MEETING REPORT

Nanoceramics and nanocomposites*

Nanoceramics/nanocomposite are defined as novel bulk materials or coating with microstructural architecture, characterized by at least one of the ceramic phases having length scale between 1 and 100 nm. The major drive for wider interest in nanoceramics and its composites has been the fact that one can potentially achieve better and some unusual material properties by manipulating length scale in the nano range. Therefore, better performance and newer application of the materials, for example, durable bone replacement materials using polymer–ceramic nanobiocomposite have now been made possible.

In the above backdrop, the workshop on nanoceramics and nanocomposites was organized. It was part of the wider activities of IIT Kanpur in the area of nanoscience and nanotechnology. Close to 100 delegates, from Japan, USA, South Korea and various Indian institutions attended the workshop.

The objectives of the workshop were to organize and review the progress and also to identify some of the important scientific issues related to nanoceramics and nanocomposites. There were three plenary sessions and six technical sessions. Different aspects of research related to production of nanoceramics and nanocomposites, properties of such novel materials, including creep and superplasticity properties, dielectric and ferroelectric properties, nanostructured hard coatings, metallic nanocomposites, biomimetics and tissue engineering, and nanofluids were discussed by 20 invited speakers.

In the first plenary session, Koichi Niihara (Nagaoka University of Technology, Japan) reviewed the area of multifunction integrated nanocomposite materials, which are being developed in various ceramic systems in an effort to significantly improve mechanical and thermal properties of structural ceramics. He also suggested that the nanocomposite structure has strong potential to develop various kinds of multifunctional materials for the energy and environment sectors. His talk elaborated on the development of new multifunctional ceramic materials with improved strength and toughness, together with new functions. One important example was a polymer-based nanocomposite with a new sensing function, like the human finger tip, which has already been industrialized as a special sensor of the intelligent robot. A significant part of Niihara's lecture dealt with the development of 'intermaterials', a special class of multifunctional materials containing inorganic, organic and metal materials, incorporated in the nano, molecular and atom level. New design concepts on molecular/cluster/lattice-level composites, their related results and future aspects of research were presented.

Rajendra Bordia (University of Washington, Seattle, USA) spoke on 'Polymer-derived nanostructured ceramics structured ceramics'. He discussed the processing of nanostructured composite coatings, use of polymer-derived ceramics to join ceramics and processing of controlled porosity ceramics (e.g. *in situ* carbon nanotubes in ceramic matrix). Bordia commented that this approach has the feasibility to form high-performance ceramics at low processing temperatures (<1200°C).

The second lecture was by H. Suematsu (Nagaoka University of Technology, Japan) on 'New processing development for metal and ceramic nanopowders'. He elaborated upon various preparation methods for the production of metal and oxide nanopowders, with particular focus on the novel pulsed wire discharge (PWD) method. The adaptability of PWD process for large-scale production in the industrial environment was also mentioned. Suematsu mentioned that PWD, a highly energy-efficient method, has the capability to produce passivated metal nanopowders, which can be used as conducting paste for electromagnetic radiation shields and in electric circuit boards.

N. K. Mukhopadhyay (Institute of Technology, BHU, Varanasi) elucidated on the 'Synthesis of nanocrystalline (Co,Ni) Al_2O_4 spinel powder from quasicrystalline materials by mechanical milling'. The results of a recent study to synthesize the nano-crystalline (Co,Ni)Al_2O_4 spinel powder by ball milling and subsequent annealing were presented. Mukhopadhyay discussed how significant enhancement in the magnetic properties of nanospinels compared to that of nano-decagonal phase could be attributed to the spinel structures. The weak ferromagnetic phase, exhibiting close to superparamagnetic behaviour was established for the first time in the nano-quasicrystalline phase.

Hai-Doo Kim (Korea Institute of Materials Science, Korea) delivered the first talk on 'Two-step sintering to produce nanocrystalline bulk silicon nitride ceramics'. He presented the recent results related to enhancement in the densification with minimum grain growth for silicon nitride ceramics with liquid phase. Some preliminary results on how to reduce the amount of liquid phase to sinter nano silicon nitride ceramics were also presented.

Parag Bhargava (IIT, Bombay) spoke on 'Production of nano YSZ powders and their consolidation through slip casting'. Different steps such as nanopowder synthesis, characterization, slurry preparation, rheological characterization of the slurry, consolidation of the slurry followed by sintering of the consolidated nanopowders were detailed in his presentation.

H. Tsuda's (Osaka Prefecture University, Japan) talk was on 'Precipitation of Ti in TiC particles of Ti matrix composites from Ti–C–N powder mixtures using reactive arc-melting'. Using the results of detailed analysis of transmission electron microscopy observations, the effects of the nitrogen content on the microstructures of TiC particles and Ti matrix were discussed.

Atul H. Chokshi (Indian Institute of Science (IISc), Bangalore) gave a talk on 'High-temperature creep and superplasticity in oxide ceramics'. His lecture focused on the fundamental aspects of creep and superplasticity in oxide ceramics, such as alumina and zirconia. The results of the sinter forging experiments to demonstrate the creep and superplasticity in nonmetallic solids were presented

*A report on the International Workshop on Nanoceramics and Nanocomposites held at the Indian Institute of Technology, Kanpur on 8 and 9 September 2007. The workshop was jointly organized by the Department of Materials and Metallurgical Engineering and the DST Unit on Nanosciences at IIT Kanpur.

with reference to current understanding of such phenomena in metals.

