Selected Abstracts of Thermal Spray Literature

Reprinted with permission from Elsevier Engineering Information, Inc., Hoboken, NJ

Armor Applications

Lightweight ballistic with additional stab protection made of thermally sprayed ceramic and cermet coatings on aramide fabrics. Ceramic and cermet coatings on fiber fabrics used in lightweight protection should enhance their performance in stab protection. Based on thermal spray technologies, a coating process for hard material layers even on temperature-sensitive fiber substrates has been developed, so that the coated fabrics retain their flexibility. High-speed and high-rate cermet and ceramic coatings are deposited with simultaneous substrate cooling in order to apply thick, hard, and refractory cermet and oxide ceramic coatings. These coatings can be applied on lightweight aramide fabrics without damaging the fibers. The hard material, aramide composite fabric combines the advantages of aramide fabrics and hard, refractory materials. A fully flexible, highly tenacious and lightweight fabric with a hard and refractory top coating is developed. The penetration of knives and blades through such hard material coated multilayer fabrics is effectively prevented.

Keywords: aramide fabrics, ceramic coatings, ceramic fibers, cermet coatings, cermets, fabrics, lightweight protection, protective coatings, stab protection, thermally sprayed ceramic

R. Gadow and K. Von Niessen, Institute for Manufacturing Technologies of Ceramic Components and Composites (IFKB), University of Stuttgart, Stuttgart, Germany. Cited: *Int. J. Appl. Ceram. Technol.,* 2006, July, **3**(4), p 284-292 [in English]. ISSN 1546-542X.

Coatings for Biology

Characterization of functionally graded hydroxyapatite/titanium composite coatings plasma sprayed on Ti alloys. Bioceramic coatings such as hydroxyapatite (HA) have shown promising bioactive properties in load-bearing implant applications. The aim of this work is to deposit functionally graded HA/Ti layers consisting of an underlying Ti bond coat, the alternating layer, and an HA top layer on Ti6A14V substrates using plasma spray to improve the coating/substrate interface properties. The alternating layers were created by means of changing the feeding rate and input power of Ti and HA powders, which gradually decrease Ti content with increasing depth from the Ti bond coat. The major consideration is to examine the stability of the graded coatings. Experimental results indicated that surface chemistry and morphology of the graded coatings were similar to those of monolithic HA coatings. The bond strength values of the as-sprayed graded coatings were much superior to those of monolithic HA coatings. The cyclic fatigue did have a statistically significant effect on bond strength of monolithic HA coatings, with a decrease of 23%. However, the graded coatings were able to survive 1 million cycles of loading in air without significantly reduced bond strength. The in vitro electrochemical measurement results also indicated that the graded coatings had a more beneficial and desired behavior than monolithic HA coatings after fatigue.

Keywords: ceramic coatings, coating/substrate interface properties, composite materials, fatigue of materials, feeding rate, functionally graded materials, graded coatings, hydroxyapatite, plasma spray, plasma spraying, titanium, titanium alloys

C.-C. Chen, T.-H. Huang, C.-T. Kao, and S.-J. Ding, Institute of Oral Materials Science, Chung-Shan Medical University, Taichung 402, Taiwan. Cited: *J. Biomed. Mater. Res—Part B Appl. Biomater.,* 2006, July, **78**(1), p 146-152 [in English]. ISSN 0021-9304.

Hydroxyapatite enhances long-term fixation of titanium implants. The aim of this study was to evaluate osseous integration of hydroxyapatite coated titanium implants over time as compared to pure titanium. In 20 rats the medullary cavity of both femoral bones was entered by an awl from the trochanteric area. With steel burrs, it was successively reamed to a diameter of 2.0 mm. Nails with a diameter of 2.0 mm and with a length of 34 mm were inserted into the medullary cavity; a pure titanium nail on the left side and a titanium nail entirely plasma sprayed with hydroxyapatite (HA) on the right side. The surface roughness of the pure titanium was characterized by R_a 2.6 μm and R_t 22 μm, and HA had a roughness of R_a 7.5 (arithmetical mean roughness) μm and R_t (maximum profile height) 52 μm. The rats were randomized to a follow-up of 6 and 12 months, respectively. At sacrifice the femoral bones were dissected free from soft tissues. The bones were radiographed and then immersed in fixative. A specimen-slice of about 5 mm thickness was prepared from the region under the trochanter minor with a water-cooled band-saw. Sample preparation for undecalcified tissue followed the internal guidelines at the laboratories of Biomaterials/Handicap Research. At 6 months the median bone-bonding contact of the implants was 40% (range 0-92) in the titanium group and 34% (0-86) in the HA group. At 12 months the median bone-bonding contact was 51% (0-97) in the titanium group and 86% (72-98) in the HA group. In conclusion, the authors found a significant (p = 0.001) increase in bone-bonding contact from 6 to 12 months of the HA coated nails and significantly (p = 0.043) enhanced bone-bonding contact in HA coated nails at 12 months as compared to pure titanium nails.

Keywords: bioactivity, biomaterials, bone, coatings, composite materials, healing, histology, histology hydroxyapatite, hydroxyapatite, implant, implants (surgical), ingrowth, metabolism, nails, orthopedics, osseointegration, plasma spraying, radiography, surface roughness, tissue, titanium

O. Reikeras, C.B. Johansson, and M. Sundfeldt, Orthopaedic Department, Rikshospitalet University Clinic, N-0027 Oslo, Norway. Cited: *J. Long-Term Effects Med. Implants,* 2006, **16**(2), p 165-173 [in English]. ISSN 1050-6934.

Cold Spray

Improvement of microstructure and property of cold sprayed Cu-4at.%Cr-2at.%Nb alloy by heat treatment. The effect of vacuum heat treatment on the microstructure and microhardness of the cold sprayed Cu-4at.%Cr-2at.%Nb alloy was investigated. After heat treatment, a Cr_2Nb phase formed in the gas-atomized powder was uniformly distributed in the matrix. Minimal grain growth of the Cr_2Nb phase was observed accompanying the healing of the incomplete interfaces between the deposited particles at the elevated treatment temperatures. The microstructure and microhardness of the annealed cold sprayed Cu-4at.%Cr-2at.%Nb alloy were comparable with those of the deposits fabricated by vacuum plasma spraying, which makes it a promising material for regeneratively cooled rocket engine applications.

Keywords: chromium alloys, cold spraying, cooled rocket engine applications, copper alloys, elevated treatment temperatures, heat treatment, microhardness, microstructure, niobium alloys, plasma spraying, thermal effects, vacuum plasma spraying

W.Y. Li, X.P. Guo, C. Verdy, L. Dembinski, H.L. Liao, and C. Coddet, LERMPS, Universite de Technologie de Belfort-Montbeliard, 90010 Belfort Cedex, France. Cited: *Scr. Mater.,* Aug 2006, **55**(4), p 327-330 [in English]. ISSN 1359-6462.

Luminescence induced by high-velocity impacts of metallic particles on metal surfaces. On impact of metallic particles on a metal surface light can be emitted from the region of impact. This phenomenon is studied experimentally for impact conditions that are typical of the cold spray deposition process; that is, particle diameters and velocities are of the order of 10^{-5} m and 500 m/s, respectively. The characteristics of impact-induced luminescence are analyzed. It is found that the intensity of luminescence depends not only on the energy of the impinging particles and on the stresses produced on impact but also on the particular combination of materials of the particles and the plate. Possible sources of luminescence are discussed.

Keywords: cold spray deposition, deposition, impinging particles, luminescence, metal surfaces, metallic films, metallic particles, spraying, stresses

K.V. Klinkov and M. Rein, Institute of Aerodynamics and Flow Technology, DLR, 37073 Gottingen, Germany. Cited: *J. Appl. Phys.,* 2006, **100**(1) [in English]. ISSN 0021-8979.

Corrosion and Chemical Resistance

Corrosion resistance of Fe-16%Cr-30%Mo-(C,B,P) amorphous coatings sprayed by HVOF and APS processes. Two kinds of Fe-16%Cr-30%Mo-(C,B,P) alloy powders having high ability to form an amorphous phase were thermal sprayed onto mild steel substrate using HVOF and APS processes. Perfectly amorphous coating was formed not only by the HVOF process but also by the APS process. The passive current densities of the amorphous coatings sprayed by the HVOF and APS processes were close each other and significantly low compared with that of SUS316L coating in $1 \cdot L^{-1}$ HCl solution. The coatings of perfectly amorphous phase were little corroded after immersion tests in $1 \cdot L^{-1}$ HCl solution for 1 week, though the coatings composed of the mixture of amorphous and crystalline phases corroded markedly.

