Frontiers in Materials Science and Technology

Summary

Tailored materials and innovative designs of products are the key drivers in many modern technologies such as communication and information technology, transportation, production engineering, environmental technology, nuclear, aerospace and defence, microelectronics and bioengineering. In each of these sectors, progress has been aided by a continuous development of capabilities. Research and development concerning advanced materials and processing has become interdisciplinary activity necessitating synergy between material scientists, metallurgists, design engineers and technologists. In the field of advanced materials, novel processing and material characterization methodologies are emerging. Tailoring the structure at the nano or even molecular level can be explored as a successful approach to materials processing when the homogeneity and the structural information of small volume elements could be scaled up to macroscopic component dimensions. The wide range of length scales of macro-, micro- and even nanoscale dimensions, extending over 8–10 orders of magnitude (nm–m), however, is a great challenge in order to establish effective and affordable multistage processing and manufacturing technologies.

A galaxy of eminent scientists and technologists, who have contributed significantly in their respective specialized fields, have been chosen for the invited articles to be presented in the special issues of *Sadhana* on Frontiers in Materials Science and Technology. These two volumes of the special issues contain the full text of papers that were accepted after due process of reviewing. The submission of papers from several countries offers a global perspective and comprehensive view of the complex issues in materials science and technology.

Based on the coverage and technical contents of the papers, the articles have been grouped into the following sections.

(1) Nanocrystalline materials
(2) Mechanical behaviour of advanced materials
(3) Development and processing of intermetallics, composites and ceramics
(4) Recent advances in welding science and technology
(5) Corrosion and surface engineering
(6) Science and engineering of bio-materials
(7) Testing and evaluation of advanced metallic and intermetallic materials
(8) Computational materials science
(9) Teaching of materials science

The papers cover fundamental research aspects as well as practical approaches necessary to understand advanced materials and provide a valuable source of knowledge especially in the areas of current concern and direction of pursuit, as to where the emphasis has been at the time of preparation of the manuscript in the respective areas. The papers collectively offer research scientists and technologists a wealth of information and data on a broad spectrum of

topics in materials science but are not planned to be all-inclusive or encyclopedic in nature, in any chosen area. However, they do represent a major step forward in an integrated approach towards providing a deep understanding of the subject matter of the paper. It is our belief that the rich diversity of information presented in these volumes will also serve as stimulus for further research on selected topics. A summary of the scientific and technical contents of the papers presented in the two volumes is provided in the following sections.

Nanocrystalline materials

Synthesis of materials and/or devices with new properties by controlled manipulation of their microstructure on the atomic level has become an emerging interdisciplinary field based on solid-state physics, chemistry, biology and materials science. Nanostructural materials are materials possessing at least one length scale of the order of a billionth of a metre. These materials are assembled from nanometre-sized "building blocks" – consisting of the crystalline and large volume fraction of intercrystalline components. It is this inherently heterogeneous structure on a nanometre scale that dictates many of their attractive mechanical properties. Materials with nanometre-sized microstructures are called nanostructured materials, nanophase materials, nanocrystalline materials or supramolecular solids. The synthesis, characterization and processing of nanostructured materials are part of the emerging and rapidly growing field referred to as *Nanotechnology*. R & D in this field emphasizes scientific discoveries related to generation of materials with controlled microstructural characteristics, research on their processing into bulk materials with engineered properties and technological functions and introduction of new device concepts and manufacturing methods. Nanostructured materials have remarkable potential in the form of bulk materials, composites or coating materials. The fields of application include electronic engineering, magnetic recording technologies and bioengineering.

The paper by Robert W Cahn addresses the rate at which new scientific discovery is taken up and further pursued around the world and the factors that govern such take up with special focus on freedom and fashion. The current state of new technology in the world has been discussed employing the terms "freedom" and "fashion". He emphasizes that in order to get the best from new scientific developments, it is essential for the best researchers everywhere to have a substantial measure of freedom, which can never be absolute. He is of the opinion that the researchers who broaden their fields of competence become famous scientists.

In order to predict the unique properties of a nanocrystalline material, it is essential to understand precisely how the structures of crystalline and intercrystalline regions vary with decrease in crystallite size. In addition, study of the thermal stabilities of nanocrystalline materials against significant grain growth is of both scientific and technological interest. A sharp increase in grain size (to micron level) during consolidation of nanocrystalline powders to obtain fully dense materials may consequently result in loss of some unique properties. The article by B S Murty, M K Datta and S K Pabi explores in detail size effects on the structure of crystalline and intercrystalline regions and thermal stabilities of nanocrystalline materials.

