Institute of Engineers India and the Institute of Aeronautical Science USA. He was recipient of the Sir Walter Puckey Indian Prize for contribution to production engineering in India, and the National Design Award.

Ghatge retired as general manager of HAL in 1970. After retirement he remained active in the general engineering field rendering consultancy services to industry in the corporate sector. Ghatge would have had some satisfying moments in his retired life, when, on the occasion of his 75th birthday HAL, jointly with Aeronautics R&D Board, Indian Institute of Science and Aeronautical Society of India, organized a two-day seminar in October 1983, on 'Design and development in aeronautics'.

Ghatge found an outlet for his creativity in portrait painting which was done mostly in water colours. He had not received any formal training but had practised figure drawing from books during his school days. He had a good eye for colour schemes and was equally good at black and white shading and sepia stump work. A voracious reader of Marathi literature, a Sanskrit scholar, and a knowledgeable critic of Indian classical music, Ghatge, in the best tradition of his generation, was a well-rounded personality. He was extremely sociable, the heart and soul of a convivial gathering in a club, and could keep one amused for hours with his forays into diverse subjects.

A keen golfer, he was elected captain of the Bangalore Golf Club in 1957, and later he was a founder member of the Karnataka Golf Association and its first president.

In summing up his own philosophy of life he is known to have said: 'Quite often in life the determined pursuit of an objective or goal is much more exciting and interesting than the achievement of the goal or objective, after which one feels a certain measure of disenchantment or disappointment. Climbing to reach the top of the hill is more exciting than reaching it.'

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ABSTRACTS

MRSI medal lectures

The Bangalore local chapter of the MRSI hosted the third annual general meeting of the Materials Research Society of India at the Indian Institute of Science, Bangalore, during 9–11 February 1992. The meeting was attended by 290 participants from more than 65 organizations.

The inaugural address was given by the President of MRSI, Prof. C. N. R. Rao. The MRSI honour lecture entitled 'Metallic structures: a magnificient obsession' was delivered by Prof. T. R. Anantharaman, Director, Thapar Corporate Research and Development Centre, Patiala. In addition, there were two special lectures. Prof. B. Ilschner, Swiss Federal Institute of Technology, Lausanne, Switzerland, spoke about 'Chemical and microstructural gradients in solid materials' and Dr A. Jayaraman, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, highlighted 'The role of high pressure in materials research'. The symposia lectures and poster sessions attracted lively participation. The abstracts of MRS-I medal lectures are given below.

Grains and grain boundaries in electronic materials

B. K. Das, *National Physical Laboratory, New Delhi 110 012*

Use of polycrystalline semiconductors, magnetic materials, ionic conductors, electronic conductors and ferroelectric materials for fabricating electronic components has led to the study of grain boundaries and their influence on electronic properties. Several techniques to control grain size and grain boundary segregation and phases in these materials have been developed in our laboratory.

Polycrystalline silicon has been successfully used to fabricate photovoltaic cells with AM1 conversion efficiency of >10%. A novel technique to cast polycrystalline silicon ingots for this purpose inside a split reusable graphite crucible has led to the possibility of low cost production of this material. Migration of impurities to grain boundaries of silicon and consequent increase in their electrical activity and deterioration of photovoltaic properties have been studied.

Control of grain boundary mobility and grain boundary phases during sintering of ceramics such as ferrites, beta alumina, zinc oxides, $LaCrO_3$ and superconducting ceramics have led to the optimization of their engineering properties. In many cases, liquid phases present at sintering temperatures were found to play an important role. Our recent work on grain alignment of bismuth-oxide based superconductors has led to the attainment of critical current density $>2500\ \mathrm{A\ cm^{-2}}$ (at 77 K, OT)

Photoquenching of EL2 in semi-insulating GaAs

V. Kumar, *Department of Physics, Indian Institute of Science, Bangalore 560 012*

The well-known intrinsic defect EL2 in gallium arsenide, responsible for its semi-insulating behaviour, is under intensive investigation currently due to its technological importance. The transfer at low temperatures to an electrically non-active metastable state EL2* under illumination with light in the range 1.05 to 1.3 eV is one of its remarkable properties. This photoquenching, EL2→EL2*, is a complex process, which has been investigated in detail in this laboratory.