Keywords: amorphous alloys, amorphous coating, atmospheric plasma spraying, corrosion resistance, crystallization, current density, high-velocity flame spraying, hydrochloric acid, iron alloys, iron-chromium-molybdenum-base alloy, sprayed coatings, thermal spraying

F. Otsubo and K. Kishitake, Department of Materials Science and Engineering, Faculty of Engineering, Kyushu Institute of Technology, Kita-Kyushu 804-8550, Japan. Cited: *Mater. Trans.,* 2005 Jan, **46**(1), p 80-83 [in English]. ISSN 1345-9678.

Evaluation of the behavior of shrouded plasma spray coatings in the platen superheater of coal-fired boilers. Nickel- and cobalt-base coatings were formulated by a shrouded plasma spray process on boiler tube steels, namely, ASTM-SA210-grade A1 (GrA1), ASTM-SA213-T-11 (T11), and ASTM-SA213-T-22 T22). The Ni-22Cr-10A1-1Y alloy powder was sprayed as a bond in each case before the final coating. The degradation behavior of the bared and coated steels was studied in the platen superheater of the coal-fired boiler. The samples were inserted through the soot blower dummy points with the help of stainless steel wires. The coatings were found to be effective in increasing resistance to degradation in the given boiler environment. The maximum protection was observed in the case of Stellite-6 (St-6) coating.

Keywords: coal-fired boilers, coatings, degradation, degradation behavior, nickel alloys, plasma spray coatings, plasma spraying, platen superheater, powder metals, shrouded plasma spray process, sprayed coatings, steel, superheaters

B.S. Sidhu and S. Prakash, Department of Mechanical Engineering, GZS College of Engineering and Technology, Bathinda Punjab-151001, India. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci.,* 2006, June **37**(6), p 1927-1936 [in English]. ISSN 1073-5623.

Hot corrosion performance of a NiCr coated Ni-base alloy. The hot corrosion performance of high-velocity oxyfuel sprayed Ni-20Cr wire coating on a Ni-base superalloy is evaluated for 1000 h at 900 °C under cyclic conditions in a coal-fired boiler. The performance of bare and Ni-20Cr coated Superni 75 is assessed via thermogravimetric data, metal thickness loss corresponding to the corrosion scale formation, scale thickness loss, and the depth of internal corrosion attack. The better hot corrosion resistance of the coated alloy is mainly attributed to the formation of a thick band of chromium oxide just above the scale/substrate interface and chromium oxide stringers along the splat boundaries, as well as to the nickel oxide and the dense and uniform fine grain structure of the as sprayed coating.

Keywords: coal-fired boilers, coatings, corrosion, crystal microstructure, high-velocity oxyfuel, hot corrosion, interfaces (materials), Ni-20Cr, nickel alloys, thermogravimetric analysis, wire coating

T.S. Sidhu, S. Prakash, and R.D. Agrawal, Metallurgical and Materials Engineering Department, Indian Institute of Technology Roorkee, Roorkee, 247667 Uttranchal, India. Cited: *Scr. Mater.,* 2006, July **55**(2), p 179-182 [in English]. ISSN 1359-6462.

An oxidation study of an MCrAlY overlay coating. Metallic overlay coatings of the MCrAlY type (where M is Ni, Co, or a combination of both) are regularly used in high-temperature plant to provide resistance to oxidation and high-temperature corrosion through the formation of a protective surface layer of alumina. Such coatings are also frequently used as a bond coat in thermal barrier coating systems. For both applications, the endurance of the coating system depends on the maintenance of the protective alumina layer. In particular, a high resistance to spallation is required and also a sufficient reservoir of aluminum within the coating so that re-healing of the alumina layer will occur should spallation occur. In this paper the results of a study into the oxidation behavior of an LPPS MCrAlY coating on a CM186LC alloy are presented. During the study extensive TGO thickness measurements were made at varying times at 1100 °C from which the oxidation kinetics have been calculated up to the point where extensive spallation occurred. Over the time range where partial spallation of the TGO occurred, between 50 to 100 h, a duplex structure in the oxide scale was revealed. Micrographs and analyses of the oxide are presented and the two values of TGO thickness at this time at temperature are shown and discussed in terms of the early oxidation kinetics.

Keywords: aluminum alloys, chromium alloys, CM186LC alloys, coating techniques, duplex structure, LPPS MCrAlY coating, oxidation behavior, oxidation resistance, power plants, reaction kinetics, thermal effects

M.P. Taylor, University of Birmingham, Birmingham, U.K. Cited: *Mater. High Temp.,* **22**(3-4), p 433-436 [in English]. ISSN 0960-3409.

Plasma sprayed coatings for oxidation protection on creep of the Ti-6Al-4V alloy. The titanium affinity for oxygen is one of the main factors that limit the application of its alloys as structural materials at high temperatures. The objective of this work was to estimate the influence of the plasma sprayed coatings for oxidation protection on creep of the Ti-6Al-4V alloy, focusing on the determination of the experimental parameters related to the creep stages. Yttria (8 wt.%) stabilized zirconia (YSZ) with a CoNiCrAlY bond coat was air plasma sprayed on Ti-6A1-4V substrates. Constant load creep tests were conducted on the Ti-6Al-4V alloy in air for coated and uncoated samples and in a nitrogen atmosphere for uncoated samples at 600 °C to evaluate the oxidation protection on creep of the Ti-6Al-4V alloy. The steady-state creep rate of the coated alloy is smaller than that of the uncoated alloy in air and nitrogen atmosphere. Results about the activation energies and the stress-exponent values indicate that the primary and stationary creep, for all test conditions, was probably controlled by dislocation climb. The plasma sprayed coatings increased the time to rupture and the strain at rupture is smaller than for uncoated samples tested in air.

Keywords: activation energy, aluminum, creep, high-temperature operations, intermetallics, oxidation, plasma sprayed coatings, plasma spraying, rupture, sprayed coatings, stationary creep, Ti-6Al-4V, titanium, vanadium

D.A.P. Reis, C.R.M. Silva, M.C.A. Nono, M.J.R. Barboza, F. Piorino-Neto, and E.A.C. Perez, Instituto Nacional de Pesquisas Espaciais, LAS, Sao Jose dos Campos 12201-970, Brazil. Cited: *Mater. High Temp,* **22**(3-4), p 449-452 [in English]. ISSN 0960-3409.

Plasma sprayed graded ceramic coatings on refractory materials for improved chemical resistance. Plasma sprayed ceramic coatings were manufactured on sintered alumina-mullite refractory bricks to improve their chemical resistance to molten glass. Mullite and alumina powders were employed. Graded layered coatings were designed and produced to reduce the thermal expansion mismatch with the substrate: in all cases, the upper layer consisted of pure alumina (very resistant to chemical attack); alumina-mullite intermediate layers were added to match the low thermal expansion of the porous substrates. Plasma sprayed coatings definitely improved both the abrasion resistance and the chemical resistance to long-time (8 h at 1400 °C) contact with molten glass, since the coating preserved its original microstructure. However, in thermal shock tests, some transverse cracks appeared; thus, thermal cycling tests in presence of molten glass indicated that, after a few cycles, the glass can penetrate down to these cracks. The tested samples were studied by means of scanning electron microscopy (SEM) with energy dispersive spectrometry (EDS) and X-ray diffraction (XRD).

Keywords: alumina, alumina-mullite intermediate layers, ceramic coatings, chemical resistance, cracks, molten glass, molten materials, plasma spraying, refractory materials, thermal cycling, thermal expansion, thermal shock resistance, wear resistance

G. Bolelli, V. Cannillo, C. Lugli, L. Lusvarghi, and T. Manfredini, Dipartimento di Ingegneria dei Materiali e dell'Ambiente, Facolta di Ingegneria, Universita di Modena e Reggio Emilia, 41100 Modena, Italy. Cited: *J. Eur. Ceram. Soc,* **26**(13), p 2561-2579 [in English]. ISSN 0955-2219.

Studies on the properties of high-velocity oxyfuel thermal spray coatings for higher-temperature applications. Materials operating at high temperatures in corrosive media suffer erosion-corrosion wear, oxidation, and hot corrosion. Among various methods used for the protection of the surfaces against degradation, one can especially mention the technology of application of coatings by high-velocity oxyfuel spraying, which gives coatings with high strength and hardness, low (less than 1%) porosity, and high erosion-corrosion and wear resistances. The characteristics of the coatings and their protective properties are presented. The role of some high-velocity oxyfuel coatings in the protection of metals and alloys against degradation at high temperatures in various media is demonstrated.

