Frontiers in Materials Science and Technology

FOREWORD

Over the last few decades of the twentieth century, great inroads were made in further development of established materials by improved and novel processing routes. It was also a period of discovery of a range of new materials such as high temperature superconductors, intermetallic compounds, conducting polymers, metal-matrix composites, ceramic-matrix composites, nanostructured materials, advanced ferritic steels, high nitrogen steels, directionally solidified and single crystal superalloys, functionally graded materials, biomaterials, intelligent and smart materials, to name a few. The new materials together with the advances in processing methodology are competing with evolutionary progress in existing materials and processes. The purpose of the special issues on Frontiers in Materials Science and Technology is to reflect on the developments, over the last decade, in the domain of materials science and related technologies. The special issues are carefully planned and comprise a set of papers by experts in their chosen field on topical areas of interest to researchers and technologists. They are being edited by one of our leading materials scientists, Dr Baldev Raj and his colleague, Dr K Bhanu Sankara Rao.

The constant pursuit of higher performance in the fields of automotive and aeroengine technology has in recent years, focused interest on the development of new and specialized materials known as "intermetallics". Among the several intermetallics, γ-based TiAl derived from the titanium-aluminum system is considered to be closest to application. Compared with nickel-based superalloys, intermetallics offer opportunities for substantial component weight reductions, coupled with better creep, oxidation, and burn resistance. At present, a major disadvantage arises when designing with γ-titanium aluminides; as these exhibit low ductility at ambient and slightly elevated temperatures. Therefore substantial amount of work is devoted to the development of more ductile alloys with higher fracture toughness. Attention is being paid to specific design methodologies for intermetallics. Other problems in implementing γ-TiAl in gas turbines include the difficulty in controlling and reproducing the microstructure when casting. Relatively small variations in the chemical composition as well as actual casting and heat treatment procedures can have considerable effect on the microstructure, and thus on the resulting properties. In order to pave the way for use of γ-TiAl, strict control of composition, processing parameters and microstructure has to be exercised. Due to poor hot workability, it has been difficult to make wrought TiAl components. The prospect of major breakthroughs in intermetallic compounds that could lead to simultaneous retention or improvement in high temperature strength and substantial improvement in low temperature ductility seem unlikely if not scientifically unfounded. Thus the focus on continuing to learn how to use the materials that are available today through improved design methods and more consistent processing seems to be a fertile direction of research.

Nanotechnology has become a very active and vital area of research, which is rapidly developing in industrial sectors and spreading to almost every field of science and engineering. Control of matter on a molecular scale is the central goal of nanoscale sciences.

Fundamental physical, mechanical, magnetic and biological properties of materials are remarkably improved as the size of their constituent grains decreases to a nanometre scale. Nanostructured materials and associated processing technologies have opened up exciting new possibilities for future applications in aerospace, automotives, electronics, coatings, nonvolatile memories, sensors, actuators, optoelectronics, drug delivery etc. India must make its technology choices here in balance with the current level of industrial development and immediate future potential. Apparently, a new vision of molecular nanotechnology will develop in coming years and the twenty-first century is likely to see technological breakthroughs in creating materials atom by atom. Widespread use of nanocrystalline components of large size requires the availability of large tonnage of well-characterized materials with reproducible properties, and this needs to be done economically. In this context, development of novel techniques is an urgent necessity. Consolidation of the fine powders and the thermal stability of the nanometre-sized grains is of concern to materials scientists. The extensive investigations in recent years on mechanical behaviour and structure-property correlations in nanocrystalline materials have begun to unravel the complexities of these materials, and pave the way for successful exploitation of alloy design principles to synthesize the materials.