In this talk, we will review the properties of the EL2 defect. Results of extensive studies of the photoquenching of EL2 in semi-insulating gallium arsenide in the temperature range 13 K to 80 K as a function of light energy and intensity will be presented. It is seen for the first time that at low temperatures the initial slow quenching is followed by a sudden switch to a fast quenching rate. A microscopic model for the EL2 defect is suggested.

Technology of bulk synthesis and growth of semi-insulating GaAs ingots

R. Thyagarajan, *Solid State Physics Laboratory, Delhi 110 054*

The prevalent technologies for the bulk synthesis and growth of GaAs single crystal ingots the world over will be surveyed. The most significant of these technologies will be discussed in the light of their inherent advantages and shortcomings. It follows that with the available technologies for the synthesis and growth of bulk GaAs, Liquid Encapsulated Czochralski Technique still enjoys an edge over other methods of growth. The activities at SSPL, Delhi, on the bulk synthesis and growth of single crystal ingots employing a variety of techniques will be recounted and the major results will be highlighted. A brief description of the activities at SSPL on the growth of Laser and electro-optic crystals will also be given.

Nanomaterials synthesis

D. Chakravorty, *Indian Association for the Cultivation of Science, Jadavpur, Calcutta 700 032*

Materials having particle sizes of the order of a few nanometers exhibit novel physical properties. Nanomaterials have attracted considerable attention in recent years. A number of techniques have been developed for preparing nanoparticles of a wide variety of materials—both metallic and inorganic. The most widely used method for making nanocrystalline metals is based on the evaporation of the metal concerned in an inert atmosphere. Inorganic materials can also be synthesized by replacing the inert gas with a reactive one. Various chemical methods have also been developed in recent years to prepare nanocrystalline/nanocomposite materials, the examples being sol-gel route, ion exchange followed by reduction of glasses and glass-ceramics, etc. An interesting possibility is the fractal growth of metal clusters within an inert matrix by an electrodeposition process. The paper will discuss the aspects of nanomaterials synthesis. Some of the physical properties of the synthesized materials will also be delineated.

The work carried out in the authors's laboratory on the design and fabrication of a low cost high pressure oxygen sputtering system with completely indigenous components for the Indian market, R & D carried out on the effect of various deposition parameters on the structure and properties of the superconducting films, the performance of the various devices fabricated will be highlighted.

Some novel approaches in ceramics fine powder processing

A. D. Damodaran, *Regional Research Laboratory, Thiruvananthapuram 695 019*

Continuing rigour in specifications and the entry of the new and futuristic materials have necessitated a fresh look into existing advanced techniques as well as into formulating altogether new ones wherever possible. Compositional purity and homogeneity, average particle size, distribution and shape determine the consolidation characteristics and sintered microstructure. Of late it is realised that particle agglomeration itself decides the extent of sinterability, subject to other factors remaining the same.

It is due to the above reasons that new studies and approaches are adopted to sol-gel and related advanced wet chemical methods themselves. Freeze-drying techniques are being tried out for complex oxidic systems. A new microwave synthesis technique has recently been introduced with great advantage. Vacuum-calcination techniques have enabled a new dimension in selected cases involving controlled decomposition of precursors.

The presentation will cover the essentials of the above mentioned aspects as applied to alumina, aluminium titanate, strontium titanate and high-T_c materials, in the context of the author's laboratory research work and related published literature.

In addition, a summary will also be presented that reviews the author's three decades long experience in the processing of special materials.

Some novel chemical reactions for hi-tech materials' preparation

P. Pramanik, *Department of Chemistry, Indian Institute of Technology, Kharagpur 721 302*

Novel chemical reactions have been developed for preparations of semiconductor grade mixed oxides of the types $A^{II}B_2{}^{III}O_4$ ($A = Cu^{2+}$, Ni^{2+}, Co^{2+}, Zn^{2+}, Cd^{2+}; $B = Fe^{3+}$, In^{3+}, Cr^{3+}) and superconducting cuprates. The reagents are trialkylammonium carbonates. Tertiary amines such as triethylamine or tri-*n*-propylamine or tri-*n*-butylamine are very appropriate. With carbon dioxide they form simple $(R_3NH^+)_2CO_3$, whereas the secondary or primary amine has a tendency to form organic carbamate which forms soluble complexes with many of the divalent metal ions, causing leaching of metal ions during filtration of precipitates of the metal carbonates. Tertiary amines and carbon dioxide can be easily purified to semiconductor grade reagents for their low boiling points.

