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E-MRS Spring Meeting 2004
May 24-28, 2004

SYMPOSIUM R

Nano-composites for space and infrastructure
applications

Symposium Organizers:

Kin-tak Lau, The Hong Kong Polytechnical University, China

Andrew D. Nurse, Loughborough University, U.K.

Stan Veprek, Technical University of Munich, Germany

Tibor Cselle, PLATIT AG, Switzerland

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E-MRS 2004 SPRING MEETING

SYMPOSIUM R

Tuesday, May 25, 2004

Morning

Session I: Nanotube/polymer composites

Session chairs: Kin-tak Lau and Stan Veprek

- R-I.1** 08:30 -Invited- NANOCOMPOSITE AND NANOSTRUCTURED TRIBOLOGICAL MATERIALS FOR SPACE APPLICATIONS
A.A. Voevodin and J.S. Zabinski, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson Air Force Base OH 45433-7750, USA
Satellites and space-born systems have a number of moveable parts, where reliability is severely limited by degradation of lubricants and excessive wear. Many systems may be in space for 10-30 years and, therefore, exposed to atomic oxygen, solar radiation, energetic particles, and temperature cycling from cryogenic to 400 K. Furthermore, systems are frequently tested on the ground and stored for many years under controlled environments before launching. Also, reusable launch vehicles are planned that will operate with space ambient cycling and with temperature spikes in excess of 800 K during reentry. A chameleon tribological coating concept was developed to address this challenge. This approach relies on the coating to change its surface (both chemistry and structure) to self-adjust to the environment and achieve long durability. The first chameleon coatings were made of WC, WS₂, and DLC; they provided superior mechanical toughness and performance in space/ambient environmental cycling. In order to address temperature variation, the second generation of chameleon coatings were made of yttria stabilized zirconia (YSZ) in a gold matrix with encapsulated nano-sized reservoirs of MoS₂ and DLC. Encapsulation of MoS₂ nanoparticles into Al₂O₃ matrix and a high temperature lubrication with low melting point glassy ceramic phases were also explored. Chameleon coatings with various chemistries are discussed along with their characterization by various analytical, mechanical, and tribological methods. Coating toughness was remarkably enhanced by a grain boundary sliding mechanism. Unique friction and wear performance was demonstrated by testing in controlled humidity air, dry nitrogen, vacuum, 500-600 K air, and in environmental cycling.
- R-I.2** 09:00 POLYIMIDE/CARBON NANOTUBE COMPOSITE FILMS FOR SPACE APPLICATIONS
Donovan M. DeLozier, Kent A. Watson, Joseph G. Smith Jr. and John W. Connell, National Aeronautics and Space Administration, Langley Research Center, Hampton VA 23681-2199, USA
Low color, space environmentally durable polymeric films with sufficient electrical conductivity to mitigate electrostatic charge (ESC) build-up have been under investigation as part of a materials development activity. These materials have potential applications as thin film membranes on antennas, solar sails, large lightweight space optics, second-surface mirrors, thermal/optical coatings and multi-layer insulation blankets on large, deployable, ultra-light weight Gossamer spacecraft. The challenge has been to develop a method to impart robust electrical conductivity into these materials without decreasing optical transparency or film flexibility. Since these spacecraft will require significant compaction prior to launch, the film portion of the spacecraft will require folding. The state-of-the-art clear, conductive coating (e.g. indium-tin-oxide) is brittle and cannot tolerate folding. The approach taken to impart sufficient electrical conductivity into the polymer film without detracting from optical properties or film flexibility is based on the use of single walled carbon nanotubes (SWNT) as conductive additives. Two methods investigated in our laboratory have involved bulk inclusion of SWNTs in the polymer through the use of reactive endgroups and as a coating of SWNTs on thin film surfaces. Both methods provided materials with surface conductivities (measured as surface resistance) in the range sufficient for ESC mitigation. This was achieved with minimal effects on the mechanical, optical, and thermo-optical, properties of the film by the coating method as compared to dispersal on SWNTs in the matrix. The chemistry and physical properties of these nanocomposites will be discussed.
- R-I.3** 09:20 A STUDY ON NI/P/CARBON NANOTUBES NANOCOMPOSITE COATINGS AND THEIR PROPERTIES
Hu-Lin Li, Zhi Yang, Hui Xu, Yan-Li Shi, Mei Lu, Department of Chemistry, Lanzhou University, Lanzhou 730000, China
Two principally different techniques for electrochemical deposition of Ni functional composite coatings with highly specific properties, such as wear resistance and corrosion resistance are possible: electroless plating and electroplating. Ni/P/carbon nanotubes(CNTs) composite coatings were fabricated successfully from a suspension of CNTs in bath. Composition, microstructure, surface morphology, mechanical properties, electrochemical and tribological behaviour of electroless and electroplated Ni/P/CNTs composite coatings were studied using X-ray diffraction (XRD), scanning electron microscope-X-ray energy dispersive spectroscopy (SEM-EDS), atomic force microscope (AFM), microhardness measurements, polarization curves and electrochemical impedance spectroscopy, wear volume and friction coefficient measurements.
Comparing with Ni/P coatings, electroless Ni/P/CNTs composite coatings showed not only high wear resistance but also low friction coefficient. The amorphous Ni/P/CNTs composite coatings provided higher corrosion resistance than the amorphous Ni/P coatings. The incorporation of CNTs in composite coatings is advantageous of forming better passive film. Ni/P/CNTs performed the higher catalytic activity than the Ni/P coatings, which is tightly related to their structures dissolved by hydrogen when prepared.

R-I.4 09:40 ELECTROMECHANICAL CONSTITUTIVE EQUATIONS OF CARBON NANOTUBE ACTUATORS FILLED WITH CONDUCTIVE POLYMER

Cheol Kim and J.T. Kim, Department of Mechanical Engineering, Kyungpook National University, Korea

An improved electromechanical constitutive equation for an actuator composed of single-walled carbon nanotubes sheets is developed in this paper to predict the straining characteristics of the actuator. Properties used in the equation include nanotube fraction, electrical constant, effective radius, density, principal Young's modulus, and specific Young's modulus. Relationships between weight fraction and volume fraction of single-walled carbon nanotubes and their hexagonal arrays are developed for the polymer/nanotubes mixtures. Some numerical examples of actuating strains are presented for various values of fractions and nanotube arrays.