Keywords: alloys, corrosion, erosion corrosion wear, high-velocity oxyfuel, hot corrosion, oxidation, porosity, protective coatings, thermal effects, thermal spray coatings, wear resistance

T.S. Sidhu, S. Prakash, and R.D. Agrawal, Metallurgical and Materials Engineering Department, Indian Institute of Technology Roorkee, Roorkee-247 667, India. Cited: *Mater. Sci.,* 2005, Nov, **41**(6), p 805-823 [in English]. ISSN 1068-820X.

Functional Coating Materials

The magnetic properties of plasma sprayed thick-film manganese zinc ferrite (MZF) and nickel iron alloy (Permalloy) composites. MnZn ferrite/Permalloy composites have potential in high-frequency magnetic applications and can be made into thick-film devices by air plasma spray. The as-sprayed composites have lower saturation magnetization than the starting powder. After annealing below 600 °C, the magnetic properties and electrical resistivity improve significantly. The changes in magnetic and electrical properties were correlated to structural changes and studied by x-ray-diffraction analysis, vibrating-sample magnetometer measurements, and microstructural analysis.

Keywords: air plasma spray, ferrites, iron alloys, magnetic properties, magnetization, magnetometers, manganese alloys, manganese zinc ferrite, nickel iron alloy (Permalloy), plasma spraying, starting powder, thick films, x-ray diffraction analysis

S. Liang, R.J. Gambino, S. Sampath, and M.M. Raja, Department of Materials Science and Engineering, Stony Brook University, Stony Brook, NY 11794. Cited: *J. Appl. Phys.,* 2006, April 15, **99**(8), p [in English]. ISSN 0021-8979.

Photocatalytic efficiency enhancement of plasma sprayed TiO_2 coatings under external bias voltage. TiO_2 coatings were prepared on stainless steel by plasma spraying. The photocatalytic efficiencies of as-sprayed coatings were evaluated through the photo mineralization of methylene blue. External bias voltages applied to the coatings have shown an enhancement of the photocatalytic efficiency reducing the recombination of photogenerated electron-hole pairs. A more efficient photocatalytic reaction would take place when a higher external bias is imposed, because the force of recombination suppression is strengthened when the external bias is higher. The highest photocatalytic efficiency enhancement was about 46%.

Keywords: electrons, external bias, photocatalytic efficiency, photogenerated electron-hole pairs, plasma spraying, sprayed coatings, stainless steel, titanium compounds

J. Liu, Y. Zeng, J. Gao, W. Qian, and C. Ding, Shanghai Institute of Ceramics,

Chinese Academy of Sciences, Shanghai, 200050, China. Cited: *Ceram. Int.,* 2006, **32**(6), p 719-721 [in English]. ISSN 0272-8842.

Mechanics and Adhesion Analysis

A comparative study of three adhesion tests (EN 582, similar to ASTM C 633; LASAT, LASer Adhesion Test; and bulge and blister test) performed on plasma sprayed copper deposited on aluminum 2017 substrates. The aim of this study was to compare three adhesion tests carried out on plasma sprayed copper coatings on aluminum substrates. The first test, the bond pull test, designated EN 582 or ASTM C 633, involves a uniaxial static stress and is commonly used in the coating industry. The second test, the LASAT (LASer Adhesion Test), is a recently developed technique based on spallation phenomenon due to laser-induced shock waves. In this test, the coating delamination results from spallation at the coating/substrate interface due to uniaxial tensile stress. The last test, the bulge and blister test, involves a quasi-static measurement of the crack propagation energy at the coating/substrate interface. These three techniques have been used to evaluate the influences of different process parameters involved in the coating adhesion such as aluminum surface roughness, substrate preheating, and plasma spray conditions.

Keywords: aluminum, bond-pull test, bulge and blister test, copper plating, delamination, laser adhesion test (LASAT), laser-induced shock waves, plasma sprayed copper, plasma spraying, shock waves, spalling, sprayed coatings, substrates, surface roughness

M. Arrigoni, S. Barradas, M. Braccini, M. Dupeux, M. Jeandin, M. Boustie, C. Bolis, and L. Berthe, Laboratoire de Thermodynamique et Physico-Chimie Metallurgiques, CNRS-UJF-INPG ENSEEG-LTPCM, Domaine Universitaire, 38402 Saint Martin d'Heres Cedex, France. Cited: *J. Adhes. Sci. Technol.,* 2006, April, **20**(5), p 471-487 [in English]. ISSN 0169-4243.

Detection of decohesion/failure of paint/coating using electronic speckle pattern interferometry. Corrosion resistance of various industrial components depends on the performance of paints and coatings. An early and accurate detection of decohesion of paints/coatings is invaluable in proper maintenance of the coated components. Recent advances in the electronic speckle pattern interferometry provide capabilities of sensitive and precise detection of out-of-plane displacements. This paper presents recent laboratory results investigating the application of ESPI as a noncontact and nondestructive technique in detection of decohesion of some typical industrial paints for naval applications.

Keywords: acoustic excitation, corrosion resistance, decohesion, electronic speckle pattern interferometry, failure analysis, interferometry, nondestructive examination, paint, protective coatings, speckle, white noise

R.K.S. Raman and R. Bayles, Departments of Mechanical and Chemical Engineering, Monash University, Melbourne, Vic. 3800, Australia. Cited: *Eng. Failure Anal.,* 2006, Oct, **13**(7), p 1051-1056 [in English]. ISSN 1350-6307.

Effect of ductile thermal spray coatings on fatigue performance of 7075-T651 aluminum alloy. The fatigue behavior of 7075-T651 Al alloy with ductile aluminum thermal sprayed coatings deposited by four different commercial arc spray devices (guns) has been characterized. Coated specimens as well as polished and shot-peened specimens were evaluated under fully reversed uniaxial loading at a constant amplitude of ±225 MPa. While the shot-peening pretreatment was observed to increase the fatigue resistance of polished specimens, application of the coatings subsequently reduced fatigue life to below that of the original polished coupons. Changes in the residual stress state of the shot-peened surface were identified as the most likely source of these reductions, even though no microstructural changes in the substrate were perceptible. Variations in fatigue life were also observed between the coatings resulting from the four spray guns. The roles of surface roughness and coating delamination in producing these decreases were investigated, and stress concentrations resulting from coating delamination were identified as the primary detrimental factor affecting fatigue resistance.

Keywords: aluminum alloys, coatings, commercial arc spray devices, delamination, ductility, fatigue of materials, fatigue resistance, microstructure, residual stresses, shot peening, spray guns, spraying, substrates, surface roughness, thermal spray coatings, uniaxial loading

B. Arsenault, A.K. Lynn, and D.L. Duquesnay, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada. Cited: *Can. Metall. Quart.,* 2005, Oct **44**(4), p 495-504 [in English]. ISSN 0008-4433.

Effects of bond coat misfit strains on the rumpling of thermally grown oxides. One factor governing the durability of thermal barrier systems is the concurrent thickening and elongation of the thermally grown oxide (TGO) upon temperature cycling. The elongation can cause cyclic rumpling of the TGO: influenced by oxide growth, bond-coat phase transformations, substrate/bond-coat interdiffusion, and constituent strengths. The individual effects of these phenomena cannot be understood by experiment alone. In the current study, simulations are conducted to isolate the effects of the misfit strains between the bond coat and substrate. These strains originate from thermal expansion mismatch, phase transformations, and bond coat swelling. For each calculation, the response of the system throughout an individual thermal cycle is linked to the stresses in the bond coat and TGO. Results obtained for representative misfit strains indicate that all three sources promote rumpling during the early stages, while phase transformations and thermal expansion mismatch are more prevalent upon extended cycling. These misfits also induce tensile stresses in the oxide large enough to cause cracking at high temperature. Further analysis has been used to assess the benefits of developing bond coats having lower phase transformation temperature, higher strength, and a more closely matched coefficient of thermal expansion.

Keywords: computer simulation, misfit strains, oxides, phase transitions, substrates, swelling, thermal barrier coatings, thermal cycling, thermal expansion, thermal expansion mismatch, thermal stress, thermally grown oxide

A.W. Davis and A.G. Evans, Mechanical and Aerospace Engineering Department, Princeton University, Princeton, NJ 08544. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci,* 2006, July, **37**(7), p 2085-2095 [in English]. ISSN 1073-5623.

Effects of oxide thickness, Al_2O_3 interlayer, and interface asperity on residual stresses in thermal barrier coatings. During high-temperature operation, the thermally grown oxide (TGO) usually forms along the bondcoat/topcoat interface in thermal barrier coating (TBC) and was characterized as a driving force for the failure of the coating system. The effects of TGO thickness and Al_2O_3 interlayer applied as an oxygen barrier layer between the bondcoat and topcoat on the magnitude of residual stresses in TBC during cooling process were interpreted using concentric-circle model. The results were coupled with finite-element method. The influences of interface asperity and interface topography on the distribution of residual stresses normal to interfaces in TBC were also discussed.

