurgy in the past, present and future development of electronic materials. Mahajan illustrated the respective roles using the following examples: zone refining, metal–semiconductor interactions, phase separation and atomic ordering in mixed group III nitrides and growth of low-dimensional structures.

In the first poster session, there were a total of 62 posters dealing with five themes: microstructural and phase evolution, mechanical properties, powder metallurgy and sintering, nanomaterials, corrosion and oxidation and modelling.

There were four talks in the final session of the day. S. Ranganathan (Indian Institute of Science, Bangalore) in his lecture on 'The shape and growth of metallic grains', discussed the interplay between static and dynamic structures in terms of geometry. Among various theories of the grain shape and grain growth, he also reviewed von Neumann law for grain growth in two dimensions and the recent extension to growth in three dimensions by MacPherson and Srolovitz. Peter W. Voorhees (Northwestern University, Evanston, USA) explained a single-order parameter model that accounts for all five degrees of freedom that determine the grain boundary energy and a multiorder parameter model for grain growth, using experimentally measured 3D grain structures in his lecture entitled 'The topology and morphology of interfaces: From phase separation to grain growth'. The talk concluded with a discussion of the factors controlling the interfacial morphology and topology found in various materials. This was followed by talks of Chandra S. Pande (Naval Research Laboratory, Washington) on 'Recent developments in grain boundary migration and grain growth' and of Srikumar Banerjee (Bhabha Atomic Research Centre (BARC), Mumbai) on the theme

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'Challenges in material science at extreme conditions'. After discussing various established models of grain growth, Pande outlined a new approach based on the stochastic methods to understand modelling of grain growth, after critically reviewing existing analytical/computational methods and available models. He showed that his approach leads to a more realistic modelling that explains most of the observed features of grain growth, at least in principle. Banerjee explained the underlying science of devices, which can be configured to release enormous amounts of nuclear energy in a short time and explained that the inertial confinement fusion facilities, driven by lasers or powerful ion beams, can be used to explore material behaviour at these extreme regimes, which are characterized by high material temperatures of around 10^8 degrees and pressures of around 10^9 bar.

On 9 December 2008, the first session of the day was entitled 'Nanocrystalline and amorphous alloys'. Suryanarayana (University of Central Florida, Orlando) delivered the first talk on 'Glass formation by mechanical alloying'. His talk focused on different aspects of amorphous phase formation achieved by mechanical alloying with special reference to Fe-based alloy systems. In particular, the criteria for glass formation, effect of the nature and amount of different solute elements, mechanical crystallization of the amorphous phases, and efforts to consolidate the amorphous powders into bulk shapes were highlighted. Kamanio Chattopadhyay (IISc, Bangalore) delivered a talk titled 'Phase evolution change during non-equilibrium processing', in which he explained how non-equilibrium solidification conditions allow selection of alternate pathways for the evolution of microstructures. Using the experimental results obtained with Fe–Ge alloys, he showed that the microstructure and the phase relations can be different depending upon the processes adopted. For example, microstructure of undercooled alloys can be different from that obtained by laser remelting. Interestingly, he argued that the pathway of phase evolution may not be explained by classical mechanism of phase transformation. Pradeep Haldar (State University at New York at Albany, USA) explained how his team has been able to engineer new building blocks at the nanoscale, which resulted in novel materials for applications in batteries and solar cells, in his talk entitled 'Powering the future with nanotechnology'. Among various examples, he reported that the nanoengineered electrodes in the form of cathodes and anodes in solid oxide and polymer electrode-based fuel cells provide higher efficiency and performance. He commented that the nano-technology applied to fuel cells enables more efficient and reduced use of precious metals – such as using platinum nanoparticles for high surface area and low volume – along with improved membrane function and durability. Christopher A. Schuh (Massachusetts Institute of Technology, USA) emphasized the unique opportunities of alloying (tungsten with nickel was used as an example) to produce nanomaterials with very fine grain sizes and explained the effect of deformation using these alloys in his presentation entitled 'Probing the transition between nanocrystalline and amorphous alloys'. In addition to processing and structural characterization, the experimental results on mechanical property transitions across this entire range of grain sizes were also presented.