R Divakar & V S Raghunathan have examined grain boundary and triple line junction structures in nanocrystalline palladium using high-resolution transmission electron microscopy (HRTEM). The main microstructural features present in the paper include the varying nature of the atomic structure of grain boundaries and the presence of disordered regions at triple line junctions. It has been shown that lattice parameter varies in the different nanocrystalline grains. Geometric phase analysis is used to quantify atomic displacements within the nanocrystalline grains. It is inferred from the non-uniformity of the displacement distributions that there is no case for disorder localized at the interfaces. Instead, the crystalline component of nanocrystalline materials has been considered in consonance with the interface component.

Alok Singh & A P Tsai have stressed on understanding the effect of interfaces on melting. Embedding lead and bismuth nanoparticles in quasicrystalline matrices creates novel interfaces and the effect of the interfaces on the melting behaviour of the nanoparticles is studied. Change in the melting temperature of nanoparticles is directly correlated to the nature of the particle–matrix interface. Sharply faceted and coherent interfaces have been shown to have sharper melting transitions while irregularly shaped and incoherent interfaces lead to lowering of melting temperatures.

R V Ramanujan discusses in his paper the applications of nanomaterials in electronics and magnetic devices. Methods of processing nanostructured materials are described. Sol–gel, rapid solidification and powder injection moulding are projected as potential processing methods for nanostructured materials.

K A Padmanabhan presents a comparative evaluation of mechanical properties of structural super-plastics and nanostructured materials in his paper. He shows that a grain boundary sliding controlled flow model originally proposed for microcrystalline super-plastic alloys can be used for understanding the mechanical response of nanostructured materials in the range where their behaviour resembles that of conventional materials deforming at high homologous temperatures.

Mechanical behaviour of materials

The need to raise aeroengine temperatures for increasing efficiency and thrust has resulted in enormous increase in turbine entry temperatures. Historically, the rise in turbine entry temperatures has been met by the replacement of forged nickel blades by cast blades, and the subsequent introduction of directionally solidified (DS) and single crystal (SX) nickel base superalloys. DS and SX blades overcome the problem of intergranular failure and offer much improved thermal fatigue resistance. The superior high temperature mechanical properties of SX superalloys are mainly derived from proper choice of chemical composition and microstructure. The microstructure of SX alloys consists of high volume fraction of γ' coherently precipitated in an fcc matrix. Under the combined influence of stress and temperature, initial γ' cuboidal particles transform and this phenomenon is referred to as directional coarsening/lamellar structure. Rafting is considered a hardening process, which enhances the creep behaviour of SX alloys in the (001) orientation. The paper by M Kamaraj deals with the thermodynamic driving force for rafting with and without stress. The nature and influence of rafting on creep properties including pre-rafted conditions are discussed. Effect of the stress state on γ' rafting, kinetics and morphological evolution is also discussed with the help of recent experimental results on CMSX-4 alloy.

In the paper by M Benyoucef, A Coujou, F Pettinari-Sturmel, S Raujol, B Boubker and N Clément, the results from *in situ* deformation by transmission electron microscope of single crystal superalloys are presented and discussed in detail. They illustrate the efficiency of *in situ* deformation under combined action of stress and temperature, by describing the different obstacles controlling movement of dislocations in a two-phase MC2 single crystal.

A quantitative analysis is developed leading to the evaluation of critical propagation stresses involved in the channels of the matrix and when crossing the γ/γ' interfaces.

Many high temperature components are subjected to complex mechanical strain cycles in combination with thermal transients, which may finally result in thermomechanical fatigue (TMF) failure. TMF is often the life-limiting degradation mode. Much research effort has been focused on predicting life under high temperature loading conditions and various life prediction methodologies have been evolved for this kind of loading condition. However, relevant damage mechanisms such as creep, fatigue and environmental attack can interact in a complex manner, and thus, most models appear to be limited to specific loading conditions and/or certain types of materials. The paper by H - J Christ, A Jung, H J Maier and R Teteruk provides a compact survey of the applications of life prediction methods based on fracture mechanics concepts as applied to isothermal and TMF conditions. The applicability of cyclic J integral (ΔJ_{eff} concept) creep-fatigue damage parameter and linear combination crack growth rate contribution from pure fatigue and environmental attack has been assessed in case of high temperature titanium alloy IMI 834 and dispersion strengthened aluminum alloy X8019, reinforced as well as unreinforced by SiC particles.