Keywords: aluminum compounds, concentric-circle model, finite-element method, high-temperature operations, interface asperity, interfaces (materials), oxide thickness, oxides, residual stresses, stress concentration, thermal barrier coatings, thermally grown oxide

X.C. Zhang, B.S. Xu, H.D. Wang, and Y.X. Wu, State Key Laboratory of Metal Matrix Composites, Shanghai Jiaotong University, Shanghai, 200030, China. Cited: *Mater. Des.,* 2006, **27**(10), p 989-996 [in English]. ISSN 0261-3069.

Evaluation of toughness of hard coatings. Repeated impact has been introduced to evaluate different properties of hard coatings, such as impact wear resistance, bonding strength, fatigue, and so forth. The load and impact number relationships are similar to that of fatigue curves, and close to some real applications of coated parts. Cr-Cu-N coatings were performed on a hardened steel substrate and the repeated impact tests were conducted on the coating substrate system. At a low impact load, the intrinsic strength of the coating layer and the bonding strength between the coating and substrate are in competition. Coating layer cracking or delamination might occur, and the strength plays an important role like that of high-cycle fatigue. When the load is increased and toward the low-cycle fatigue regime, toughness of the coating layer turns out to be predominant. The cohesive failure in high load regime preferentially depends on the toughness of the coating layer, and the failure cycles can be employed as a toughness criterion.

Keywords: adhesion, bonding, coating layers, evaluation, failure (mechanical), fatigue of materials, hard coatings, low-cycle fatigue, protective coatings, repeat impact, toughness, wear resistance

M.D. Bao, X.D. Zhu, and J.W. He, State Key Laboratory for Mechanical Behaviour of Materials, Xi'an Jiaotong University, Xi'an 710049, China. Cited: *Surf. Eng.,* 2006, Feb, **22**(1), p 11-14 [in English]. ISSN 0267-0844.

Modeling of residual stresses variation with thermal cycling in thermal barrier coatings. Thermal barrier coatings (TBCs) are commonly used as protective coatings for engine metal components to improve performance. Many investigations have shown that residual stresses in TBCs applications play an important role, but the residual stresses are mainly obtained by simulation method. As is known, there are a few analytical solutions of residual stress in TBCs system. In this paper, a new two-dimensional analytical solution has been obtained under the condition of nonlinear coupled effects of temperature gradient, thermal fatigue, deposited residual stress, thermally grown oxide (TGO) thickening, elastoplasticity deformation, and creep deformation of TBC. Moreover, the influences of bending moment and curvature on stress variation in TBCs are considered during thermal cycling. The calculated results are in agreement with the prior experimental results.

Keywords: computer simulation, creep deformation, elastoplasticity, plastic deformation, residual stresses, stress variation, thermal barrier coatings, thermal cycling, thermal gradients, thermally grown oxide

W.G. Mao, Y.C. Zhou, L. Yang, and X.H. Yu, Key Laboratory for Advanced Materials and Rheological Properties, Ministry of Education, Xiangtan University, Xiangtan, Hunan 411105, China. Cited: *Mech. Mater,* 2006, Dec, **38**(12), p 1118-1127 [in English]. ISSN 0167-6636.

Preliminary study of improvement of fatigue properties of welded joints by plasma spray process. The addition of a low modulus coating by a spray process was used to improve the fatigue properties of a fillet-welded joint. Fatigue tests were performed on TIG welded cruciform joints in 1Cr18Ni9Ti stainless steel under stress ratio $R = 0$, in the as-welded, flame sprayed, and plasma sprayed conditions. These showed that the plasma spray process was

effective in increasing the fatigue strength of the cruciform welded joints, but flame spraying was less effective. In particular, the fatigue strength of the as-welded joints was increased by 26% with plasma sprayed coating, but by only 10% with the flame sprayed coating. The corresponding increases in fatigue life were 1.58 to 9.62 for the plasma sprayed specimens compared with 1.55 to 1.97 times for the flame sprayed specimens. Finite-element stress analysis showed that the stress concentration factor at weld toe of the spray coated specimens was much decreased. It also confirmed that the stress perpendicular to the interface between the spray coating and base metal was greater than the adhesion strength of the flame sprayed coating, which resulted in the coating near the weld toe peeling off during the fatigue tests. As a result, the fatigue life of the flame sprayed specimens was lower than that of the plasma sprayed ones.

Keywords: coating methods, electric arc welding, fatigue improvement, fatigue of materials, finite-element method, flame sprayed coating, flame spraying, gas tungsten arc welding, plasma spraying, stainless steel, strength of materials, welds

L. Huo, Z. Zhang, D. Wang, and Y. Zhang, Welding Division, College of Materials Science and Engineering, Tianjin University, Tianjin, China. Cited: *Weld. World,* 2006, July/Aug, **50**(7-8), p 58-63 [in English]. ISSN 0043-2288.

Residual stresses and their effects on the durability of environmental barrier coatings for SiC ceramics. Qualitative residual stresses in current environmental barrier coatings (EBCs) were inferred from the curvature of EBC-coated SiC wafers, and the effects of EBC stresses on the durability of EBC-coated SiC were evaluated. The magnitude of substrate curvature correlated fairly well with the EBC-SiC coefficient of thermal expansion (CTE) mismatch, EBC modulus, and thermally induced physical changes in EBC. BSAS ($1 - x\text{BaO}\cdot x\text{SrO}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$, $0 \leq x \leq 1$) components in the current EBCs; that is, Simullite or mullite + BSASBSAS or yttria-stabilized zirconia (YSZ: ZrO2-8wt%Y_2O_3), were the most beneficial for reducing the EBC stress in as-sprayed as well as in postexposure EBCs. The reduced stress was attributed to the low modulus of BSAS. The addition of a YSZ top coat significantly increased the substrate curvature because of its high CTE and sintering in thermal exposures. There were clear correlations between the wafer curvature and the EBC durability. The Simullite + 20 wt% BSASBSAS EBC maintained excellent adherence, protecting the SiC substrate from oxidation, while the Simullite + 20 wt% BSASYSZ EBC suffered delamination, leading to severe oxidation of the SiC substrate, after a 100 h –1300 °C exposure in a high-pressure burner rig.

Keywords: ceramic materials, coating techniques, environmental barrier coatings, high-pressure burner rig, oxidation, residual stresses, silicon carbide, silicon wafers, thermal expansion

K.N. Lee, J.I. Eldridge, and R.C. Robinson, NASA Glenn Research Center, Cleveland, OH 44135. Cited: *J. Am. Ceram. Soc.,* 2005, Dec, **88**(12), p 3483-3488 [in English]. ISSN 0002-7820.

Surface-stiffened elastic halfspace under the action of a horizontally directed Mindlin force. This paper presents an analytical solution to the problem of the interaction between a thin plate that is adhesively bonded to the surface of an isotropic elastic halfspace and a concentrated Mindlin-type force that acts parallel to the bonded surface. The model is an idealization of a surface-stiffened region that has potential applications ranging from mechanics of thin films, thermal barrier coatings, layering created by attrition, and wear of surfaces and functionally graded materials. The solution also illustrates the influence of the flexural plate model in mitigating the development of unbounded displacements during the application of localized loading directly at the bonded plate.

Keywords: adhesively bonded plate, Cerruti's problem, force control, functionally graded solid, interfaces (materials), internal loading of halfspace, loading, mathematical models, mechanics of thin films, plates (structural components), problem solving, stiffness, surface topography, thermal barrier coatings

A.P.S. Selvadurai and K. Willner, Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Quebec, H3A 2K6, Canada. Cited: *Int. J. Mech. Sci,* 2006, Oct, **48**(10), p 1072-1079 [in English]. ISSN 0020-7403.

Nanostructured Coatings and Bulk Materials

Correlation of microstructure and wear resistance of Al_2O_3-TiO_2 coatings plasma sprayed with nanopowders. Correlation of microstructure and wear resistance of $\text{A1}_2\text{O}_3$-TiO_2 coatings plasma sprayed with nanopowders was investigated in this study. Four kinds of nanostructured Al_2O_3-13wt.%TiO_2 coatings were fabricated by varying plasma spraying parameters and were compared with an $\text{A1}_2\text{O}_3$-13.%TiO_2 coating fabricated with conventional powders. The nanostructured coatings showed a bimodal microstructure composed of fully melted regions of γ-$\text{A1}_2\text{O}_3$ and partially melted regions, while the conventional coating mostly consisted of fully melted γ-$\text{A1}_2\text{O}_3$, together with some TiO_2-rich regions and unmelted $\text{A1}_2\text{O}_3$ powders. The wear test results revealed that the wear resistance of the nanostructured coatings was three or four times better than that of the conventional coating, because the preferential delamination seriously occurred along TiO_2-rich regions in the conventional coating. In the nanostructured coatings, TiO_2 was homogeneously dispersed inside splats and around, thereby leading to higher splat bonding strength and to better wear resistance over the conventional coating.