The second technical session was devoted to the theme 'Materials characterization at nanoscale'. K. A. Padmanabhan (Anna University, Chennai) revealed new facets of the effect of grain-boundary structure on superplasticity in his talk 'Grain boundary siding-controlled flow and its relevance to superplasticity in metals, alloys and intermetallics and strain rate dependent flow in nanostructured materials'. Ian Robertson (University of Illinois at Urbana-Champaign, USA) kept the audience spellbound with his *in situ* transmission electron microscopy video images in his presentation 'Direct determination of structure–property relationship by performing experiments directly in the TEM'. With various examples, he demonstrated how to reveal the dislocation dynamics at high temperature, in gaseous environments and in ultra-fine grained metals. Anil K. Sachdev (General Motors Research and Development Centre, USA) presented an interesting talk on 'Interdependence of modelling and experiments on materials design', in which he highlighted how modelling and experimental procedures can be combined to provide technological solutions, with some examples. The video images of tensile testing of nano samples were particularly revealing. Sachdev captured how newer experimental techniques are shedding light towards understanding the underlying mechanisms controlling properties of various materials of automotive interest, and also how the experiments provide a critical connection to efforts in materials modelling for further anticipated gains. In the last talk of the session, K. Muraleedharan (DMRL, Hyderabad) explained the use of an advanced characterization technique in '3D APFIM investigation of advanced materials'. He discussed how atom probe microscopy can be useful to study of nano-scale hardening precipitates in ultra-high strength steel as well as to investigate alloying element partitioning in an indigenously developed and patented single-crystal nickel-base superalloy. In the post-lunch poster session, altogether 21 posters were presented under six themes on material processing, application and process overview, characterization, steels, intermetallics and electronic materials.

The last session was on 'Microstructure and mechanical deformation'. In the first talk, G. Malakondiah (DMRL, Hyderabad) provided some relevant examples showing the development of novel steels in his presentation, 'Development of specialty low alloy steels'. He briefly discussed the results of the comprehensive research being undertaken at DMRL on the development of a new ultra-high strength low-alloy steel with strength and toughness properties quite comparable to highly alloyed 250 grade maraging steel. He also presented how continuous casting and controlled rolling technology has been developed to produce large-size plates of DMR-249A steel, as required by the Indian Navy for ship-building. The day concluded with a presentation by Mattew R. Barnett (Deakin University, Australia) on 'Influence of grain size and twinning on mechanical response', in which he co-related the size effect that accompanied deformation twinning can explain the steep Hall–Petch slopes seen in metals, where yielding occurs by twinning like in the case of magnesium. He showed that the Hall–Petch slope associated with the yield stress is significantly steeper when twinning dominates than when it is absent. A size effect that invariably accompanies deformation twinning was identified and it was shown that this can explain the steep Hall–Petch slopes seen in metals where yielding occurs by twinning.

On 10 December 2008, the first technical session, titled 'Novel processing of advanced materials', had four invited