To substitute carbon dioxide, an alternative route has also been developed using $(NH_4)HCO_3$. The compound can be easily purified by repeated sublimation. Ammonium bicarbonate with appropriate amount of trialkylamine and formaldehyde produces a reagent which is equivalent to trialkylammonium carbonate.

$$4(NH_4)HCO_3 + 8R_3N + 6CH_2O \longrightarrow$$

$$4(R_3NH)_2CO_3 + (CH_2)_6N_4 + 6H_2O$$

The appropriate mixture of metal salts with little excess of organic carbonate gives homogeneous precipitation of the mixed carbonate which, on calcination, gives ultrafine high-purity mixed oxide.

Another novel reaction has been investigated for the preparation of monolithic gels of silicates of multivalent metal ions by the sol-gel technique. It has been shown that formates of aluminium, zirconium and other divalent metal-ions form monolithic gels with tetraethylorthosilicate. This method does not involve any costly metal alkoxide.

An excellent method has been invented for deposition of commercially important electrochromic NiO thin film. The reaction is based on the electroless deposition of NiO using Ni-salt, ammonium persulphate, and ammonium hydroxide. The technique is useful for bulk production of smart-windows. The mechanism of deposition and the characterization of the material have been studied in detail.

Self-organization of dislocations and instabilities in plastic flow

G. Ananthakrishna, *Materials Research Centre, Indian Institute of Science, Bangalore 560 012*

We show that jerky flow is due to self-organized behaviour of dislocations. Starting from a statistical theory of dislocations we explain most of the results known on creep of simple materials such as LiF (ref. 1). The theory leads to a set of coupled equations for the mobile and immobile densities and hence a quantitative estimate of the mobile density[2]. We then include another type of dislocation and some additional transformations between them. For a range of physically relevant parameters, these equations support limit cycle oscillatory solutions, thus explaining steps on creep curves[3]. The model is extended to the case of constant strain rate by coupling these equations to the machine equation. It is then shown that the temporal oscillatory state is a result of Hopf bifurcation beyond a stability limit of the drive parameter, namely the strain rate[4]. The theory explains several generic features such as the negative strain rate behaviour of the flow stress, the existence of a window of strain rates, the dependence of critical strain or strain rate, the dependence of the amplitude of serration on strain, etc.[4] The theory also predicts period-doubling bifurcation[4]. This means that analysis of stress drops should exhibit fractal dimensions. Preliminary analysis of experimental data does show that this prediction is correct, further emphasizing that the mathematical mechanism suggested by the theory, namely that it is of dynamical origin, is correct. Directions for further study, including the spatial aspect of the problem, are outlined.

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Fatigue and fracture

S. Banerjee, *National Metallurgical Laboratory, Jamshedpur 831 007*

A large percentage of the failure of engineering components and critically loaded structures in service, occur due to fatigue and fracture. Therefore, one should attempt to understand, prevent and control fatigue and fracture. To accomplish this, a new approach for the analysis and testing of fatigue and fracture has emerged over the last 25 years. The new approach takes into account, quite appropriately, the effect of the presence of a crack on the fracture and fatigue of the material. This lecture would highlight some of the results obtained by the author and his colleagues in this problem area. These results mainly concern the evaluation of the effect of the size and geometry, so that one can then obtain the true resistance of a material to the growth of a crack in it. In addition to the result on metals and alloys, some of the latest results obtained by the author and his colleagues on the fracture and fatigue testing of ceramics would also be presented.