Takashi Goto (Tohoku University, Japan) delivered a lecture on 'Nanostructured thick oxide coating by laser CVD', wherein he discussed a new laser-based chemical vapour deposition (LCVD) technique, that could achieve 100–1000 times higher deposition rates than that of conventional CVD for wide-area coatings. He commented that the LCVD process can be useful to obtain various kinds of oxide coatings by changing the precursor source materials. This new technique for thick oxide coatings is applicable for a wide range of engineering coatings.

Ashok K. Ganguli (IIT, Delhi) presented his work on 'A novel oscillatory behaviour of the dielectric properties as a function of nano-additive in sintered compacts of nano and micron sized particles of titanates, zirconates, niobates and tantalates'. Oscillatory variation of the dielectric constant, dielectric loss with increase in the amount of nanoparticles in nanocomposites of titanates ($SrTiO_3$, $BaTiO_3$ and $PbTiO_3$) and variation in the dielectric constant at T_c to reflect the behaviour of the ferroelectric transition were also presented.

The first day of the workshop ended with a panel discussion on 'Future perspectives on the development of nanomaterials', wherein the need for a product-oriented research programme was expressed and also that India should focus more on developing technologies to fabricate nanoceramics/nanocomposite-based products.

In the second plenary session on the second day, the plenary lecture was delivered by Arup K. Raychaudhuri (S. N. Bose National Centre for Basic Sciences, Kolkata) on 'Growth of anisotropic composites in nanoporous alumina using electrochemical deposition'. Using the results of some novel experiments from his research, Raychaudhuri illustrated how the filling up of pores can be carried out using metal (and also semiconductor) nanowires and nanotubes by electrochemical growth method with rotating electric field. He also demonstrated how such an approach can lead to the development of the composites with novel properties, that utilize long aspect ratio of the nanowires and nanotubes.

Arvind Sinha (National Metallurgical Laboratory, Jamsehdpur) gave a talk on 'Biomimetic nanocomposites for tissue engineering'. He discussed the successful exploitation of molecular cavities present in globular proteins to carry out *in situ* synthesis of magnetic and bioceramic nanoparticles. He commented that such nanoparticles could be further transformed into aqueous ferrofluids and microporous hydroxyapatite granules for different biomedical applications.

Panchanan Pramanik (IIT, Kharagpur) gave a talk on 'Preparation and characterization of hydroxyapatite/polymer nanocomposite for bone implant applications'. He discussed the synthesis of nanocomposite between nanosized hydroxyapatite and various polymers, having functional groups like –OH, $–NH_2$, –COOH. The dramatic improvements in mechanical properties of all the composites with increase in the amount of HAp particles up to optimum level were also discussed with reference to their potential application for bone-implants.

The last lecture on 'Nanoceramic approaches to antibiotic therapy for bone infections' by T. S. Sampath Kumar (IIT, Madras) highlighted the need for processing of nanocrystalline bioactive calcium phosphate ceramics for antibiotic delivery. The emphasis was on the silver-substituted hydroxyapatite with incorporated bactericidal effects as a new class of nanomaterials, especially as a construct for tissue-engineering applications.

Indranil Manna (IIT, Kharagpur) spoke on 'Nano-dispersed solid alloys and thermal fluids'. He touched upon some of the issues related to nanoscale dispersion phenomena in amorphous solids (structural application) and liquids (thermal engineering). The role of kinetic and thermodynamic factors in determining the final microstructure comprising nano-intermetallic and amorphous phases was then discussed.

A. K. Suri (BARC, Mumbai) spoke on 'Nanoceramics'. He introduced the effect of pressure on green density and pore-size distribution in the compact as well as on the shrinkage during sintering. He also elucidated upon the rate of heating and the importance of dispersibility of the nanoceramic powder on the densification of nanoceramics powders with special reference to zirconia–yttria system.

In the third plenary session, H. S. Maiti (Central Glass and Ceramic Research Institute, Kolkata) delivered a plenary lecture entitled 'Nanostructured ceramics for fuel cell and battery applications'. He spoke about various state-of-the-art materials for solid oxide fuel cells (SOFC) and emphasized that the major drive for the use of such nanostructured ceramic is to enable the operation of SOFC in the temperature range 500–650°C. It was shown that the doping of nanosized Ag in $LiCoO_2$ cathode increases the electrical conductivity by 2–3 orders of magnitude with reference to undoped materials. The synthesis of nanocrystalline $Li_4Ti_5O_{12}$ using an aqueous combustion process with alanine fuel was discussed.

In the last technical session, the invited talk entitled 'Mechanical properties of hard coatings: Monolayers, multi-layers and nanostructures' was presented by Vikram Jayaram (IISc). Initially, Jayaram described the fundamental theory related to the application of contact deformation and fracture in hard coatings. The experimental results obtained using a combination of depth-sensing indentation and focused ion beam were also presented.

Suman K. Mishra (National Metallurgical Laboratory, Jamshedpur) delivered a lecture on 'Nano and fine hard ceramic composites and coatings by SHS and PVD processes'. In her presentation, the novel processing routes, such as self-propagating high temperature synthesis and sputtering process were discussed with reference to *in situ* synthesis of the nano, fine composites and nanocomposite coatings. The talk focused on fabrication of hard boride–alumina dense bulk ceramic composite by SHS process and nanocomposite hard coatings of silicon carbonitride (Si–C–N) and titanium diborides systems by magnetron sputtering. She also presented results in developing ZrO_2–ZrB_2 composites using SHS-processed ZrB_2 powders and sinter-HIP route.

The concluding session discussed how such meetings will facilitate the cross-fertilization of ideas in the emerging area of nanoceramics and nanocomposites.

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