Keywords: alumina, bond strength (materials), delamination, metallographic microstructure, nanopowders, nanostructured coatings, nanostructured materials, plasma spraying, powders, titanium dioxide, wear resistance

J. Ahn, B. Hwang, E.P. Song, S. Lee, and N.J. Kim, New Materials and Component Research Center, Research Institute of Industrial Science and Technology, Pohang 790-600, South Korea. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci.,* 2006, June, **37**(6), p 1851-1861 [in English]. ISSN 1073-5623.

Development of nanostructured Al_2O_3-Ni HVOF coatings. HVOF thermal spraying has been developed to deposit dense Al_2O_3 coatings for improved protective properties. As compared to generally used plasma sprayed coatings, HVOF coatings can be prepared much denser and thus are better suited for applications where protective properties of the coating are needed. In this paper the authors describe the development of HVOF spraying technologies for nanocrystalline Al_2O_3 and Al_2O_3 Ni coatings. The microstructure and the mechanical properties of these novel coatings are reported and compared to a conventionally processed Al_2O_3 coating.

Keywords: alumina, coatings, mechanical properties, microstructure, nanocomposites, nanostructured materials, nickel, plasma sprayed coatings, plasma spraying, thermal spraying

S.-P. Hannula, E. Turunen, J. Keskinen, T. Varis, T. Fait, T.E. Gustafsson, and R. Nowak, VTT Industrial Systems, 02044 VTT, Finland. Cited: *Key Eng. Mater.,* 2006, **317-318,** p 539-544 [in English]. ISSN 1013-9826.

Development and properties of nanostructured thermal spray coatings. Nanostructured thermal spray coatings have been intensively studied because of their potential in a wide variety of industrial applications. In the present paper, current development status of nanostructured thermal spray coatings is presented, mainly based on the results of the authors. In the nanostructured WC-Co wear-resistant coatings, the influence of feedstock characteristics on the coating properties was discussed to suggest the desirable morphology of feedstock for thermal spraying. For the nanostructured Cr_2O_3-based solid-lubricant coatings, the advanced feedstock has been developed in order to solve the inhomogeneity problem of the conventional coatings. Various properties of the nanostructured coatings were evaluated and compared with those of the conventional counterparts. These results clearly demonstrate that the significant improvement in coating performance can be achieved by utilizing proper nanostructured coatings.

Keywords: industrial applications, nanostructured coatings, nanostructured materials, solid lubricants, solid-lubricant coatings, sprayed coatings, thermal spray, WC-Co coatings, wear resistance

J.-H. Kim, H.-S. Yang, K.-H. Baik, B.G. Seong, C.-H. Lee, and S.Y. Hwang, Research Institute of Industrial Science and Technology (RIST), Pohang, 790-600, South Korea. Cited: *Current Applied Physics,* 2006, Oct **6**(6 SPEC. ISS.), p 1002-1006 [in English]. ISSN 1567-1739.

Microstructural feature, thermal shock resistance, and isothermal oxidation resistance of nanostructured zirconia coating. Nanostructured and conventional zirconia coatings on superalloys have been deposited to show thermal shock resistance and oxidation resistance by atmospheric plasma spraying. The results showed that the nanostructured zirconia coating mainly contained two kinds of microstructures, nanosized zirconia particles embedded in the matrix and micrometer-sized columnar grain structures of zirconia similar to those of conventional zirconia coating. Compared with the conventional zirconia coating, the nanostructured coating is denser and has finer and less porous structure and fewer microcracks with higher thermal shock resistance and isothermal oxidation resistance. With increasing zirconia coating thickness from 100 to 500 μm, the thermal shock resistance of both nanostructured and conventional coatings decreased. The increased properties of nanostructured zirconia coating are related to improved toughness and decreased porosity and microcrack of the coating.

Keywords: atmospheric plasma spraying, heat resistance, inorganic coatings, isothermal oxidation resistance, microcracks, microstructure, nanostructured materials, oxidation resistance, plasma spraying, porosity, superalloys, thermal shock resistance, toughness, zirconia, zirconia coating

W.Q. Wang, C.K. Sha, D.Q. Sun, and X.Y. Gu, Key Laboratory of Automobile Materials, School of Materials Science and Engineering, Jilin University, Changchun, 130025, China. Cited: *Mater. Sci. Eng. A,* 2006, May 25, **424**(1-2), p 1-5 [in English]. ISSN 0921-5093.

Nano-SiC particles reinforced plasma sprayed WC-Co coating by laser melting process. The laser melting process of SiC nanoparticles coated on the plasma sprayed WC-Co coating was performed. The SiC nanocomposite coating was prepared, and the microstructure and the mechanical properties of it were investigated. After laser irradiation, parts of nano SiC particles are turned into the inner of coating with the nano-micro composite structure. The existence of SiC nanoparticles in the coating brings the better fine microstructure and the higher densification. The wear-resistant and the corrosion-resistant properties of the coating with SiC nanoparticles are improved more

than the coatings prepared by laser melting process without the SiC nanoparticles.

Keywords: coated materials, laser applications, laser melting, mechanical properties, nanostructured materials, plasma sprayed, plasma spraying, SiC nanoparticles, tungsten carbide, wear of materials

J.F. Zhao, Y. Li, and L. Wang, Laser and Rapid Prototyping Research Centre, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China. Cited: *Key Eng. Mater.,* 2006, **315-316,** p 575-578 [in English]. ISSN 1013-9826.

Synthesis of bulk FeAl nanostructured materials by HVOF spray forming and spark plasma sintering. This paper examines the efficiency of two consolidation processing techniques: high-velocity oxyfuel (HVOF) spray forming and spark plasma sintering (SPS) to obtain bulk nanostructured materials from an Y_2O_3 reinforced Fe-40Al (at.%) milled powder. The microstructures of the sintered end-products were characterized by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) in order to gain new insights in their microstructure formation mechanisms. HVOF spray forming is more effective to retain fine nanograins, in particular within retained unmelted powder particles. The drawbacks of this technique are that it inevitably leads to a high fraction of porosity and, because of lack of wetting, large areas (the melted zones) without any Y_2O_3 oxide. Comparatively, SPS has a much higher potential to create sub-micrometer microstructures within which the oxides are more homogeneously distributed.

Keywords: iron aluminides based on FeAl, iron compounds, microstructure, nanostructured intermetallics, nanostructured materials, plasma spraying, scanning electron microscopy, sintering, synthesis (chemical), transmission electron microscopy

T. Grosdidier, G. Ji, F. Bernard, E. Gaffet, Z.A. Munir, and S. Launois, Laboratoire d'Etude des Textures et Application aux Materiaux (LETAM), UMR CNRS 7078, Universite de Metz, 57045 Metz Cedex 01, France. Cited: *Intermetallics,* 2006, Oct/Nov, **14**(10-11), p 1208-1213 [in English]. ISSN 0966-9795.

Thermal stability and mechanical properties of plasma sprayed Al_2O_3/ZrO_2 nanocomposite coating. Alumina/zirconia nanocomposite coating was fabricated by plasma spraying using agglomerated feedstock from fine powders of about 100 nm. The coating was consisted of fine γ-alumina and zirconia crystals with size of several nanometers and some amorphous boundary layers. The amorphous phase was crystallized and disappeared after heat treatment at 930 °C. However, the crystallite size was kept under 50 nm even after 1500 °C 100 h heating, so the alumina-zirconia nanocomposite showed good thermal stability against the grain growth.

Keywords: alumina, amorphous boundary layers, coatings, composite materials, crystallite sizes, fine powders, grain growth, nanostructured composite coatings, nanostructured materials, plasma spraying, thermodynamic stability, zirconia

S. Sodeoka, M. Suzuki, and T. Inoue, National Institute of Advanced Industrial Science and Technology (AIST) West Tsukuba, Ibaraki, 305-8569, Japan. Cited: *Key Eng. Mater.,* 2006, **317-318,** p 513-516 [in English]. ISSN 1013-9826.