Realization of economical and reliable energy is a prime requirement for success in the manufacturing industry on which the well-being and standard of living of mankind is dependent. Advanced power generation technologies seek to supply this demand for energy within the increasingly stringent economic and ecological restraints with respect to plant costs, fuel conservation and environmental impact. An improvement in power plant efficiency can be obtained by increasing the operating temperature and pressure of steam turbines. Steps to develop more efficient power plants necessitates the development of new forged and cast ferritic steels with improved creep strength for high pressure and low pressure rotors, cast valve bodies, turbine casing and main steam lines. All these components should have similar creep strength irrespective of their manufacturing route. Achieving this goal is a great challenge to material scientists. Austenitic stainless steels and superalloys are being considered for very high temperature applications. For successful service application and acceptance, weldability, assessment of long-term creep behaviour and development of repair welding procedures for components made out of new materials are very important aspects. Gas turbine technology is the key to performance improvement in combined steam and gas cycle power plants. Advanced materials technology is primarily aimed towards ensuring high creep rupture strength and low cycle fatigue properties of gas turbine hot gas path materials, together with development of enhanced casting processes. Directionally solidified and single crystal blades of nickel-based superalloys, high oxidation resistant and thermal barrier coatings and ceramic parts for the hot gas path are being successfully used in gas turbines. Development of advanced superalloys and intermetallics, and exploitation of oxide dispersion strengthening seems to hold promise for enhancing gas turbine performance in the next few decades.

Breakthroughs in biomaterials and tissue engineering have made significant impact in medicine, medical devices and health care. It has changed our lives and improved the lifestyles of many patients. This can be noticed in the recent advances in new medical devices such as total implantable heart, prosthesis of hip joint, tissue-engineered skin, implantable biosensors, artificial eye etc. These breakthroughs are the results of integrating materials science and engineering with cell biology to bring about a new age of research and education in biomaterials. Characteristics of the environment in which the biomaterial is to operate and the function it has to perform, set the boundary conditions for the design of a new implant. The minimum requirements of biomaterials for medical applications are for them to be non-toxic, effective, and sterilizable. Biomaterials used currently do meet these requirements, but most of them lack mechanical and interfacial biocompatibility. The poor mechanical biocompatibility is largely attributed to mismatching of material rigidity or modulus with natural tissues. This mismatching causes deterioration of the host tissue through so-called stress-shielding effect, when an implanted material of high rigidity carries most of the applied stress. Reducing the rigidity of the biomaterial to a value comparable with the host material is likely to result in inadequate strength, because natural tissues generally have high ultimate tensile strength and low initial modulus. These unique mechanical properties are quite different from those of man-made materials. The final goal of tissue engineering is to create biological substitutes for replacement of defective and lost tissues, as well as organs, by use of cells and biomaterials. Such biological substitutes will have high biofunctionality of tissue engineered products and automatic biocompatibility. Future work on controlling cell-biomaterial interactions will focus on continually smaller (microscopic to molecular to genetic) scales. Micro-electro mechanical system (MEMS) processes and nanotechnologies may yield exciting, breakthrough strategies and techniques which can be used to fine-tune the surface properties of traditional biomaterials which already possess desirable bulk properties. New analytical methodologies need to be developed in order to quantitatively confirm and characterize the novel surface modifications, as well as cell/biological responses to such modifications. With the development of permanent magnet materials, such as ferrites, alnicos, and rare earth magnets, attempts have been made to utilize these materials in medical applications. Use of magnets in medical applications range from their simple use of retention, through orthopedics and fracture healing, to magneto-motive artificial hearts and pioneering brain surgery, where magnets are used to guide catheters. Magnets also find use in applications such as magnetic resonance imaging scanners and drug delivery systems. Due to their advantageous combination of biocompatibility and mechanical properties, titanium alloys are often used for orthopedic and dental implants. Under physiological conditions, these implants are subjected to a complex interaction of variable amplitude cyclic loading and chemical biological loading. Despite this realization, implant materials have been scarcely examined under realistic loading and environment conditions and the influence of different physiological media has hardly been considered.

Basic research in superconductivity is perhaps enjoying a renaissance. During the last couple of years, material scientists have discovered a wide variety of materials including iron, carbon-60, DNA, and MgB_2 that lose their electrical resistance at low temperatures. Commercial applications of superconducting materials have been slow to take off and the early promise of magnetically levitated trains, compact electric motors of stunning power, and super-efficient power transmission are yet to be realized on commercial levels. Recent installation of power cables made from ribbons of high temperature super conductors in Detroit suggests that unlocking the potential of superconducting materials could take place in the coming years. However, cost remains a dominant barrier to the widespread exploitation of superconducting materials.

The nature of materials science and engineering is rapidly changing. The progress in computer technology is accompanied by mathematical modelling and simulation to play a significant role in predicting and understanding the behaviour of new materials. At present, researchers are able to analyse materials in greater detail at the atomic level, to design modelling at the macro level. More meaningful interactions between the research scientists and modelling specialists would pave the way for quicker development of new materials and their more successful application.

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