Electromechanical actuators consisting of single-walled carbon nanotubes were shown to generate higher stresses than natural muscles and higher strains than high-modulus ferroelectrics. Like natural muscle, the macroscopic actuators are assemblies of billions of individual nanoscale actuators. Unlike conventional ferroelectric actuators, low operating voltages of a few volts generate large actuator strains. Numerical predictions suggest that actuators using optimized nanotube sheets may provide substantially higher work densities than any previously known technology. There is experimental evidence that carbon nanotubes can be dramatically bent and buckled many times without damaging the crystalline structure. Atomistic simulations have proven to be an effective approach for understanding the electromechanics of carbon nanotubes. In this paper, we use the molecular structural mechanics approach to estimate the electromechanical behaviors and the tensile strength of nanotubes. In this approach, a simple linkage between computational structural mechanics and computational electromechanics was established.

R-I.5 10:00 PROCESSING OF CARBON NANOTUBE REINFORCED SILICON NITRIDE COMPOSITES BY SPARK PLASMA SINTERING

Cs. Balázs(a), Z. Shen(b), Z. Kónya(c), Zs. Kasztovszky(d), F. Wéber(a), Z. Vértesy(e), L.P. Biró(f), I. Kiricsi(c), P. Arat(a), (a)Ceramics and Refractory Metals Laboratory, Research Institute for Technical Physics and Materials Science, Budapest, Hungary, (b)Stockholm University, Arrhenius Laboratory, Department of Inorganic Chemistry, 10691 Stockholm, Sweden, (c)Department of Applied and Environmental Chemistry, University of Szeged, Rerrich Béla tér 1, 6720 Szeged, Hungary, (d)Department of Nuclear Research, Institute of Isotope and Surface Chemistry, Chemical Research Center, Budapest, Hungary, (e)Magneto-optics and Diagnostics Laboratory, Research Institute for Technical Physics and Materials Science, Budapest, Hungary, (f)Laboratory for Nanostructures Research, Research Institute for Technical Physics and Materials Science, Budapest, Hungary

This study is focusing on exploring new preparing processes to tailor the microstructure of carbon nanotube (CNT) reinforced silicon nitride-based ceramic composites. Because CNTs present exceptional mechanical, thermal and electrical properties, it is expected that the addition of CNTs will radically improve the quality of ceramic matrix composites. So far, only modest improvements of properties were reported in CNT reinforced silicon carbide and silicon nitride matrix composites, whereas a noticeable increase of the fracture toughness has been achieved in CNT reinforced alumina matrix composites. In order to get the full use of the benefits provided by CNTs it is crucial to retain CNT un-attacked in the composites and to optimize the interfacial bonding between CNT and matrix. By conventional sintering techniques, which are characterized by the requirement of extended holding at very high temperatures, the destruction of CNT has been reported. In the present work we examined the validity of a novel technique, namely Spark Plasma Sintering (SPS), in consolidating and tailoring the microstructure of multiwall carbon nanotube (MWNT) reinforced silicon nitride-based ceramic composites. SPS makes it possible to prepare fully densified composites at comparatively lower temperature with substantial short holding. It also provides a means of precious modification of the kinetics of densification, reactions and grain growth that involved in an entire sintering cycle. For sake of comparison the hot isostatic pressing (HIP) was also used for composite elaboration. Morphological and structural observations, as well as mechanical properties characterization revealed considerable differences among composites prepared by these two techniques.

10:20

BREAK

Session II: Nanotube/polymer composites

Session chairs: Andrew D. Nurse and Kin Liao

R-II.1 11:00 -Invited- GLASS TRANSITION BEHAVIOUR OF SILICA/POLYSTYRENE NANOCOMPOSITES

Amitabh Bansal, Hoichang Yang, Chang Y. Ryu, Linda Schadler, Dept. of Materials Science and Engineering, Rensselaer Nanotechnology Center, Dept. of Chemistry, Rensselaer Polytechnic Institute, USA

The effect of adding silica nanoparticles on the glass transition (T_g) behavior of monodisperse polystyrene (PS) was investigated. It was found that the T_g decreases monotonically with filler. The T_g is found to reduce at a faster rate below a measured spacing of $3R_{EE}$ (R_{EE} is the statistical end-to-end distance of polymer chains) and is qualitatively similar to data on thin films of PS. The depression in T_g is hypothesized to be due to increased mobility of polymer chains in the vicinity of the nanoparticle surfaces. The ligaments between nanoparticles can be visualized as thin films and the depression in T_g can be described by an empirical model that shows that the SiO₂/PS interface is less mobile than a PS free surface. Assuming a diffuse interphase with a thickness comparable to the R_{EE} of the polymer chains, the interface T_g was calculated to be 360 K (depressed ~ 19 K below that of the bulk value). Dynamic mechanical analysis results showing a broader loss modulus peak supports this hypothesis.