Powders

Nanopowder dispersion and spray drying process: The case of Cr_2O_3. The work reported in this paper was performed in order to develop and to optimize the dispersion of Cr_2O_3 nanopowders by a ball-milling method and to produce spherical micrometer-sized granules by spray drying. The targeted application for such granules is the development of wear-resistant nanostructured Cr_2O_3 coatings by plasma spraying. Cr_2O_3 nanopowders were dispersed in deionized water. The suitable dispersant (DarvanC) was determined by zeta potential measurements and the dispersant quantity was optimized by rheological tests. The influence of milling time, diameter of milling balls, and weight ratio of milling balls to powder was studied by granulometric measurements. A well-dispersed and stable suspension was then obtained and spray dried. Dense and spherical micrometer-sized granules, with a monodispersed distribution centered about 50 µm, have been achieved and Cr_2O_3 plasma sprayed coatings have been realized.

Keywords: chromium compounds, coatings, Cr_2O_3, deionized water, dispersions, granular materials, nanopowders, nanostructured materials, optimization, plasma spraying, spray drying, suspensions (components)

A. Cellard, R. Zenati, V. Garnier, G. Fantozzi, and G. Baret, Insa Lyon, Batiment Blaise Pascal, GEMPPM, 69621 Villeurbanne Cedex, France. Cited: *Int. J. Mater. Res.,* 2006, May, **97**(5), p 632-638 [in English]. ISSN 1862-5282.

Spheroidization of metal and ceramic powders in thermal plasma jet: Comparison between experimental results and theoretical estimation. For smooth and uniform feeding of powders into plasma jet, for thermal spray coating, the powder particles have to be spherical in shape since they have good flow quality. Spheroidization of micron-sized metal and ceramic powders to produce flow-quality powders using plasma processing is a modern concept. In the present work a theoretical estimation of the percentage of spheroidization of particles has been made from basic fluid dynamic equations. Particles of nickel and alumina of 50 to 60 µm were considered at different plasma gas flow rates and temperatures (input power). Particles with the same specifications were spheroidized using plasma processing. Optical micrographs showed spherical shape of processed powders. Percentage of spheroidization was measured by irregularity parameter (IP) and roundness (RN) and the same were compared with theoretical estimation. Experimentally a maximum of 87% spheroidization was obtained. Comparatively the maximum difference between theory and experiment is 7% that of the experimental value.

Keywords: argon plasma, ceramic materials, heat treatment, irregularity parameter, melting, melting time, parameter estimation, plasma jets, plasma spraying, powder metals, residence plasma, roundness, spheroidization

S. Kumar, V. Selvarajan, P.V.A. Padmanabhan, and K.P. Sreekumar, Department of Physics, Bharathiar University, Coimbatore, 641 046, India. Cited: *J. Mater. Process. Technol.,* 2006, June 6, **176**(1-3), p 87-94 [in English]. ISSN 0924-0136.

Process Modeling and Analysis

In Flight

3D modeling of kerosene-fueled HVOF thermal spray gun. Liquid-fueled high-velocity oxyfuel (HVOF) thermal spraying systems are capable of generating more momentum output to powder particles in comparison with gas-fuelled systems. The use of low-cost fuel such as kerosene makes this technology particular attractive. High-quality coating requires thermal spraying systems delivering consistent performance as a result of the combustion during HVOF spraying. The combustion of kerosene is very complicated due to the variation of fuel composition and subsequently makes it extremely challenging for process control. This paper describes a 3D simulation using mathematical models available in a commercial finite volume CFD code. The combustion and discrete particle models within the numerical code are applied to solve the combustion of kerosene and couple the motion of fuel droplets with the gas flow dynamics in a Lagrangian fashion. The effects of liquid fuel droplets on the thermodynamics of the combusting gas flow are examined thoroughly.

Keywords: combustion, composition, computational fluid dynamics, computer simulation, finite-element method, gas dynamics, gas flows, high-velocity oxyfuel, kerosene, mathematical models, process control, spray guns, thermal spraying systems

S. Kamnis and S. Gu, School of Engineering and Applied Science, Aston University, Birmingham, B4 7ET, U.K. Cited: *Chem. Eng. Sci.,* 2006, Aug, **61**(16), p 5427-5439 [in English]. ISSN 0009-2509.

Computational study of particle in-flight behavior in the HVOF thermal spray process. A computational framework is developed for the multiphase flow in a high-velocity oxyfuel (HVOF) thermal spray coating process with steel powders as the feedstock. The numerical model includes continuum-type differential equations that describe the evolution of gas dynamics and multidimensional tracking of particle trajectories and temperature histories in the turbulent reacting flow field. The numerical study shows that the particle temperature is strongly affected by the injection position while the particle velocity is less dependent on this parameter. Moreover, both particle velocity and temperature at impact are strongly dependent on particle size, although the spatial variation of these two variables on the substrate is minimal. It is also found that not all the particles are deposited on the substrate perpendicularly (even if the spray angle is 90°), due to substantial radial fluid velocities near the stagnation point. A statistical distribution of particle velocity, temperature, impinging angle, and position on the substrate as well as particle residence time is obtained in this work through independent random tracking of numerous particles by accounting for the distributed nature of particle size in the feedstock and injection position as well as the fluctuations in the turbulent gas flow.

Keywords: computational fluid dynamics, computer simulation, differential equations, gas dynamics, high-velocity oxyfuel, HVOF thermal spray, injection position, mathematical models, modeling, multidimensional tracking, multiphase flow, particle in-flight behavior, sprayed coatings, stochastic particle tracking

M. Li and P.D. Christofides, Department of Chemical and Biomolecular Engineering, University of California, Los Angeles, CA 90095. Cited: *Chem. Eng. Sci.,* 2006, Oct, **61**(19), p 6540-6552 [in English]. ISSN 0009-2509.

Modeling of arc behavior inside a F4 APS torch. The plasma arc inside the F4 torch used for atmospheric plasma spraying is characterized by means of analytical and numerical methods. A simplified analytical model is formulated to understand the physical behavior of the plasma arc. A three-dimensional numerical model is developed to simulate the realistic plasma arc flow inside the torch. At a given torch power and gas flow rate, possible combinations of the arc core radius and arc length are predicted. The thermodynamic principle of minimum entropy production is used to determine the combination of arc core radius and arc length, which corresponds to the actual physical situation of the arc inside the torch. The effect of arc current and gas flow rate on the plasma arc characteristics is clarified. The effect of hydrogen content in the

plasma gas on its velocity and temperature profiles at the nozzle exit is shown. Predicted torch efficiencies are comparable to measured ones. The results of the numerical model are similar to that an analytical model. Previously published experimental and numerical results support part of the present results.

Keywords: entropy, fluid dynamics, gas flow rate, hydrogen content, mathematical models, plasma gas, plasma spraying, plasma torches, temperature profiles, thermodynamics

K. Ramachandran, J.L. Marques, R. Vassen, and D. Stover, Institute for Materials and Processes in Energy Systems IWV-1, Forschungszentrum Julich GmbH, Julich, Germany. Cited: *J. Phys. D: Appl. Phys.,* 2006, Aug 7, **39**(15), p 3323-3331 [in English]. ISSN 0022-3727.

Numerical simulation on supersonic flow in high-velocity oxyfuel thermal spray gun. This paper analyzes the behavior of coating particles as well as the gas flow both inside and outside of the high-velocity oxyfuel (HVOF) thermal spray gun by using a quasi-one-dimensional analysis and a numerical simulation. The HVOF gun in the present analysis is an axially symmetric convergent-divergent nozzle with the design Mach number of 2.0. From the present analysis, the distributions of velocity and temperature of the coating particles flying inside and outside of the HVOF gun are predicted. The velocity and temperature of the coating particles at the exit of the gun calculated by the present method agree well with the previous experimental results. Therefore, the present method of calculation is considered to be useful for predicting the HVOF gas and particle flows.

Keywords: coating particles, compressible flow, computer simulation, fuels, gases, high-velocity oxyfuel, jets, mathematical models, one-dimensional, oxygen, particles (particulate matter), quasi-one-dimensional analysis, spray guns, sprayed coatings, supersonic flow, thermal spray, velocity measurement

H. Katanoda, H. Yamamoto, and K. Matsuo, University of Kitakyushu, Fukuoka, 808-0135, Japan. Cited: *J. Therm. Sci.,* 2006, March, **15**(1), p 65-70 [in English]. ISSN 1003-2169.

On the "rocket" effect during plasma arc spraying. The surface of a particle is not heated uniformly during plasma arc spraying: the side of the surface that faces the torch is hotter than the opposite side. If the particle temperature is high enough for substantial evaporation to occur, the imbalance of the vapor pressure gives rise to a net recoil force accelerating the particle toward the substrate. Estimations show that if particle loss of mass due to evaporation, the suggested effect is as important for particle dynamics as aerodynamic drag. (M is the particle mass, U_d is the particle speed and is the speed of the evaporating atom, m is its mass, and T is the particle surface temperature.)