oral presentations. S. N. Ojha (Institute of Technology, Banaras Hindu University (BHU), Varanasi) explained how process variables during atomization and spray deposition processing of the melt critically control the microstructure of the deposit in his talk, 'Spray deposition processing of Al-alloys and their composites'. The process variables during atomization and spray deposition processing of the melt were shown to critically control the microstructure of the deposit in various metallic systems, including monolithic Al–Si, Al–Cu, Al–Cu–Si and Al–Cu–Si–Pb alloys as well as that of their composites. The wear resistance of spray-formed composite materials was shown to be better than that of monolithic alloys. P. M. Ajayan (Rice University, Houston, USA) reviewed the latest developments in the area of fabrication of carbon nanotube-based architectures, in his talk 'Engineering at the nanoscale: The carbon nanotube experience'. Ajayan spoke about his path-breaking discovery of paper-like batteries based on carbon nanotubes. The efforts of his research group on the strategies of growth and manipulation of nanotube-based structures were presented. During his talk, several novel applications, like nanostructured electrodes for sensors, electrical interconnects, unique filters for separation technologies, thermal management systems, multifunctional brushes, and polymer-infiltrated thin film and bulk composites were also mentioned. Sanjay Sampath (State University of New York at Stony Brook, USA) reviewed the recent advances in thermal processing of materials, with particular emphasis on coating design and industrial practice of thermal-spray processing. Some of the key aspects related to thermal spraying were discussed, with particular examples from 3D process multi-instrument diagnostics and 3D process modelling, quantitative characterization of porosity using sophisticated instrumentation, defect-property correlations and their relevance in design, performance and processing, multiscale methods for determining design-relevant coating properties, and methodologies for integration of design, materials and processes. M. Vijayalakshmi (IGCAR, Kalpakkam) outlined the philosophy of development of ferritic steels and their use in nuclear energy applications, in her talk 'Ferritic steels for nuclear reactors: Progress and challenges'. She mentioned how low alloy ferritic and bainitic steels, such as 2.25Cr–1Mo, Fe–0.5Mo–0.5Ni–1.25Mn–0.2C (A533B), were successfully employed at low operating temperatures in steam-generator circuits of fast reactors, pressure vessels and pressure boundary components in commercial light-water reactors. The strategy adopted on ferritic steels for future fast fission and fusion reactors was the co-development of conventional Cr–Mo steels with improved chemistry and advanced materials like oxide dispersion strengthened alloys.

The second session was on the theme 'Modelling and experiments for novel materials'. Srikant Lele (BHU, Varanasi) explained the application of a new method to understand thermodynamic properties of metals and alloys in his presentation, 'Computational thermodynamics of alloys using cluster variation method'. A simple and general description of the small, but crucial vibrational mixing contributions to Gibbs function was given and recent results of the computation of some optimized binary alloy phase diagrams were presented. Dipak Mazumdar (IIT Kanpur) showed the relevance of modelling to industrial practice by taking the example of the steel industry, in his talk entitled 'From laboratory to steel making shop: The role of fundamental process engineering'. Through process engineering, it is possible to reduce yield losses in several domestic integrated and mini steel mills. To accomplish this, tundish designs can be marginally altered leading to considerable reduction in tundish skull. Gautam K. Dey (BARC, Mumbai) explained the use of high-resolution microscopy in understanding nanostructures and interfaces in his presentation 'High-resolution electron microscopy (HREM) of interfaces'. He demonstrated how HREM has emerged as a powerful tool for understanding the structure of alloy phases and nanocrystalline materials. Results of HREM investigations of the interfaces associated with intermetallic phases produced in a very fine morphology by crystallization of Zr-based bulk metallic glasses and micropyretically synthesized Ti-based intermetallic compounds were presented.

The last session of the conference was devoted to 'Degradation of metals and alloys'. R. W. Revie (CANMET Materials Technology Laboratory, Ottawa, Canada) briefed the audience about the effect of both metallurgical and environmental factors on stress corrosion cracking and hydrogen-induced cracking and their relevance in the billion-dollar oil industry of Canada, in his talk entitled 'Metallurgical factors in stress corrosion cracking and hydrogen-induced cracking'. Vinod S. Agarwala (US Office of Naval Research Global, London) briefed the audience about the problems, challenges and achievements concerning corrosion in the military, and the lifecycle costs related to it, in his presentation entitled 'Corrosion in the military and lifecycle costs'. He showed practical examples in which corrosion control was achieved in naval and military applications by careful analysis of the corrosion problem. L. K. Singhal (Jindal Steels Ltd, Hisar) highlighted the latest developments in stainless steel technology, especially emphasizing on the development of low-nickel stainless steels, in his presentation 'Impact of advances in technology on stainless steel products'. Singhal stressed on the development of high-nitrogen stainless steels, which on suitable thermo-mechanical processing can exhibit highest combination of strength and fracture toughness. In the final talk of the conference, Paul T. Craddock (formerly of British Museum, London) described the early technology used for producing zinc and discussed the likely origins of the methodology in his interesting lecture 'Zinc: An advanced material of India'. The important role played by India in large-scale zinc extraction was particularly highlighted. Craddock described the early technology and discussed the likely origins of the blast-furnace process that is currently in operation at Chittogarh to smelt the mined ores.

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