- R-II.2** 11:30 **CHEMICAL BONDING BEHAVIOUR OF SWNTS-ECPS COMPOSITES**
Hu-Lin Li, Zhe Wang, Bo Wang, College of Chemical and Engineering, Lanzhou University, Lanzhou 730000. China, Lanzhou institute of Chemical physics, Academic institute of Science, 730000 Lanzhou, China
 This paper reports the latest research on the chemical bonding behavior between the single-walled carbon nanotubes (SWNTs) and the chains of electronically conducting polymers (ECPs). The SWNT-filled polyaniline (SWNTs-PANI) and polypyrrole (SWNT-PPY) composites prepared by in-situ polymerization process exhibit many particular physical properties, i.e. uniform black coloration, high solubility in chloroform and dimethyl formamide (DMF), and semiconductivity to ohmic electrical behavior. XPS results for both hybrid materials indicate that the N + in quinoid ring of PANI, serving as conjugation channel? plays a significant role during the formation of the conjugated system. The electrons are transmitted through these channels?from quinoid rings unit of polyaniline to the carbon nanotubes. However, the curve fitting of XPS C (1s) core-level spectra proves the physical doping of PPY with the carbon nanotubes in SWNTs-PPY composites. Four-probe conductivity data reveal that the enhanced effect of conductivity caused by SWNTs on PANI is more obvious than that on PPY due to electrons exchange in the way of conjugation between the quinoid of polyaniline and carbon nanotubes. This new network connected by SWNTs probably acts as a new conductive system and leads to a higher conductivity.
- R-II.3** 11:50 **SINGLE-WALLED CARBON NANOTUBE / POLYMER COMPOSITES: RHEOLOGY AND THERMAL PROPERTIES**
Karen I. Winey, Fangming Du, Jennifer R. Lukes, John E. Fischer, University of Pennsylvania, Philadelphia, USA
 Single-walled carbon nanotube (SWNT) / thermoplastic nanocomposites were prepared via a coagulation method that provides uniform distribution of the nanotubes in the polymer matrix, as quantitatively characterized by Raman imaging. The rheology of these nanocomposites was investigated using linear viscoelastic measurement in oscillatory shear with a strain amplitude of 0.5% at 200Hz. At low frequencies, G' becomes almost independent on the frequency as nanotube loading increases, suggestive of the onset of solid-like behavior. By plotting G' versus nanotube loading and fitting with a power law function, the rheological threshold of SWNT/PMMA nanocomposites is 0.18wt%, which is comparable to the percolation threshold of electrical conductivity, 0.39wt%, indicating the presence of a nanotube network. The onset of solid-like behavior at low SWNT concentrations might limit the polymer processing methods that are viable for SWNT/thermoplastic nanocomposites. The effects of alignment and dispersion of the nanotubes and the molecular weight of polymer matrix on the rheological behavior of the nanocomposites are also interpreted in terms of nanotube interactions. The thermal conductivities of SWNT/thermoplastic and SWNT/thermoset nanocomposites were measured via a comparator method as a function of SWNT concentration and length.
- R-II.4** 12:10 **FATIGUE FAILURE MECHANISMS OF SINGLE-WALLED CARBON NANOTUBE ROPES**
 Y. Ren(a), T. Xiao(b), Y.Q. Fu(a), F. Li(c), H. M. Cheng(c) and K. Liao(a), (a)School of Mechanical and Production Engineering, (b)School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore 639798, (c)Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, China
 The extraordinary mechanical properties of carbon nanotubes (CNTs) render it an ideal class of super strong reinforcement for high-performance composite materials. Numerous studies concerning the mechanical behavior of CNT and CNT-reinforced composites, such as its elastic properties, tensile strength, interfacial strength between CNT and polymer matrix, as well as load transfer mechanisms, have been reported in recent years. Despite these tremendous efforts, however, the long-term behavior of CNTs has been receiving less attention. The fatigue behavior of unidirectional, aligned single-walled nanotube (SWNT) rope reinforced epoxy composite under tension was presented, for the first time, in our previous reports [1,2]. In this work, fatigue failure mechanisms of single-walled carbon nanotube (SWNT) bundles embedded in epoxy matrix under tensile load were studied. Observed damage and failure modes of SWNT bundles include: 1) splitting of SWNT bundles, 2) kink formation and subsequent failure, and 3) fracture of SWNT bundles. Patterns of crack propagation under tension in a SWNT were studied by molecular mechanics simulations, where defect-free SWNTs and SWNTs with two different modes of Stone-Wales defects were studied. It is demonstrated by the results of molecular simulation that the observed fracture surfaces of SWNT can be reproduced reasonably well, suggesting possible fatigue failure mechanisms of SWNT in the composite. A life prediction scheme for CNT fatigue based and molecular simulation and kinetic fracture concept will also be presented.
 [1] Y. Ren, F. Li, H. M. Cheng, and K. Liao, Advan. Comp. Lett. 12,19 (2003).
 [2] Y. Ren, F. Li, H. M. Cheng, and K. Liao, Carbon, 41, 2159 (2003).
- R-II.5** 12:30 **EFFECT OF SOLVENT SELECTION FOR CARBON NANOTUBES DISPERSION ON THE MECHANICAL PROPERTIES OF EPOXY-BASED NANOCOMPOSITES**
Mei Lu, Kin-tak Lau, Hang-yin Ling and Hu-Lin Li, Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
 Carbon nanotube (CNT) dispersed with various solvents were incorporated into epoxy matrix and the mechanical properties of the resulting composites were studied. The results indicated that the solvent selection had a significant influence on the Vicker's hardness and the flexural strength of the cure reaction. The change trend of the mechanical properties was found to be related to the boiling point of respective solvent used. Further evidence of this influence was obtained by fourier transform infrared (FTIR) spectra, which displayed the difference in the molecular structure of the final composites depending on the solvent used.
- 12:50 **LUNCH**