Analytical nondestructive evaluation for materials characterization

Baldev Raj, *Metallurgy and Materials Programme, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102*

The science and technology of nondestructive testing and evaluation has contributed immensely to the safety and productivity of industrial plants. In recent years, nondestructive evaluation (NDE) has emerged as a frontline research area of equal, if not greater, technological relevance for materials characterization as well. Materials characterization requires quantitative NDE. Quantitative NDE is essential for ensuring fitness for purpose at the start of the life and assessing degradation of material during service. Moreover, quantitative NDE enables characterization of the dynamics of certain phenomena, leading to better understanding of the performance of materials in relation to unavoidable defects in the materials. Advanced composites and structural ceramics are required to be made into components with defect levels in the range of tens of microns. Life estimation of old plants requires analytical NDE to precisely assess degradation in microstructures and influence of service defects. These realistic problems have very limited solutions at the present development level of NDE science and technology. This prime necessity is an impetus to the high pace of the interdisciplinary research and development efforts in NDE.

It is clear that for solutions to the problems outlined above, universal standards with artificial defects (as conventionally practised) are invalid and illusory. This observation is based on the fact that many individual factors can simultaneously influence the 'sensor' used to interrogate materials for assessing their microstructure and, morphological and mechanical property variations. Sophisticated interpretational methods are required to extract desired information from the signals, with respect to material properties or characteristics. Thus advanced signal analysis becomes mandatory for these situations.

Characterization of colloids, suspensions and bubbles in water, grain boundary segregation in steels, fatigue cracks in maraging steel weldments, porosities in aluminium weldments, lack of fusion in thin complex geometries, leaks and crack growth in pressurized heavy water reactors, defects in composites, etc., are some of the spectacular achievements made possible by the signal analysis approaches developed in the author's laboratory.

The above studies form the basis of specialized software packages leading to new standards and expert systems for specific applications. The developed packages contain algorithms for signal transformation and evaluation, signature analysis, feature extraction, pattern recognition and classification.

R&D in materials science and product development: from laboratory to production

C. G. Krishnadas Nair, *Hindustan Aeronautics Limited, Bangalore 560 017*

Success of R&D in process and product development is in the successful transfer of such technologies to production. Some of the criteria for successful transfer of technology from research laboratory to production are that R&D should be need-based, commercially attractive, involvement of the user industry in the R&D planning and continuous interaction between the laboratory and user/manufacturing industry at all stages of research through pilot plant to full-scale production. A mature, forward-looking industry should not be content with mere absorption of technology from R&D laboratory but must continue to interact with the laboratory and carry on further development and application.

A few case studies based on HAL's experience in taking research to production will be dealt with during the lecture. The development and productionizing of technology for master alloys, precision investment castings, high-strength aluminium alloy extrusions, high-temperature coatings for aeroengine components, metallo-ceramic brake pads for aircrafts and the fibre reinforced composites for aerospace applications are discussed. These pertain to cases of in-house R&D to in-house production, in-house R&D to external production and external R&D to in-house production.

Crystal growth for the present and for the future

P. Ramasamy, *Crystal Growth Centre, Anna University, Madras 600 025*

Human life would have lost its charm if it was deprived of the many facilities which it is currently enjoying, thanks to semiconductors, ferrites, garnets, diamonds, nonlinear materials, superconductors, solid state lasers, piezoelectric-, ultraviolet- and infrared-sensitive materials. All these advances are basically determined by the current research and development in crystal growth. Such crystals are pillars of modern technology. Crystals find such an important place in present day technology that there is practically no one frontline technology that does not have requirements of single crystal growth.

Crystal Growth Centre of Anna University has grown more than 120 crystals by melt, solution, flux, vapour and Verneuil growth techniques. The Centre has established a very active research group for crystal growth of III-V semiconductors, high-temperature superconducting single crystals, nonlinear materials, garnets, ferroelectrics, solid state lasers, urinary crystals and epitaxy.

The variation of interfacial tension with the size of the cluster has been established. Nucleation parameters such as the surface free energy, activation energy and critical size have been studied. The growth mechanism of crystal from vapour phase, in a chloride transport system has been studied. Lattice match of the substrate with the deposit was studied.