Integrity of components during seismic events is one of the critical issues in the design of nuclear power plants. Load fluctuations during seismic activity may be random, with postulated cracks and flaws experiencing tensile as well as compressive load amplitudes of high magnitudes leading to their extension or growth. In order to incorporate seismic factors in design, resistance to fracture under such loading conditions must be used during leak-before-break analysis of piping components. In the paper by S Tarafder, V R Ranganath, S Sivaprasad and P Johri the ductile fracture resistance of SA 333, Grade 6 steel – the material used for Indian pressurized heavy water reactors – under monotonic and cyclic tearing loading has been documented. An attempt has also been made to understand the mechanism responsible for the high fracture toughness of the steel through determination of the effect of constraint on the fracture behaviour and fractographic observations.

In metastable austenitic stainless steels, the transformation of paramagnetic austenite to ferromagnetic martensite can occur in localized regions due to plastic deformation. Depending on the alloy composition, austenite is either converted directly or indirectly over the hexagonal ε-martensite into α'-martensite. Th Nebel & D Eifler study the effect of chemical composition of austenitic stainless steels on the transformation behaviour of α' under cyclic loading conditions at ambient and elevated temperatures. The transformation behaviour of austenite to martensite has been monitored by non-destructive testing methods including SQUID and GMR measurements.

Substantial improvement in structural efficiency, fuel savings and payload in aerospace can result if the net weight of the structure is reduced considerably. Weight reduction arising from design modifications or enhancements in mechanical properties alone is marginal as compared to what can be achieved by the use of newer materials with lower density. Aluminium–lithium alloys hold promise in this regard. However, these alloys have not yet greatly displaced the conventionally used denser Al alloys on account of their poor ductility, fracture toughness and low cycle fatigue resistance. In their paper, N Eswara Prasad, A A Gokhale and P Rama Rao have addressed several issues pertaining to the mechanical property limitations of various Al-Li alloys and indicated the directions to overcome them.

Development and processing of intermetallics, composites and ceramics

NiAl and Ni_3Al have attracted a great deal of interest because of their potential applications in the aerospace and automobile industries. As is the case with other aluminides, NiAl and Ni_3Al depict inadequate ductility at ambient temperature and lack of good high temperature creep resistance. Lack of ductility at room temperature has been attributed to an inherently low cleavage stress, which is partly assigned to a low mobile dislocation density and the inability to initiate a sufficient number of independent slip systems to satisfy Von Mises criterion for generalized plasticity of polycrystalline aggregate. Several attempts have been made to alleviate the problem of limited room temperature ductility in NI_3Al and NiAl through modification of slip system, use of single crystals, micro alloying and altering the manufacturing processes. Extensive research and understanding on processing, physical metallurgy and mechanical behaviour has led to a successful factor demonstrator engine test with NiAl turbine vanes.

In the article by G K Dey, the physical metallurgy of NI_3Al and NiAl has been presented. Besides information on crystal structure and ordering behaviour, considerable importance has been given to the microstructure development in these two alloys under different processing conditions and after different alloying additions. Special emphasis has been given to the examination of slip systems operating in these two intermetallics compounds and reasons for limited ductility have been ascertained. Methods for ductilizing these two intermetallics compounds have been described.

The discovery of superconductivity in the binary intermetallics MgB_2 has resulted in a flurry of activity that includes determination of superconductivity gap, coherence length, penetration depth and critical fields. Theoretical calculations of superconductivity in this system can be understood in the framework of electron–photon interactions. In the paper by A Bharathi, Y Hariharan, J Balaselvi and C S Sundar results pertaining to studies on superconductivity in carbon-doped MgB_2 and investigations on the temperature-dependence of vibration modes in MgB_2 through infrared absorption spectroscopy measurements are presented. It has been found that the changes in lattice volume, as obtained from X-ray diffraction measurements, can account only partially for the observed decrease in T_c. Observed variation of T_c with carbon content is seen to correlate with Debye temperatures, obtained from an analysis of the resistivity data.