Tuesday, May 25, 2004

Afternoon

Session III: Synthesis and characterization of nano-materials

Session chairs: Jorg Patscheider and Stan Veprek

- R-III.1** 14:00 -Invited- **SUCCESS OF NANOSTRUCTURED COATINGS PREPARED BY NOVEL ARC TECHNOLOGY**
Pavel Holubar, SHM, s.r.o., Czech Republic, Tibor Cselle, PLATIT AG, Switzerland, Mojmir Jilek, SHM, s.r.o., Czech Republic, Marcus Morstein, PLATIT AG, Switzerland
The development of novel superhard nanocomposite, nano-layered coatings and of a coating technology based on vacuum arc evaporation from rotating electrodes is summarized. The nc-(Al_{1-x}Ti_x)N/a-Si₃N₄ coatings in which the nanocrystals of the Al-rich solid solution with the fcc crystal structure of TiN are imbedded into a thin matrix of amorphous silicon nitride show high thermal stability, oxidation resistance and excellent performance in dry and fast machining that is superior to the state-of-the-art (Ti_{1-x}Al_x)N coatings. The combination of nano-layered and nanocomposite coatings prepared by novel LARC® and MARWIN® PVD technologies enables to use the coatings in various cutting applications which are evaluated. Successful transfer of the mentioned technologies from the research and development stage to industrial use is described as well.
- R-III.2** 14:30 **NANO-ALUMINUM AS A FILLER FOR SOLID PROPELLANTS**
G.L. Marra, L. Meda, Ist. Donegani Polimeri Europa, via Fauser 4, 28100 Novara, Italy and L. De Luca, L. Galfetti, F Severini, Politecnico di Milano, Solid Propulsion Laboratory, 20158 Milano, Italy
Aluminum nano-powders have recently been used in order to increase solid propellant performances. Actually, this kind of filler increases the energy release during aluminum oxidation, so improving burning rates, shortening the ignition delays and shortening burning times of filled propellants. The real difference between the use of nano aluminum than larger aluminum particles is the higher oxidation efficiency, close to 100%. Nano-particles coming from different producers are considered in this work, as well as composite propellants made of 17% HTPB binder, 68% ammonium-perchlorate (AP), and 15% nano-aluminum. A detailed investigation of nano-particles by themselves and of filled propellants is carried out by using: XRD, Electron Microscopy (SEM-TEM) and XPS. Burning rates measurements are also carried out at the Solid Propulsion Laboratory of Politecnico di Milano, in special chambers maintained at low pressure and controlled atmosphere. Combustion condensed products are collected in powder form and are characterized too by the same techniques as described before. Nano-aluminized propellants show residues of small size, with regular shapes, constituted mainly by different crystalline-phases of alumina, that are correlated to the experienced temperature. Aim of this work is to study the influence of nano-aluminum on the burning surface characteristics.
- R-III.3** 14:50 **CONTROL OF THE NITROGEN CONTENT IN NANO-COMPOSITE TiN/SiNx COATINGS DEPOSITED BY AN ARC-SPUTTER HYBRID PROCESS**
F.-J. Haug, J. Patscheider, Swiss Federal Laboratories for Material Testing and Research (EMPA), Surfaces, Coatings, and Magnetism, Überlandstrasse 129, 8600 Dübendorf, Switzerland and M. Tobler, Ionbond AG, Industriestrasse 21, 4600 Olten, Switzerland
We have developed a hybrid process for the deposition of TiN/SiNx nanocomposite layers where Ti is eroded from a conventional, industrial arc source and Si is simultaneously sputtered from an UBM target in Ar/N₂ atmosphere. The stoichiometry of the SiNx phase is related to the nitridation state of the silicon target which in turn is controlled by the Ar/N₂ mixture. Monitoring the characteristics of the silicon target allows an effective control of the process. Nanocomposite coatings of TiN and SiNx show enhanced protective properties compared to coatings of pure TiN. The addition of Si results in an improved oxidation resistance irrespective of the SiNx stoichiometry. A second advantage of the composite material is its increased hardness. The stoichiometry of the SiNx phase controls the amount of crosslinking in the matrix and to the TiN grains which is decisive for the formation of the hardness improvement. In composites with insufficient nitridation of the SiNx phase no improvement of the hardness is observed.
- R-III.4** 15:10 **MULTI-FUNCTIONAL POLYMER NANOCOMPOSITES FOR SPACE APPLICATIONS**
Zoubeida Ounaies, Cheol Park, Kris Wise, Joycelyn Harrison, Virginia Commonwealth University, National Institute of Aerospace, NASA Langley Research Centre
- R-III.5** 15:30 **FABRICATION AND THE MICROSTRUCTURE OF NANOCOMPOSITE Ti(C,N)-BASED CERMET PREPARED BY SPARK PLASMA SINTERING**
Yong Zheng, Shengxiang Wang, Wenjun Liu, Quan Yuan, College of Mechanical and Materials Engineering, China Three Gorges University, Yichang 443002, P.R. China
Several Ti(C,N)-based cermets with different amounts of grain growth inhibitor VC were prepared by spark plasma sintering. The microstructures and grain size of these cermets were studied using scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive X-ray analysis (EDX). The microstructure and grain size of a cermet as function of the typical grain growth inhibitors VC was revealed. VC addition could remarkably refine the grains. The microstructure of the cermet without VC consisted of large ceramic grains with 搵ack core-white rim?besides some small ceramic grains with 搵hite core-black rim? However, in the cermet with VC added, nearly all grains had 搵obviously 搵ore-rim?structure, and the amount of very fine grains increased greatly. The smallest grain size was 575 nm as confirmed by TEM observation. EDX results showed that V element congregated around the hard grains, which reduced the surface energy of solid grain γSV, and consequently inhibited the aggregation of nano ceramic grains during spark plasma sintering.

R-III.6 15:50 **MANUFACTURING AND MECHANICAL RESPONSE OF NANOCOMPOSITE LAMINATES**
Ming-Hwa R. Jen, Yu-Chung Tseng, Chun-Hsien Wu, Dept. of Mechanical and Electro-Mechanical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan 80424, ROC
 The work aims to manufacture the nano-composite laminates first. The prepreg form of AS-4 Graphite/PEEK laminae was used to make APC-2 composite laminate of 16 plies about 2 mm thick with two lay-ups of quasi-isotropic and cross-ply by a hot press via the modified diaphragm curing process. The nano-particles SiO₂ with the average diameter of 15? nm were uniformly spreaded in the specific interfaces of a laminate according the stacking sequence by sol-gel method. The total amount of nano-particles was measured about 1-10% by wt.
 Second, from tensile test we find that the optimal content of nano-particles is 3% by wt. The ultimate strength of optimal laminates increases about 10 % and elastic modulus 22 % in quasi-isotropic nano-laminates in comparison with APC-2 laminates. Whilst, the improvement of cross-ply nano-laminates is less than that of quasi-isotropic laminates. At elevated temperature (RT, 50, 75, 100, 125, 150℃) the ultimate strength decreases slightly below 75℃ and the elastic modulus reduces slightly below 125℃, however, both properties degrade highly at 150℃ (about T_g) for two lay-ups generally. Finally, the constant stress amplitude tension-tension (T-T) cyclic testing was conducted with stress ratio 0.1 and sinusoidal wave at room temperature for both layups. It is found that the stress-cycle (S-N) curves are very close below 104 cycles for cross-ply laminates w/wo nano-particles, and the S-N curve of nano-laminate slightly bent down after 105 cycles. Whilst in quasi-isotropic laminates, the S-N curve of nano-laminate is always slightly below that of APC-2 laminate through the life. That shows a little improvement of fatigue behavior in nano-composite laminates.