The nucleation theory for electrocrystallization has been developed. Computer-simulation studies have been made to investigate the voltammogram and the surface coverage during electrocrystallization. In the field of melt growth, extensive studies about the effect of convective motion have been carried out. Bulk GaAs and InP crystals have been grown in India, opening a new important door in the field of telecommunication, high-speed digital devices and optoelectronics. Crystal cutting and wafer polishing facilities are being developed.

The Centre is presently engaged in developing facilities for the growth of technologically important crystals such as BSO, BGO, sapphire, KTP, KTN, KDP, UREA, and nonlinear organic crystals.

Studies on Langmuir–Blodgett films

P. Ganguly, *Materials Chemistry Division, National Chemical Laboratory, Pune 411 008*

New experimental results on the spreading of Langmuir-monolayers at the air–water interface are presented. Such studies include the spreading of C_{60}, amines, etc. The deposition of Langmuir–Blodgett films from such monolayers is also reported. A new structural model which accounts better for the 'even–odd' intensity oscillation of the $00L$ diffraction peak is presented. Novel methods for deposition of trivalent metal ions as well as metal oxides, such as TiO_2, ZrO_2 in Langmuir–Blodgett films are presented. The importance of such films in the study of electron attenuation lengths in photoelectron spectroscopy is demonstrated.

Superconducting films — plasma processing techniques and characterization

S. Mohan, *Instrumentation and Services Unit, Indian Institute of Science, Bangalore 560 012*

Conventional deposition techniques fail to provide the required stoichiometry and structure in the as deposited superconducting films and have to be modified and improved. Among the various physical deposition techniques, plasma processing techniques have been found to be more suitable in preparing superconducting films with composition very much nearer to the bulk materials. However, even in this case, with the conventional low-pressure sputtering techniques with argon as the reactive medium the films prepared have still composition different from that of the starting material.

This paper gives a brief review of the conventional plasma deposition techniques, the problems associated with the negative ion sputtering and how these problems have been solved by the modifications incorporated in sputtering systems such as high-pressure oxygen sputtering and facing target sputtering techniques.

The presence of plasma in the other evaporation techniques, including molecular beam epitaxy, and its influence in producing as deposited superconducting films will also be discussed.

Design of coatings for gas turbine blades

R. Sivakumar, *Sree Chitra Tirunal Institute of Medical Sciences and Technology, Thiruvananthapuram 695 011*

The performance and the reliability of critical components such as gas turbine blades are dependent upon their ability to resist environmental attack such as oxidation and hot corrosion. This problem has been addressed over the years by forming protective coatings based on NiAl intermetallic compound, replaced later by the complex NiCoCrAlY-type compositions. The recent research effort is to thermally insulate the surface with partially stabilized ZrO_2 ceramic coatings. These coatings have been formed by different techniques such as pack cementation, electron beam evaporation and plasma spraying. The properties of the coatings are significantly influenced by the coating process.

This talk will address the rationale behind the selection of coatings and their limitations. The issues involved in optimizing the coating processes will be discussed based on the experience developed over the years at the Defence Metallurgical Research Laboratory, Hyderabad. The areas where further research effort is required will be highlighted.

A materials science approach to solid particle erosion

G. Sundararajan, *Defence Metallurgical Research Laboratory, Hyderabad 500 258*

Solid particle erosion implies material removal from component surfaces by repeated impact of hard, angular particles travelling at considerable velocities. Many of the components in thermal power plants, gas turbine engines of aircrafts, helicopters, coal gasification and liquefaction systems and slurry-carrying pipelines experience considerable erosion during service. Over the last 30 years, considerable data pertinent to the erosion behaviour of a variety of materials such as metals and alloys, ceramics, polymers, composites and coatings have been generated. However, the accent has largely been on the study of the influence of erosion variables like impact velocity and impact angle rather than the effect of microstructural and mechanical property-related variables on erosion. Thus, there is a clear need for obtaining structure–property correlations under erosion conditions.

The objective of the presentation will be to illustrate through specific examples, the influence of material-related properties on its erosion behaviour. Further, the influence of material variables on erosion will be rationalized on the basis of a material-based theoretical model.