The largest commercial applications of superconductors have been based on the ability to carry current without resistance, and have been in the form of superconducting magnets producing high magnetic fields. P Chaddah describes the measurement and importance of J_c in superconducting materials. His paper outlines the current status of research in two promising superconductors $YBa_2Cu_3O_7$ (and other rare earth-based 123 oxides) and MgB_2.

M Pal & D Chakravorthy review different physical and chemical processes exploited for growing nanocrystals of magnetic phases, either metallic or ceramic. The coercivity in these materials can be changed drastically by varying the particle size or the matrix in which they are dispersed. Nanocrystalline soft ferrites, e.g., $MnFe_2O_4$ and $(Ni_{0\cdot5}Zn_{0\cdot5})Fe_2O_4$ show an increase in coercivity as compared to their bulk counterparts. The Curie temperature appears to depend markedly on their particle size in these systems. Nanocomposites of α-iron and $(Ni_{0\cdot5}Zn_{0\cdot5})Fe_2O_4$ show a wide range of magnetization and coercivity properties depending on the volume fractions of the components present.

In the field of advanced ceramic manufacturing, novel processing approaches are emerging that combine traditional powder technologies with physical and chemical and (micro) biological processes. Advanced concepts for ceramics engineering have to fulfill the requirements of increased precision in both design and manufacturing to achieve greater uniformity and predictability in material performance. Current trends in processing of medium and large-scale production of micro components of a wide range of materials are described in the paper by V Piotter, T Gietzelt and L Merz. With the spectacular advances in machine technology and special sintering procedures, the microinjection-moulding process enables the manufacturing of metal and ceramic devices with small wall thicknesses of about 50 μm and structured details less than 3 μm in size. Using ultrafine ceramic powder and high-quality LIGA mould inserts, high quality surface finishes have been achieved.

During product development, expenditure for the fabrication of prototypes and functional models is very high. This is especially true for ceramic micro-components because of high tooling costs of conventional shaping processes like high-pressure injection moulding. As ceramic parts, fabricated by solid free-form fabrication techniques either do not have sufficient resolution or do not provide the final properties of conventionally fabricated parts, they cannot be used for performance tests for design optimization. In their paper, R Knitter & W Bauer have presented a rapid prototyping process chain that enables the rapid manufacture of ceramic micro components from functional models to small lot series within a short time. This process chain combines fast and inexpensive supply of master models by rapid prototyping with accurate and flexible ceramic manufacture by low-pressure injection moulding.

Aluminum matrix composites (AMCs) are of great interest because of their superior properties such as increased strength, improved stiffness, reduced density, improved high temperature properties, controlled thermal expansion co-efficient and improved damping, abrasion and wear resistance as compared to unreinforced aluminum. In recent years, aluminum matrix composites are being increasingly used in high technology structural and functional applications, including aerospace, defence, automotive, thermal management, sports and recreation. The paper by M K Surappa deals with the current state-of-art of aluminum matrix composites with regard to processing, microstructural properties and applications. The issues and challenges ahead in intensifying the engineering usage of AMCs are also addressed in detail.

In the modern world, carbon is one of the most magnificent elements that have revolutionized materials science. High strength fibres (carbon fibres), solid lubricants (graphite), the best electrically conducting electrodes (graphite), structural materials for high temperature tribological applications (carbon–carbon composites), porous gas absorbers (activated carbon), non-crystalline impermeable material (vitreous carbon), the hardest known material (diamond) and fullerenes are all made of carbon. All these forms are made by meticulously choosing the raw materials and processing conditions. Activated porous carbons are the subject matter of the paper by Satish M Manocha. She discusses in detail the steps involved in processing of activated carbon, structure of porous carbons, absorption by activated carbons and applications of activated carbons.

Carbon–carbon composites are a family of materials with choice of variations in fibre and matrix architecture, structure, microstructure, a spectrum of mechanical, thermal and physical properties etc. These are currently being used in very high performance applications that require high strength at elevated temperatures, high thermal conductivity and frictional properties. Lalit M Manocha discusses in detail the processing, structural aspects, mechanical, thermal and frictional properties, and oxidation protection of carbon–carbon composites.