16:10

BREAK

Session IV: Synthesis and characterization of nano-materials

Session chairs: Jang-Kyo Kim and Stan Veprek

- R-IV.1** 16:30 -Invited- **TRIBOLOGICAL PERFORMANCE OF NANOCOMPOSITE MATERIALS**
Klaus Friedrich, University of Kaiserslautern, Germany
- R-IV.2** 17:00 **INVESTIGATION OF MECHANICAL PROPERTIES OF HYBRID POLYMER MATERIALS ON MESO, MICRO AND NANO-LEVEL**
 A. Sarkissov(a), **H. Fischer**(b), H.E.H. Meijer(a), (a)Materials Technology (MaTe), Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands, (b)TNO Institute of Applied Physics, 5600 AN Eindhoven, The Netherlands
 Polymer-clay nanocomposites are hybrid materials composed of a polymer matrix in which inorganic clay minerals of nanoscale dimension are dispersed. The incorporation of a very small filler content can lead to a significant alteration in various mechanical, thermal, optical and barrier properties. Although in the recent years an extensive research has been devoted to the investigation of the polymer-clay nanocomposites, the underlying microscopic mechanisms responsible for the improvement of the mechanical properties of these materials have not been fully identified.
 The goal of this work is to investigate the micro-mechanical deformation mechanisms of polymer-clay nanocomposites in order to account for their macro-mechanical properties of composites based on semi-crystalline matrices. Two different types of clay were used ?layered silicates and fibrous clay minerals. It is well recognized that an addition of a small weight percent of clay particles can have a pronounced effect onto the morphology of the polymer matrix. This is mainly a result of the nanosize dimensions and the huge surface area of the clay minerals. Furthermore, the clay minerals display a high Young's modulus and a very big aspect ratio, which makes them an appealing candidate as reinforcing elements. This study deals with the identification of the morphology of nanocomposite materials on different length scales, starting at the level of polymer crystals and going up to few hundreds microns, followed by the evolution of the structure during tensile deformation in order to relate the microscopic deformation processes to the macroscopic response of the material.
- R-IV.3** 17:20 **THERMALLY INDUCED RELAXATION PROCESSES IN SUPER-HARD NANOCOMPOSITES STUDIED BY MEANS OF INTERNAL FRICTION MEASUREMENTS**
 S.Z. Li(a), Q.F. Fang(b), Z.S. Li(b), J. Gao(c), P. Nesladek(d), J. Prochazka(d) and **S. Veprek**(d), (a)Qingdao University of Science and Technology, Qingdao 266042, P.R. China, (b)Key Laboratory of Internal Friction and Defects in Solids, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei 230031, P.R. China; (c)Chengdu Tool Research Institute, Chengdu 610051, P.R.China; (d)Institute for Chemistry of Inorganic Materials, Technical University Munich, 85747 Garching, Germany
 We investigated the processes that are responsible for the stability of nanostructure and/or self-hardening of superhard nc-TiN/a-Si₃N₄ and nc-TiN/a-Si₃N₄ nanocomposites upon annealing, using the internal friction measurements by means of torsion pendulum and vibrating reed method. It is shown that stable nanocomposites, that were deposited under conditions of a sufficiently high nitrogen pressure and temperature in a high density plasma, show neither self-hardening nor internal friction up to a temperature of 800 °C achievable in our friction measurements. These stable nanocomposites show no change of the superhardness of ~8805; 40 GPa upon annealing to 1100 °C. In contrast, the unstable coatings that were deposited under a low temperature or nitrogen pressure or low plasma density show self-hardening and a distinct internal friction peak with well defined activation energy due to completion of the stable nanostructure upon the annealing. Both the self-hardening and the friction peak vanish after annealing to 750 °C.

- R-IV.4** 17:40 **ON MODELS CONSTRUCTING IN MECHANICS OF NANOCOMPOSITES**
A.N. Guz, Institute of Mechanics, Dynamics and Stability of Solids, Nesterov Str. 3, 03680 Kiev, Ukraine
 The report is devoted to discussion of the problem on models constructing in mechanics of nanocomposites. The point is the mechanics of nanocomposites may be considered as separate branch of more wide scientific direction which may be defined as the structural mechanics. The investigations on materials science in the main relationships of which the parameters of internal structure are involved may be included in the structural mechanics. Macromechanics, mesomechanics, micromechanics and nanomechanics may be considered as separate branches of the structural mechanics of materials. Of course, macromechanics, mesomechanics, micromechanics and nanomechanics of materials study the inhomogeneities and discontinuities of different scales. In view of its the structural mechanics of materials may be considered as multi-scales mechanics, moreover micromechanics is nearest to nanimechanics. Micromechanics of composite materials with polymer and metal matrix was presented in 12-volumes edition [1]. Taking into account above mentioned results [1] in this report the some approaches to constructing of models of nanocomposites mechanics are considered. These models are applicable to the problems of statics, dynamics and stability loss of nanocomposites and to the problems of nanocomposites fracture in part which may be described in the framework of solid mechanics.
 1. Mechanics of Composites, Edition in 12 volumes (A.N.Guz ?Editor-in- Chief), Kiev, v.1-4 Naukova Dumka, v.5-12 Publisher 摳C.K.? 1993-2003 (in Russian).
- R-IV.5** 18:00 **EFFECT OF MOISTURE ON THERMO-MECHANICAL PROPERTIES OF POLYMER-CLAY NANOCOMPOSITES**
 Chugang Hu and Jang-Kyo Kim, Department of Mechanical Engineering, Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong
 The moisture barrier characteristics are studied of epoxy-based nanocomposites reinforced with two different layered silicates, namely octadecylamine modified montmorillonite (I30P) and the quaternary alkylamine modified montmorillonite (KH-MT). The moisture absorption rate for the I30P system was much lower than the KH-MT system, the latter of which could be fitted to the Fick's second law. The deviation from the Fickian diffusion behaviour of the I30P system is associated with exfoliated morphology and more uniform dispersion of clay particles, which altered the diffusion path of water molecules. The moisture diffusivity of nanocomposites decreased with increasing clay content, the reduction being more pronounced for the I30P system. The normalized permeability showed a systematic decrease with increasing clay content, which agrees well with the prediction based on the tortuous path model. The DMA analysis showed that the reduction of glass transition temperature due to moisture absorption was much less for the I30P system than the KH-MT system.
- R-IV.6** 18:20 **DESIGN OF A NEW THICK FILM CAPACITIVE PRESSURE AND CIRCUITRY INTERFACE**
K. Arshak, E. Jafer, Electronic & Computer Engineering Department, University of Limerick, Plassey Technological Park, Limerick, Ireland
 In recent years have been a number of studies made to investigate the use of capacitance effects in the mechanical transducers. By changing the distance between the electrode of a capacitor or the chemical constitution of the dielectric, it is often possible to extract a relationship between the quantity to be measured and the change in capacitance. This fact has been used to develop sensors that measure quantities such as strain, acceleration, gas concentration, humidity etc [1]. This paper is focused toward developing a low-cost pressure sensitive device using thick film technology. The paper describes the design specifications set out and how the sensor and signal conditioning circuitry performed against expectations. One of the design constraints was ensuring the operation of the sensor in a hostile operating conditions. Several device configurations were created using both commercial Cermet and a PZT paste developed through this work. The relative performance of these materials as a dielectric-sensing element is compared in terms of their sensitivity, repeatability, stability and hysteresis. Two physical electrode configurations were also tested and recommendations for future designs made. An efficient signal conditioning circuitry, which deals with the large levels of data needed by controllers in a system and interfaced to PC, has been developed. The purpose of the circuitry is to allow the controller to make control decisions based on accurate stable pressure readings obtained by at the circuit. In this paper, the full system design of pressure transducer and compensation circuitry was considered.
 [1] M. Prudenziati, Handbook of sensors and actuators, Vol 1, Thick film sensors,

R/P.01**AQUEOUS SYNTHESIS OF YTTRIA STABILISED ZIRCONIA-ALUMINA NANOCOMPOSITES**

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Composites based on alumina and zirconia have been studied widely because of their good mechanical properties. When nanoparticles of one metaloxide are introduced in a larger matrix of the other metaloxide, improved and innovative physical and mechanical properties can be obtained for these materials.