Keywords: aerodynamic drag, evaporation, particle accelerators, particle dynamics, particle mass, plasma spraying, plasma torches, recoil force, substrates, vapor pressure

V. Nemchinsky, ESAB Welding and Cutting Products, Florence, SC 29501. Cited: *J. Phys. D: Appl. Phys.,* 2006, May 21, **39**(12), p 2540-2543 [in English]. ISSN 0022-3727.

Oxidation during electric arc spray forming of steel. Twin wire electric arc spraying is being developed as a technique to form thick steel deposits for rapid production tooling by robotically manipulating several arc guns over a ceramic pattern. Even though nitrogen atomizing gas is used to spray the steel, entrainment of oxygen from the surrounding atmosphere of the large extraction booth results in deposits that are high in oxide and substantially lower in carbon than the original steel feedstock wire. The amount of oxidation and carbon loss can be reduced if spraying is carried out in a smaller, enclosed chamber. Under chamber spraying conditions, controlled additions of oxygen to the nitrogen atomizing gas leads to an increase in deposition temperatures, better bonding with the substrate, a coarser microstructure, a decrease in deposit hardness and increased deposit brittleness through intersplat delamination and oxide cracking. Differences in substrate shape, gun manipulation, and oxygen entry point into the spray between chamber and spraying in a booth using a robot also alters the balance of oxidation and carbon loss processes. Oxidation during the spraying of thick steel deposits can happen in three main ways: (a) primary droplets in-flight prior to deposition, (b) incorporation of secondary droplets generated by splashing, (c) at the deposit top surface.

Keywords: alloying element loss, brittleness, carbon, chamber spraying, deposit microstructures, droplet oxidation, feedstocks, hardness, manipulators, metal forming, microstructure, nitrogen, oxidation, oxygen, steel, substrates, thermal spray

A.P. Newbery and P.S. Grant, Department of Chemical Engineering and Materials Science, University of California, Davis, CA 95616. Cited: *J. Mater. Process. Technol.,* 2006, Sept 14, **178**(1-3), p 259-269 [in English]. ISSN 0924-0136.

Shockwave atomization: Physical mechanisms of a modulated DC plasma torch during spray coating. This work is an attempt to understand the physical mechanisms of using DC torch modulation technology for spraying. The influence of the plasma disturbances created by means of arc current modulation and the influence of these disturbances on thermodynamic parameters and dynamic viscosity of the modulated plasma jet are investigated. As a result of this investigation, the phenomena causing the modulation effects—both in the plasmatron and in the mechanisms influencing the plasma technology parameters—have become understandable. It is shown that inserting hydrocarbons into the air plasma jet is a contributing factor for the transition of the torch to the laminar spraying mode (with vortex stabilization of the arc), with a high-coefficient use of powder. The physical estimations obtained have made the mechanisms of the formation of the sprayed coatings understandable. The results of interaction between the pulse-modulated plasma jet and the wire and powdery material being sprayed have been scrutinized. When plasma spraying is performed with DC current pulses superimposed in a reverse and direct polarity to the arc, the through-gas permeability of the coating is reduced by the order of magnitude. The most important explanation behind the phenomena is the disintegration of particles sprayed specific to the modulation process. By modulating the plasma arc current, sequential plasma shock waves disintegrate the spray particles, up to the size of the nanoparticles, and accelerate them toward the target substrate. The plasma arc current is precisely controlled to ensure a short-time constant in the plasma, so that rapid changes in the plasma arc current form plasma shock waves that strongly impact the spray particles. There is a brief description of the advantages and shortcomings of plasma spraying technology, HVOF, cold spraying, plasma spraying with modulation, and detonation technologies. Each technology has important features, such as high velocity of spraying particles, melted spraying material, and nonmelted spraying material; however, these technologies have rigid requirements with regard to the size of spraying powder. In one case, it is possible to neglect these requirements (to a certain degree); plasma technology with modulation combines all advantages of the above-mentioned technologies, and it has been applied in civil, military, and space techniques.

Keywords: arc current modulation, atomization, dynamic viscosity, gas permeability, plasma spraying, plasma torches, protective coatings, pulse modulation, pulse-modulated plasma jet, shock waves, viscosity, vortex flow

B.B. Gutman, St. Johns University, Touro College, NY. Cited: *Atom. Sprays,* 2006, **16**(3), p 279-298 [in English]. ISSN 1044-5110.

Process Modeling and Analysis

Splat Formation

3D predictions of thermally sprayed polymer splats: Modeling particle acceleration, heating and deformation on impact with a flat substrate. During thermal spray deposition, jets of high-temperature and high-velocity gases are used to melt and accelerate materials injected into the jet and propel them toward the surface to be coated. Upon impact at the surface, multiple hot particles deform, cool, and consolidate to form a coating. Mathematical models have been developed to predict the particle transport and splatting on impact with a flat substrate during the high-velocity oxyfuel (HVOF) combustion spraying of polymeric materials. The predicted shapes of deformed particles exhibited good qualitative agreement with experimentally observed splats including a characteristic "fried-egg" shape with large, nearly hemispherical, core in the center of a thin disk. These shapes were formed by polymer particles having a low-temperature, high-viscosity core and a high-temperature, low-viscosity surface.

Keywords: computer simulation, cooling, deformation, droplet impacts, jets, mathematical models, paint spraying, protective coatings, solvent-free coatings, splats, thermal spraying of polymers, viscosity

M. Ivosevic, R.A. Cairncross and R. Knight, Department of Chemical and Biological Engineering, Drexel University, PA 19104. Cited: *Int. J. Heat Mass Transfer,* 2006, Sept **49**(19-20), p 3285-3297 [in English]. ISSN 0017-9310.

Constructal theory of droplet impact geometry. In this paper the authors rely on the constructal law of maximization of flow access in order to construct a theory of geometry generation (selection, evolution) during molten droplet impact. We show that immediately after impact the liquid spreads inviscidly as a ring with a radial velocity that scales with the initial impact velocity. If the initial droplet is small and slow enough, the "splat" comes to rest (dies) viscously, as a disc. If the droplet is large and fast enough, the ring splashes and is continued outward by needles that grow radially until they are arrested by viscous effects. The authors optimized the number of needles such that the total splash time is minimum. The theoretical dimensionless group that governs the selection of geometry (G) is the ratio of two lengths, the final radius of the disc that dies viscously, divided by the radius of the still inviscid ring that just wrinkles. Splats form when $G \leq O(1)$ and splashes are favored when $G \geq O(1)$. Experimental measurements reported in the literature confirm several of the features of the constructal development of splat versus splash flow architecture.

Keywords: blood spatter, constructal theory, drop formation, fingering, flow interactions, forensic medicines, geometry, geometry generation, molten droplets, molten materials, optimization, selections, splashing, splat, spray coating, viscosity

A. Bejan and D. Gobin, FAST—UMR 7608 (CNRS - Univ. Paris VI and XI), 91405 Orsay, France. Cited: *Int. J. Heat Mass Transfer,* 2006, July, **49**(15-16), p 2412-2419 [in English]. ISSN 0017-9310.

A study on the impact and solidification of liquid metal droplets during thermal spray deposition onto a substrate with concentric grooves or ridges. In this study, a numerical investigation has been performed on the spreading and solidification of a coating material droplet onto the rigid substrate in the thermal spray process. The computational model is validated through the comparison of the predicted numerical result and the experimental data for flat substrate. An analysis of the deposition formation on a substrate with small concentric grooves or ridges was performed. To examine the characteristic of the impact and solidification of a liquid droplet on the substrate with concentric grooves or ridges, a parametric study was conducted with various shapes and sizes of concentric grooves or ridges.

Keywords: coatings, computation theory, concentric grooves, deposition, liquid metal droplets, liquid metals, mathematical models, numerical analysis, ridges, solidification, thermal spray deposition

E.-J. Ha, W.-S. Kim, and G.-D. Jeun, Department of Mechanical Engineering, Hanyang University, Ansan, Kyeonggi-do, 425-791, South Korea. Cited: *Heat Transfer Eng.,* 2006, April, **27**(3), p 55-67 [in English]. ISSN 0145-7632.