Recent advances in welding science and technology

For successful service application and acceptance in practice, the weldability of material is one of the most important aspects. The weldability of austenitic stainless steels is a promising and applied research area due to the susceptibility of this class of materials to solidification cracking. This occurs in the fusion zone caused by the inability of the solid–liquid aggregate to support the strain induced by solidification shrinkage and thermal stresses. The article by V Shankar, T P S Gill, S L Mannan and S Sundaresan describes the role played by various elements in the cracking process. It further analyses critically the available literature on the effects of N and Ti. Nitrogen, in particular, is shown to have complex effects on both unstabilized and stabilized stainless steels. An important part of this review is a discussion on various criteria for assessment of weld cracking. The carbon and power plant chromemoly steel welds are prone to hydrogen-assisted cracking (HAC). The paper by S K Albert, V Ramasubbu, N Parvathavarthini and T P S Gill reveals that susceptibility to HAC increases with alloy content and associated increase in the hardenability of steels. Studies of HAC and measurement of diffusible hydrogen content in different Cr–Mo steel welds reveal that under identical conditions, susceptibility to cracking increases and diffusible hydrogen content decreases with increase in alloy content. It has been further demonstrated that the variation in diffusible hydrogen and hydrogen diffusivity can be represented as a function of carbon equivalent. Repair welding of prematurely failed components due to design and manufacturing defects is a key factor in the economic management of power plants. As most of the repair-welding technologies are closely guarded information, there is a growing necessity for in-house development of repair welding procedures by power utilities. In the paper by A K Bhaduri, S K Albert, S K Ray and P Rodriguez, repair and refurbishing of steam turbine components are discussed from the perspective of the repair-welding philosophy including applicable codes and regulations. The next paper by P Rodriguez, S K Ray and A K Bhaduri describes an empirical method and the important parameters involved in characterizing resistance to ductile fracture. This method stipulates that the post-necking regime during tensile deformation is dominated by micro-void growth and coalescence process, and therefore the energy absorbed in this regime can be used to estimate resistance of the necked region to ductile fracture of metallic materials. The usefulness of the approach in selecting the optimum post-weld treatment of dissimilar weld joints is emphasized.

Corrosion science and surface engineering

Hydrogen embrittlement results from the combined action of hydrogen and residual or applied stress leading to the reduction in load bearing capacity of the component. It manifests in diverse modes of metal failures each of which is highly specific to the alloy system. R K Dayal & N Parvathavarthini provide critical assessment of phenomenological and micromechanistic aspects of hydrogen embrittlement in steels and analyse various techniques employed for prevention of hydrogen embrittlement. The effects of hydrogen concentration and heat treatment procedures on the hydrogen embrittlement behaviour of β-titanium alloys have been presented in detail by H - J Christ, A Senemmar, M Decker and K Prüssner.

Hydrogen charging has been shown to have significant influence on fracture strain, cyclic life, fatigue crack growth threshold and brittle-to-ductile transition temperature. The paper by R K Singh Raman discusses stress corrosion cracking of duplex stainless steels and their weldments in marine environments and the potential role of microbial activity in inducing SCC susceptibility. Electroless deposition is being extensively used in the preparation of coatings of amorphous solids. In this method, alloys with or without external reinforcement of particulate composites are deposited in the form of uniform films on catalytic surfaces by reduction reactions. In the paper by R C Agarwala & Vijaya Agarwala, different electroless alloy/composite coatings with respect to their composition, applications, wear and corrosion properties are discussed. The paper by J Dutta Majumdar & I Manna provides an overview of the applications of lasers in materials forming, joining, and machining. A major part of the discussion in the paper is focussed on laser surface engineering which has attracted a good deal of attention due to its technological significance and scientific challenges.

Science and engineering of biomaterials

Materials are essential and central to the development of new medical techniques and therapeutical capabilities. Biocompatible structural materials for medical and surgical implants have been developed in recent years with the goal of improving mechanical, chemical and wear properties, thus resulting in extended lifetimes, increased safety of the implant and reduced damage to human health by wear and corrosion debris. At the same time, development of implant materials aims at lower cost and wider availability, as a growing section of the world's population hopes to benefit from advanced medical techniques and services in the near future. As technological research contributes to wealth creation and improvement in the quality of life, it is imperative that developments that lead to the implantation of advanced materials and devices within the body in order to treat disease and injury should have high priority. Biodegradable implant materials and materials for tissue engineering are two research-intensive and promising fields that are still on their way to achieving public awareness. Since, more often than not, it is the surface of a biomaterial that determines its acceptability and functionality, surface modification and characterization of biomaterials is an important research field that attracts worldwide attention.