In this work nanocomposites are fabricated by incorporating yttria stabilised zirconia nanoparticles in an alumina submicron matrix. The nanoparticles are synthesized via an aqueous solution-gel method. First a stable aqueous precursor solution of Zr and Y is prepared, which is afterwards converted in an amorphous gel by solvent evaporation in a furnace. Via thermo-oxidative decomposition of the gel, nanoparticles are obtained. XRD and TEM results show that the nanopowder consists of completely tetragonal yttria stabilised zirconia of about 15 nm with a narrow size-distribution. These nanoparticles are deagglomerated and incorporated in the matrix by mechanical milling. After freeze drying, a dry powder is obtained containing the Y-ZrO₂ nanoparticles which are homogeneously distributed in the Al₂O₃ matrix. This powder mixture is pressed and subsequently sintered. The particle sizes can be followed up in function of the sinter temperature via image-analysis. The influence of the processing conditions, resulting density, microstructure and zirconia content on the properties of the nanocomposites are determined.

R/P.02**CHARACTERIZATION OF NANOCOMPOSITE CeO₂-Al₂O₃ COATINGS ELECTRODEPOSITED ON STAINLESS STEEL**

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CeO₂-containing materials are widely employed as structural and electronic promoters of heterogeneous catalytic reactions. The addition of ceria generally improves the behavior of alumina-based catalysts used for automotive emission control. The ceria stabilizes Al₂O₃ support against surface area loss by preventing the transformation of γ-Al₂O₃ to α-Al₂O₃ which is dependent on CeO₂ loading. A new electrochemical method using a nonaqueous electrolyte is utilized for deposition of nanocomposite ceria-alumina coatings on stainless steel substrates. The coatings were obtained in a solution of 5g/l CeCl₃ x 7H₂O; + 55g/l AlCl₃ x 6H₂O; diluted in alcohol. SEM and XPS studies of the morphology, structure and chemical composition of the CeO₂-Al₂O₃ coatings were performed. The as-deposited layers are dense and without cracks. The thickness of the coatings is 3 - 5 μm. After annealing SEM examination showed a microstructure formed by small (50-150 nm) compacted spherical micro aggregates. X-ray photoelectron spectroscopy was used to examine the chemical composition and the oxidation state of the as-deposited and annealed coatings depending on the ceria loading.

R/P.03**SYNTHESIS OF CuInS₂ NANOWIRES AND THEIR CHARACTERIZATION**

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CuInS₂ is one of the most promising candidates for applications in photovoltaic devices. On the other hand, the CuInS₂ nanorods and nanotubes synthesized by a chemical treatment method were reported and comprehensively examined by x-ray diffraction, transmission electron microscopy, and other structural techniques by Y. Jiang et al. In this work, we make a report regarding the relation between the conditions of syntheses and resultant nanowire structures. CuInS₂ nanowire samples were synthesized using a chemical treatment process similar to the one reported previously. Pure copper, indium, and sulfur powders were placed in a stainless steel reactor together with ethylenediamine as solvent. The sealed reactor was kept in an electric furnace at the temperature between 280 and 300 °C for 24 h.

The product obtained at 300 °C (sample A) was chocolate brown, while the product obtained at 280 °C (sample B) was black. According to the image of field emission-scanning electron microscopy, most nanowires from sample A are 30 ~ 100 nm in diameter and several micrometers in length. On the other hand, sample B displays long (at a micrometer scale) belt structures with thickness of 30-50nm and width of 200 nm ~ 500 nm. There is a strong correlation between the color and lateral dimensions of the resultant structure. The smaller dimensions the brighter is the color of the powder. This relationship reflects the absorption properties of the products. Sharp peaks in an x-ray diffraction pattern can be indexed to almost chalcopyrite structure, in agreement with the reported data on CuInS₂ of the chalcopyrite structure.