Design of crystal structure-specific surfactants based on molecular recognition at mineral surfaces

Pradip, *Tata Research Development & Design Centre, Pune 411 001*

A variety of surface-active agents are employed in mineral-processing operations involving solid/solid, solid/liquid and liquid/liquid separation. These reagents range from common organic chemicals used for froth flotation (collectors and frothers), grinding aids, selective flocculants and dispersants, dewatering agents, filtering aids to solvent extractants and ion exchange resins used in effluent treatment and hydrometallurgical operations. Even though most of the conventional reagents currently being used in the industry were discovered through trial and error methods, it has become necessary now, due to the complexity of benefaction problems, to develop highly selective, almost tailor-made reagents for mineral separation. A theoretical framework that can provide practising engineers a scientific and rational basis for the choice of reagents for a particular separation problem at hand is lacking at present.

The main distinguishing feature of mineral processing reagents is their efficiency in achieving selective separation. The trend in recent years has been to design reagents based on metal ion chelation chemistry, that is, to select functional groups which are specific to the metal ion present on the mineral surface. The problem with this approach is that the reagents for separation amongst minerals having the same constituent metal ion, for example, sparingly soluble calcium minerals, namely calcite/flourite/apatite/dolomite cannot be designed on this basis.

Thus, the development of novel reagents possessing not only ion specificity (specific to the crystal structure) is vital for the present day needs of exploiting lower grade, more complex and disseminated ore deposits. Some of the salient features of this emerging science of reagent design will be illustrated in this presentation with appropriate examples drawn from the author's own work as well as from the work of those currently active in this field. It is an interdisciplinary area of research requiring inputs from coordination chemists, organic chemists, polymer chemists, applied surface and colloid chemists and mineral engineers.

It is to be emphasized that scientific principles as well as the underlying surface chemistry governing selectivity in mineral separation systems are similar to several other disciplines such as, for example, the design of tailored macromolecules with high degree of surface specificity to provide control over crystal growth. With the help of properly designed surfactants one can not only control the morphology of growing crystals but can even inhibit crystal growth completely by blocking growth sites, particularly on the fastest growing surfaces. One obvious application of this knowledge is in the area of preventing scale formation in pipelines, water treatment and other corrosion-prone industrial systems.

Optical composites

S. R. Rajagopalan, *Materials Science Division, National Aeronautical Laboratory, Bangalore 560 017*

Composites of metallic particles in a dielectric matrix exhibit interesting optical properties, if the particle sizes of the constituents are less then 100 nm. These are called optical composites. They conduct electricity like metals and show low reflectivity like dielectric materials. They can be prepared by deposition techniques such as physical vapour deposition and electrodeposition.

Electrolytically deposited optical composites find application as solar selective coatings and for imparting coloured finishes. Black chromium coating is an example of the former application and electrolytically coloured aluminium is an example of the latter application.

It is shown here that the properties of black chromium can be understood by treating it as a composite of chromium metal and Cr_2O_3. The colours of electrolytically coloured aluminium are explained on the basis of an optical composite of Al_2O_3 + metal particles + air.

Smart composites

N. Balasubramanian, *Eternit Everest Ltd., R & D Centre, Bangalore 560 058*

Materials and structures which contain distributed sensors, actuators, electronic signal processing and adaptive control systems are termed "SMART". They can be used in many applications requiring a high degree of adaptability to changing external and internal conditions. This paper discusses smart composites such as

(1) Hollow graphite epoxy beam filled with an electrorheological (ER) fluid: changes in the electrical field imposed on the ER fluid can alter the rheological characteristics of the fluids and hence the mass, stiffness and dissipative characteristics of the composite structures.
(2) Composites with shape memory alloy (SMA) fibers as reinforcement and actuator.
(3) Composites with piezoelectric (PE) devices embedded for control of vibration.

The proposed models for the calculation of the elastic properties of the composites with embedded SMA will be discussed.