Diseased tissues are the origin of many human health deficiencies. They cause discomfort and pain, and may lead to early death. Tissues altered in their physiological functions help to create medical and surgical disciplines and concomitantly lead to the development of an elaborate pattern of technical support systems, i.e. devices, implants and instruments. Tissue engineering is a very complex subject. Quite often, tissue engineers do not have all the relevant parameters for designing a new material or a scaffolding device and they have to depend on approximately known and sometimes even unknown parameters which can include physical, chemical and biological data alike, and still design the material or device with specific material properties. The disciplines involved in tissue engineering are loosely knit and there is a need to learn a common language which necessitates a robust dialogue between researchers engaged in the disciplines of cell biology, materials science, surface technology, biochemistry and related fields.

The paper by D F Williams provides an account of the rationale for the development of implantable medical devices over the last five decades and explains criteria that have controlled the selection of biomaterials for critical applications. The paper also addresses the limitations that are faced in the usage of implants today and develops the theme in order to describe recent innovations in tissue engineering. The paper also attempts to place clinical applications in the context of the expectations for medical devices, the performance of biomaterials and the relationship between materials science and the biology of human beings.

Kalyani Nair, C V Muraleedharan and G S Bhuvaneshwar discuss the developments that have taken place in the recent past in mechanical heart valve prostheses. The functional requirements of materials for mechanical heart valves have been addressed and efforts that have gone into the development of indigenous valves have been enumerated. Revolutionary advances that have been brought in the design of valves by the introduction of tilting disc/bi-leaflet valves have been highlighted. Mechanical valves made with high strength biocompatible materials are durable and have long-term functional capability. The paper by D Basu deals with fatigue behaviour of fine-grained alumina hip-joint heads. Alumina-based fine-grained ceramics are exceptionally inert in the physiological environment and offer excellent biocompatibility. For prosthetic application of alumina, reliability is an essential pre-requisite and therefore mechanical behaviour of the material for a period of 20–30 years is of utmost importance. The results presented in this paper are very interesting since data have been generated on alumina femoral heads using the actual cyclic loading conditions experienced by hip-joints in the process of walking. *In vivo* corrosion is an important condition affecting the service of orthopaedic devices made out of stainless steels, titanium alloys and cobalt–chromium alloys. Bulk alloying of stainless steels with titanium and nitrogen, surface alloying of stainless steels and titanium alloys by ion implantation and surface modification of stainless steels with bio-ceramic coatings have been found to be very effective in diminishing corrosion rates and achieving the much desired biocompatibility. Several of the issues pertaining to corrosion and its alleviation in implant materials are outlined and discussed in detail in the paper by U Kamachi Mudali, T M Sridhar and Baldev Raj.

Magnetism and magnetic materials have a very strong role to play in healthcare and biological applications. Magnetic properties change dramatically when particle size reduces beyond a critical limit and attains single domain and sub-domain regions. Below a critical size, particles show super-paramagnetic properties. This property is exploited extensively in sophisticated bio-medical applications such as cell separation, drug delivery and magnetic intracellular hypothermia treatment of cancer. The paper by D Bahadur & J Giri addresses the salient features of biocompatible magnetic materials in clinical applications.

The well-organized multifunctional structures, systems and biogenic materials found in nature have attracted the interest of scientists working in many disciplines leading to the development of an entirely new discipline known as biomimetics. It is being viewed as a tool for learning to synthesize materials under ambient conditions with least pollution to the environment and as a means of success in tissue engineering. The article by P Ramachandra Rao deals with a few natural materials and systems and explores how ideas from nature are being interpreted and modified to focus efforts aimed at designing better machines and synthesizing newer materials.

Testing and evaluation of advanced metallic and intermetallic materials

Improvements in processing and compositional control have resulted in consistent and reproducible improvement in room temperature ductilities in many intermetallic systems.

The paper by A K Gogia, R G Baligdad and D Banerjee deals with the approaches followed in the ductilisation of Ti_2AlNb-based intermetallics and Fe_3Al; the former is ductilised by stabilizing the *bcc* phase of titanium into Ti_3Al structure whereas the addition of carbon to form $Fe_3AlC_{0.5}$ phase imparts ductility to the latter while enhancing both tensile and creep strength. K Bhanu Sankara Rao, in his paper addresses the means of improving the high temperature fatigue resistance of NiAl by proper selection of manufacturing routes and by micro-alloying additions of nitrogen and zirconium. The effects of microstructure on low cycle fatigue properties of γ-TiAl are also discussed in detail.