- R/P.04** INORGANIC COPOLYMERS BASED ON SYLANES AND FERROCENE MONOMERS, PRECURSORS FOR ADVANCED NANOSTRUCTURED CERAMICS
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 The synthetic metal-containing polymers combine the processability of organic polymers with the physical and chemical characteristics of the metallic element or complex. The copolymers, poly(ferrocenylsilanes) with backbone of ferrocene and organo-silane units are currently being investigated as charge- dissipation materials, precursors to advanced nanostructured ceramics.
 The recent studies suggest that organosilicon polymers may be more practical precursor for advanced ceramics, as they have the advantage of three-dimensional network and good procesability. The cross-linked metal containing polymers are converted in advanced ceramics materials with tuneable electric and magnetic properties. That may find utility as protective coatings, electromagnetic and antistatic shielding. The effort for synthesis of these structures has been oriented on chemical route using transition-metal-catalyzed ring-opening polymerization of strained metallocenophane monomers. The silicon-polymers, from silane and silazane, are usually obtained by plasma polymerization and poly(ferrocene) are currently chemical synthesized, but reports have produced. The contribution concerns with advantages offered by plasma assisted chemical vapour deposition for synthesis of copolymers based on monomers above mentioned. This method is more suitable for precursors in nanostructured ceramics as ready for sintering. Plasma polymerization has been done in a large volume RF- Reactor, inductive coupled and collected powder was converted in a ceramic by thermal treatment at 12000 C. FT-IR, XRD, TEM, dielectric and magnetic properties are taken in account to evaluate the performances of these materials. The properties can be controlled by pyrolysis conditions and the iron dispersion in ceramic matrix.
- R/P.05** THERMAL STABILITY OF TI-SI-N NANOCOMPOSITE THIN FILMS
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 The study of multiphase materials, commonly called nanostructured materials, and based on grain refinement has deserved special attention. These materials, with a characteristic length scale below 20 nm, reveal unusual mechanical and structural properties, such as superhardness and enhanced elasticity. Their thermal stability is, however, critical and one of the most important properties. In this work, the thermal stability of Ti-Si-N films will be studied as a function of the preparation conditions, namely the variation in the ion bombardment. The films were prepared by dc reactive magnetron sputtering from a Ti target (with incrustated Si pieces), in an Ar/N₂ gas mixture. The ion current density in the substrate was varied by the superimposition of an axially symmetric external magnetic field between substrate and target. The variation of the magnetic field strength induced changes in the ion current density in the substrate with a consequent change in film properties. XRD results revealed the development of a two-phase cubic B1 NaCl structure system, with an increasing lattice parameter with the ion to atom arrival rate ratio. Thermal treatments were conducted in vacuum till temperatures as high as 900 筭 with no significant variation of the coatings hardness. Detailed XRD structural stability studies of the two-phase mixture will be presented and correlated with the preparation conditions.
- R/P.06** EFFECTS OF IRON ADDITION ON THE STRUCTURE AND MECHANICAL PROPERTIES OF TITANIUM NITRIDE FILMS
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 FeTiN nanocomposite films with various iron contents were deposited on Si and NaCl single-crystal substrates by DC reactive magnetron sputtering. The structure and chemical composition of films were determined by X-ray diffraction (XRD), energy dispersive X-ray (EDX) and transmission electron microscopy (TEM) investigations. The effects of Fe addition on the structure and mechanical properties of FeTiN nanocomposite were investigated. X-ray diffraction and TEM analysis revealed for FeTiN a cubic B-1 structure while no sign of iron phase was observed. It was found that the lattice parameter decreased and microhardness of nanocrystalline FeTiN increased with increasing the Fe/Ti atomic ratio and reached, at Fe/Ti=0.6, 0.420 nm and 30 GPa respectively.
- R/P.07** STRUCTURE AND TRIBOLOGICAL BEHAVIOUR OF REACTIVELY SPUTTERED Zr-Si-N NANOCOMPOSITE COATINGS
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 Zr-Si-N films were deposited on silicon and steel substrates by DC magnetron sputtering of a Zr-Si composite target in Ar-N₂ reactive mixtures. The silicon concentration in the films was adjusted by varying the surface of Si chips located on the erosion zone of the target. The films were characterised by X-ray diffraction, electron probe microanalysis, Fourier transform infrared spectroscopy, X-ray photoemission spectroscopy, atomic force microscopy and wear tests. The structure and the tribological properties of Zr-Si-N films were compared to those of ZrN coatings. Depending on the silicon concentration, the films were either nanocomposites (nc-ZrN / a-SiN_x) or amorphous. Introduction of silicon into the zirconium nitride coatings induced a change in the preferential orientation of the ZrN grains: [111] for ZrN films and [100] for Zr-Si-N ones. This texture modification was also observed for a ZrN film deposited on an amorphous SiN_x layer. Thus, within our deposition conditions, the occurrence of a-SiN_x enhanced the [100] preferred orientation.
 Friction and wear behaviour of the films were carried out against spheres of alumina or 100Cr6 steel by using a ball-on-disc tribometer. The results show that addition of silicon into ZrN-based coating induced a strong decrease in the friction coefficient and in the wear rate compared to those of ZrN films. These results will be discussed as a function of the films structure and composition.

- R/P.08** THE SYNTHESIS AND CHARACTERIZATION OF HYDROXYAPATITE/ULTRAFINE DIAMOND COMPOSITE
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A novel hydroxyapatite (HA) composite with ultrafine diamond (UFD) as reinforcement was synthesized by wet-chemical precipitate method. The colors of specimens changed gradually from white to gray with the increase of UFD content in the composite. The component and morphology of the materials were characterized by X-ray diffraction (XRD) and transmission electron microscopy (TEM). The hardness and compressive strength were measured by micro-hardness tester and material testing system. The results indicated that the UFD and HA were dispersed uniformly. With the increase of UFD content, the hardness and compressive strength of the materials increased, attaining a peak value of 6.04 GPa and 360.22 MPa at 3.0 wt% UFD addition, respectively. After reaching the peak value, both the hardness and compressive strength decreased. The hardness and compressive strength of the composite were both better than the pure hydroxyapatite, which will improve the mechanical properties of artificial bone materials.
- R/P.09** THERMAL EXPANSION OF SINGLE-WALLED CARBON NANOTUBE REINFORCED NANO-AL COMPOSITE
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It is generally known that Carbon nanotubes (CNTs) have outstanding mechanical properties, extraordinary low thermal expansion, and high thermal conductivity. CNTs may be promising reinforcement for composites, and several investigations on the fabrication and properties of CNT reinforced composites have been reported recently. The previous studies mainly focus on the mechanical properties of the composites, while their thermal properties are rarely mentioned.
In this study, The single-walled carbon nanotube (SWNT) reinforced nanocrystalline Aluminum (nano-Al) composites (SWNT/nano-Al) with different volume fraction (0 vol%~20 vol%) were fabricated by hot vacuum-consolidation under 1.0 GPa pressure at 380 °C. Based on the successful fabrication of SWNT/nano-Al, the thermal expansion behavior of the composite was investigated. For comparing the property of the composite with traditional Al and semiconductor materials, coarse-grained Al and single crystal silicon (Si) samples with same size (8.0 mm) were employed in this study. The coefficient thermal expansion (CTE) of the composite was obtained in the temperature range of 20 °C to 250 °C with a high-precision dilatometer, and compared with the predictions of various theoretical models. The comparison of the thermal expansion behaviors between the SWNT/nano-Al composite and Si indicates that SWNTs are promising filler to optimize coefficient thermal expansion for electronic packaging material.
- R/P.10** SUBSTRATE BIAS VOLTAGE EFFECT ON THE PROPERTIES OF COPPER/CARBON NANOCOMPOSITE FILMS PREPARED BY MICROWAVE PLASMA-ASSISTED DEPOSITION TECHNIQUES
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Copper/hydrogenated amorphous carbon (a-C:H) nanocomposite films have been deposited on 316L stainless steel substrates by sputtering of a copper target associated with microwave plasma-enhanced chemical vapor deposition of carbon from argon-methane gas mixtures of various compositions (30~40% CH₄/70~60% Ar). The substrates were either at the floating potential or biased up to 70 V. The mechanical properties of Cu/a-C:H films determined by nanoindentation measurements were found to be dependent on the substrate bias voltage. For films deposited on substrates at the floating potential, the hardness was relatively low (2 GPa) and load versus displacement diagrams revealed the behavior of polymer-like materials. As the substrate bias voltage was varied from 0 to 70 V, the hardness, H, and elastic modulus, E, of films increased by a factor of two and six, respectively. In addition, the elastic recovery of these films was weak, which is a characteristic of metal materials. Nanocomposite films deposited on biased substrates exhibited reduced friction coefficients of approximately 0.1, i.e., a factor of 2.5 to 3.5 lower than the friction coefficient of films deposited on substrates at the floating potential. The features of wear tracks examined by scanning electron microscopy were correlated to the mechanical properties of films and testified the change of the wear mechanism from viscoelastic to plastic mode with increasing substrate bias voltage.
- R/P.11** STUDY ON THE PREPARATION AND CHARACTERIZATION OF ULTRA-HIGH MOLECULAR WEIGHT POLYETHYLENE/CARBON NANOTUBES COMPOSITE FIBER
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The ultra-high molecular weight polyethylene (UHMWPE)/carbon nanotubes (CNTs) composite fibers were prepared by gel spinning. To realize the homogeneous dispersion and good load transfer between the CNTs and the polymer matrix, the purification and functionalization of the CNTs were carried out. TEM, SEM, XRD, IR and Raman were used to characterize the CNTs, its dispersion in the matrix, the functional group changes on the surface of the CNTs and the interaction between the CNTs and the matrix. The results showed that there was no obvious aggregate in the obtained composite fibers and a good interaction between the CNTs and the UHMWPE matrix was also established. Furthermore, it was found that the addition of CNTs resulted into a peculiar structure, a more regular alignment of the UHMWPE macromolecules