The use of strain actuators (SMA, PE, electrostrictive, magnetostrictive) in a composite can control damage. In the vicinity of a propagating crack, the activation of the embedded actuator will change the stress distribution at the crack tip, resulting in a reduction of the stress intensity factor. The applications of smart composites include:

a) Active vibration control and acoustic suppression for submarines, robot manipulators, propeller aircraft, large flexible structures, etc.
b) Failure detection/prevention of structures (i.e. bridges, walkways, phone and electrical cables and mechanical components)
c) Active control of helicopter rotor blades
d) Thermal expansion balancing
e) Robot manipulators (fingers)
f) Thermally activated valves, ducts and switches
g) Structural dimension adjustment and environment adaptation for antennas.

The role of microstructure and processing parameters on the properties of Al-matrix composites

Y. R. Mahajan, *Defence Metallurgical Research Laboratory, Hyderabad 500 258*

Aluminium metal-matrix composites (MMCs) containing particulate reinforcements have merged as an important class of high-performance materials for structural and non-structural applications. Defence Metallurgical Research Laboratory (DMRL) is actively engaged in the development of these composites produced via powder metallurgy route. An attempt will be made to present various aspects pertaining to processing techniques, interfacial effects on physical properties and strength, tensile ductility and toughness, and engineering applications of the MMCs. In particular, this presentation will address the issues under study at DMRL.

Sensors: materials and mechanisms

K. T. Jacob, *Department of Metallurgy, Indian Institute of Science, Bangalore 560 012*

Recent progress in the theory, design and application of solid-state sensors for high-temperature application will be reviewed. The theory of non-isothermal sensors and the design criterion for temperature compensated reference electrodes will be presented. The non-isothermal sensors can be used for continuous monitoring of concentration or chemical potential in corrosive melts. In the "feeder design", a rod of the solid electrolyte is continuously lowered into the melt at a rate commensurate with the dissolution or reaction of the electrolyte with the corrosive medium. Bielectrolyte combinations permit the extension of the range of applicability of solid electrolytes. The role of homo- and heterojunctions is explored. Auxiliary electrodes permit sensing of species different from the mobile ion in the solid electrolyte. Examples include the use of β-alumina and Nasicon in sensors for SO_x and Co_x and the use of oxide solid electrolytes for measuring the concentration of Si in steel or hot metal. Hafnia-based solid electrolytes and zirconates of alkaline earth elements have been found to have lower oxygen-potential boundary for electronic conduction than zirconia solid electrolytes at steel-making temperatures. It is now possible to design multielement sensors for some pyrometallurgical processes. Amperometric devices are superior to potentiometric gauges for measuring small variations in concentration.

Studies on fuel-clad chemical interactions in the FBTR

S. P. Garg, *Metallurgy Division, Bhabha Atomic Research Centre, Bombay 400 085*

Plutonium-rich mixed carbide as the fuel and SS-316 L as the clad have been selected for the Fast Breeder Test Reactor (FBTR) at Kalpakkam. The mixed carbide fuel, produced by carbo thermic reduction of mixed U/Pu oxide, contains residual oxygen in the range of 5000 to 7000 ppm and 5 to 15% sesquicarbide with typical overall composition of $U_{0.3}Pu_{0.7}C_{1.0}O_{0.1}N_{0.01}$. The carburization of the SS clad has been identified as the main chemical interaction for such a hyperstoichiometric carbide fuel. Two main controlling factors for the rate and extent of carburization of the clad are (i) carbon potentials in the clad and in the fuel and (ii) partial pressure of $CO_{(g)}$ over the fuel. The gradient of carbon potential acts as the driving force and $CO_{(g)}$ as the carrier. The prevailing temperature gradient in the fuel pin, melting temperature of the fuel, residual hydrogen in the fuel and the cover gas pressure also play important roles in the carburization process.

Most of these thermophysical properties of the FBTR fuel and clad were not available and have been determined for the first time at BARC. These include determination of i) carbon potential in the fuel, ii) carbon potential in SS 316, iii) partial pressure of $CO_{(g)}$ over the fuel, iv) direct solid–solid reaction between the fuel and the clad, and v) peritectic melting temperature of the fuel.

In this paper a summary of the above investigation shall be presented. The presentation concludes with a thermodynamic analysis of fuel-clad compatibility in the FBTR based on the experimental, theoretical and reported data on the present high plutonium and the conventional U-25% Pu-mixed carbide fuels.