Increase in the thermal efficiency of fossil fuel-fired power plants can be most effectively achieved by increasing the operating temperature and pressure of the turbines. This imposes stringent requirements on the materials of construction and necessitates the application of steels with improved creep strength and oxidation resistance. The paper by P J Ennis & A Czyrska-Filemonowicz discusses recent developments in creep-resistant 9%Cr steels P91, P92 and E911. For long-term creep strength, the sub-grain structure that is produced by martensite transformation and the precipitation of carbides, nitrides and carbonitrides are found to be decisive microstructural features. The potential for the development of steels of higher chromium (11%Cr) contents to improve oxidation resistance whilst maintaining creep resistance are highlighted. In the paper by J Foct, a precise assessment is made of the global trends that are likely to influence future developments of high nitrogen steels and high nitrogen alloys. The scientific foundations of these steels and possible new applications of these materials are outlined.

The principles and parameters involved in scattering techniques and their applications for characterization of surface roughness are discussed concisely in the paper by C Babu Rao & Baldev Raj. Industrial applications of laser scattering in monitoring corrosion and surface modification of metals and alloys are also presented in detail. Convergent beam electron diffraction (CBED) is being used extensively for the determination of crystal structure of a diffracting crystal, by determining the number of parameters ranging from the symmetry of the crystal to the position of atoms within the unit cell. The paper by M Vijayalakshmi, S Saroja and R Mythili provides a review of the fascinating developments in the area of CBED starting from its historical development. The usage of CBED in identification of lattice strain and point defects has been elucidated.

Bulk glass-forming alloys possess attractive properties like corrosion resistance, wear resistance and reduced eddy current losses in ferromagnetic ribbons as compared to crystalline alloys of identical compositions. They also display unique combinations of strength, toughness, and resilience. Enhancement in properties of metallic glasses can be obtained by appropriate heat treatments. A broad overview of the present status of the science and technology of bulk metallic glasses and their potential technological applications are presented in the paper by J Basu & S Ranganathan.

Radiation-induced defects are known to play a major role in influencing phase transformations in several alloy systems. High voltage electron microscopy has proved to be a very effective technique for studying the real time progress of the order $\leftrightarrow$ disorder transition under irradiation. Progressive changes in the diffuse intensity patterns during the early stages of ordering in an HVEM provide an insight into the structure of the evolutionary stages of ordering. HVEM using electron energies adequate for causing displacements of atoms from the lattice sites is a very effective technique for studying mechanisms of solid phase transformations and for charting the path of phase evolution in real time. S Banerjee has demonstrated this in his paper on studies on chemical ordering in Ni–Mo alloys and on the $\beta \rightarrow \omega$ displacement in zirconium–niobium alloys.

Computational materials science

Availability of high performance computers and development of efficient algorithms have led to the emergence of computational materials science as an important branch of materials research, complementing traditional theoretical and experimental approaches. It is creating new virtual realities in materials design enabling the discovery of novel materials with desired properties. The paper by Vijay Kumar deals with the recent developments related to superalloy and steel design as well as the study of matter at the nanoscale level by using first principle methods.

New process design and control methods are needed for significantly improving productivity and reducing the costs of thermomechanical processes such as hot metal forging. Substantial improvements in effectiveness and efficiency in hot forging can be realized through holistic approaches that optimize whole system performance, encompassing individual subsystems such as workpiece material behaviour, material flow in dies, and equipment responses. In the paper by Baldev Raj & S Venugopal, recent advances in the application of dynamical modelling and process design techniques using ideal forming concepts and trajectory optimization are discussed. Methods for on-line monitoring of the process and an intelligent forging system have been proposed.

Teaching of materials science

Excellence in science is universally linked with development of new research techniques, generation of new results and new interpretations. In order to sustain the momentum of doing excellent research and to maintain excellent reputation, state-of-the-art knowledge has to be translated to the minds of young researchers and students. Teaching becomes a crucially important factor in creating research and development capability in any region of the world. The article by B Ilschner illustrates the tasks, priorities, goals and means ahead in the teaching of Materials Science and Engineering. The article provides ideas to stimulate discussions among those who develop and teach materials science and engineering for sustainable development.

These special issues of *Sādhanā* thus present a wide range of interesting research work in the frontier areas of materials science and technology. It is hoped that these issues will serve as valuable sources of information for scientists and technologists in their respective fields of specialisation.

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