- R/P.12** TITANIUM DIOXIDE DOPED POLYANILINE - CHARACTERIZATION OF Ni/P AUTOCATALYTIC DEPOSITS CONTAINING ULTRAFINE DIAMOND
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Titanium dioxide doped polyaniline has been successfully prepared by in-situ polymerization. TiO₂ nanoparticles with an average diameter of about 20 nm were used as a dopant of polyaniline. The doping effect of TiO₂ was characterized by SEM, FT-IR, EDS and electrical conductivity measurement. SEM study shows that TiO₂ nanoparticles have a strong effect on the morphology of composites. The FT-IR spectra reveal that the interaction between TiO₂ and PANI is primarily based on the formation of H-bonding. Electrical conductivity measurement exhibits that the conductivity of composites at low TiO₂ content is much higher than that of neat PANI, while with the increasing content of TiO₂, the conductivity shows an orderly decrease. Ultrafine Diamond (UFD) was synthesized by using the detonation method. It was an industrial diamond with a unique particle size and shape. The Ni/P/UFD composite coatings were prepared by autocatalytic deposition. The tribological properties, hardness and corrosion behaviours of the composite coating on medium carbon steels were investigated. It was found that the composite coatings exhibited not only high wear resistance but also low friction coefficient compared with Ni/P coating. The prominent influences of UFD on tribological properties of the composite coatings may be attributed to structure close to spheres and ultrahard properties of nanodiamond particles. Microhardness of the Ni/P/UFD composite coatings before and after heat treatment are also reported. The highest microhardness of the composite coating was obtained by heat treated at 673K. The corrosion behaviors of amorphous composite coatings with varied UFD content were evaluated by polarization curves and electrochemical impedance spectroscopy in NaCl 0.1M solution at room temperature. It was noted that the corrosion resistance of the composite coating was superior to that of Ni/P coating. The excellent electrochemical performance of Ni/P/UFD composite coatings may be ascribed that UFD have a favourable chemical stability and size of the diamond nanoparticles, reduce the size of the hole in the composite coatings and prevent corrosive pits from growing up.
- R/P.13** NANOSTRUCTURAL EVOLUTION AND SPECTRAL IMAGING OF Cu-Al₂O₃ NANOCOMPOSITES PREPARED BY IN-SITU REDUCTION AND THERMO-MECHANICAL PROCESSED
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The uniform dispersion of Al₂O₃ particles in a copper matrix provides unique characteristics to the material, enabling its use in high temperature applications. In recent years, it has been experienced that the physical and mechanical properties of these composites are improved significantly if the dispersion of the constituents is homogeneous and the particle sizes are in nano-scale. Previous results have shown that the microstructure of the nanocomposites is formed by a copper matrix, with grains in the sub-micron scale, and a homogeneous dispersion of Al₂O₃ particles in nano-scale size. HRTEM observations have show that the Al₂O₃ particles are in the range of 10 to 60/70 nm, but mostly in the lower range up to 30 nm. By comparing a computer generated X-Ray STEM elemental mapping with experimental ones taken at very high magnifications it is possible to achieve a better understanding of the real composition of the Cu/Al₂O₃ interface and also to assess the formation of a third phase in the consolidated material. Finally, studies on thermo-mechanical processing have shown that, even after cold-rolling down to 50% of reduction in thickness and annealing at 900oC for one hour, a high density of dislocations and sub-grain boundaries have still remained in the microstructure. This is an important information about the structural stability of the composite when considering technological applications.
- R/P.14** POSSIBILITY OF FABRICATING CARBON NANO-SIZED FIBER REINFORCED COPPER COMPOSITE USING LIQUID INFILTRATION PROCESS
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The alloyed Cu, which is the most widely used connector materials, possesses inherently lower conductivity compared to the unalloyed counterpart. In order to overcome this inherent shortcoming associated with conventional Cu alloys, the development of high-conducting, high-strength phase reinforced Cu composite has been being explored. In the present study, the possibility of fabricating CNF reinforced Cu composite using liquid infiltration process was evaluated. The minimum stress required for liquid Cu to completely infiltrate into the bundle of CNF was calculated based on a force balance equation, calculated permeability and compaction behavior of CNF. The present calculation demonstrated that the external pressure required for the infiltration was as low as 11.8 MPa. Finally, the CNF reinforced Cu composite was fabricated by liquid infiltration route at relatively low pressure employing a simple hydrostatic pressurization principle. The present study, however, demonstrated that a low cost, nano-sized fiber reinforced metal matrix composite fabrication was possible by liquid infiltration process at applied pressure as low as 20 MPa with a proper temperature control and mold design.