Space and Nuclear Applications

Optimization and characterization of tungsten thick coatings on copper-base alloy substrates. Tungsten is a promising armor material for plasma facing components of nuclear fusion reactors because of its low sputter rate and favorable thermomechanical properties. Among all the techniques able to realize W armors, plasma spray looks particularly attractive owing to its simplicity and low cost. The present work concerns the optimization of spraying parameters aimed at 4 to 5 mm thick W coating on copper-chromium-zirconium (Cu,Cr,Zr) alloy substrates. Characterization of coatings was performed in order to assess microstructure, impurity content, density, tensile strength, adhesion strength, thermal conductivity, and thermal expansion coefficient. The work performed has demonstrated the feasibility of thick W coatings on flat and curved geometries. These coatings appear as a reliable armor for medium heat flux plasma facing component.

Keywords: armor, C0600, coatings, composition, copper alloys, F0800, fusion reactions, M0300, nuclear reactors, substrates, T0600, T1000, tungsten

B. Riccardi, R. Montanari, M. Casadei, G. Costanza, G. Filacchioni, and A. Moriani, Associazione Euratom-ENEA sulla Fusione, 00044 Frascati, Roma, Italy. Cited: *J. Nucl. Mater.,* 2006, June 30, **352**(1-3), p 29-35 [in English]. ISSN 0022-3115.

Plasma sprayed tungsten-base coatings and their usage in edge plasma region of tokamaks. Tungsten is a candidate material for plasma facing components for ITER and other fusion devices. Plasma spraying is among prospective fabrication technologies, thanks to its ability to coat large areas and the possibility of in situ repair. Several types of tungsten-base coatings were produced at IPP Prague, using water-stabilized plasma spraying. Their structure, porosity, oxide content, and mechanical and thermal properties were characterized. Several stages of the spraying process optimization toward the foreseen application were performed. The usage of these coatings as plasma facing materials (covering different diagnostic tools) in the edge plasma region was tested at the CASTOR tokamak at IPP. Behavior of 0.4 to 2 mm thick plasma sprayed surfaces and their influence on the discharge quality was studied. Plasma sprayed tungsten-base samples, solid tungsten, and graphite were inserted into the plasma at various radii and exposed to tokamak discharges (30 ms pulse length, 30 kW ohmic heating). Moreover, the samples were biased by positive and negative voltages to increase electron and ion interaction with the sample surface. Broad scans over the biasing voltages (from –300 to +200 V) and sample surface locations (from the plasma edge up to the core region) were performed. Afterward, the sample surfaces were imaged by electron microscopy. Only a moderate surface modification was observed—narrow bright tracks, probably caused by unipolar arcing. Compositional changes in sprayed surfaces were also measured by RBS and ERDA methods. Hydrogen and carbon deposition, and oxygen content decrease were observed. Generally, pure tungsten coatings are suitable for covering different edge plasma diagnostics because of their low surface erosion and negligible influence on the discharge parameters.

Keywords: coatings, electron microscopy, fusion devices, in situ processing, optimization, plasma facing components, plasma sprayed coatings, plasma spraying, porosity, tokamak devices, tungsten

J. Matejicek, V. Weinzettl, E. Dufkova, V. Piffl, and V. Perina, Institute of Plasma Physics, Academy of Sciences of the Czech Republic, 182 00 Prague 8, Czech Republic. Cited: *Acta Technica CSAV (Ceskoslovensk Akademie Ved),* **51**(2), p 179-191 [in English]. ISSN 0001-7043.

Radiation properties modeling for plasma sprayed alumina-coated rough surfaces for spacecrafts. Spacecraft thermal control materials (TCMs) play a vital role in the entire service life of a spacecraft [NASA Preferred Reliability Practices: Spacecraft Thermal Control Coatings Design and Application (Practice No. PD-ED-1239), 1995, p 1-6]. Most of the conventional TCMs degrade in the harmful space environment [R.D. Karam, Satellite Thermal Control for Systems Engineers, AIAA, VA, 1998, p 147-163]. In the previous study, plasma sprayed alumina (PSA) coating was established as a new and better TCM for spacecrafts, in view of its stability and reliability compared to the traditional TCMs [R.M. Li, S.C. Joshi, and H.W. Ng, Presented in Second International Conference on Materials for Advanced Technologies and IUMRS, Singapore, 2003, p 1-4]. During the investigation, the surface roughness of PSA was found important, because the roughness affects the radiative heat exchange between the surface and its surroundings. Parameters such as root-mean-square roughness cannot properly evaluate surface roughness effects on radiative properties of opaque surfaces [M.F. Modest, Radiative Heat Transfer, 2nd ed., Academic Press/Elsevier Science, 2003, p 90-92]. Some models have been developed earlier to predict the effects, such as Davies' model [H. Davies, Proceedings of IEEE Vol. 101, part IV, 1954, p 209-214], Tang and Buckius's statistical geometric optics model [K. Tang, R.O. Buckius, Int. J. Heat Mass Transfer 2001, **44,** p 4059-4073]. However, they are valid only in their own specific situations. In this paper, an energy absorption geometry model was developed and applied to investigate the roughness effects with the help of 2D surface profile of PSA coated substrate scanned at micron level. This model predicts effective normal solar absorptance (α_{ne}) and effective hemispherical infrared emittance (ε_{he}) of a rough PSA surface. These values, if used in the heat transfer analysis of an equivalent, smooth and optically flat surface, lead to the prediction of the same rate of heat exchange and temperature as that of for the rough PSA surface. The model was validated through comparison between a smooth and a rough PSA coated surfaces. Even though not tested for other types of materials, the model formulation is generic and can be used to incorporate the rough surface effects for other types of thermal coatings, provided the baseline values of normal solar absorptance (α_n) and hemispherical infrared emittance (ε_h) are available for a generic surface of the same material.

Keywords: alumina, aluminum oxide, infrared emittance, infrared radiation, light absorption, plasma processing, plasma spraying, radiation effects, satellite thermal control, solar absorptance, spacecraft, surface roughness

R.M. Li, S.C. Joshi, and H.W. Ng, Division of Aerospace Engineering, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, 639798, Singapore. Cited: *Mater. Sci. Eng. B,* 2006, July 25, **132**(1-2), p 209-214 [in English]. ISSN 0921-5107.

Thermal optical properties of plasma sprayed mullite coatings for space launch vehicles. Thermal optical properties, for example, solar absorptance α and thermal emittance ε of thin plasma sprayed mullite coatings, were determined to assess the suitability of the material for space application. The mullite coatings were developed in an attempt to find a new material for thermal protection systems as well as thermal barrier coatings for atmospheric reentry vehicles. All mullite coatings show the properties of a solar reflector and hence suggest a potential application as thermal control coating to protect space-bound structures from the effect of heating by solar radiation in the low Earth orbit. Preliminary space stability tests including atomic-oxygen resistance tests confirmed that the coatings show only negligible variations both in their mechanical and thermal optical properties under the conditions selected.

Keywords: aerospace vehicles, atmospheric reentry vehicles, optical properties, oxygen, plasma spraying, reentry, solar radiation, space-bound structures, thermal barrier coatings, thermal control coating, thermal protection systems

S. Seifert, J.I. Kleiman, and R.B. Heimann, Technische Universitat Bergakademie Freiberg, D-09596 Freiberg, Germany. Cited: *J. Spacecraft Rockets,* 2006, March/April, **43**(2), March/April 2006, p 439-442 [in English]. ISSN 0022-4650.

Structural Characterization

Formation of amorphous and nanocrystalline phases in high-velocity oxyfuel thermally sprayed a Fe-Cr-Si-B-Mn alloy. High-velocity oxyfuel (HVOF) thermal spray was used to deposit a Fe-Cr-Si-B alloy coating onto stainless steel (1Cr18Ni9Ti) substrate. Microstructures of the powder and the coating were investigated by x-ray diffraction (XRD), scanning election microscopy (SEM), transmission election microscopy (TEM), and differential scanning calorimeter (DSC). The coating had layered morphologies due to the deposition and solidification of successive molten or half-molten splats. The microstructures of the coating consisted of a Fe-Cr-rich matrix and several kinds of borides. The Fe-Cr-rich matrix contained both amorphous phase and nanocrystalline grains with a size of 10 to 50 nm. The crystallization temperature of the amorphous phase was about 605 °C. The formation of the amorphous phase was attributed to the high cooling rates of molten droplets and the proper powder compositions by effective addition of Cr, Mn, Si, and B. The nanocrystalline grains could result from crystallization in amorphous region or interface of the amorphous phase and borides by homogeneous and heterogeneous nucleation.

Keywords: amorphous phase, crystal microstructure, crystallization, deposition, differential scanning calorimetry, high-velocity oxyfuel thermal spray, iron alloys, microstructure formation, morphology, nanocrystalline grains, nanostructured materials, scanning electron microscopy, solidification, sprayed coatings, thermal effects, transmission electron microscopy, x-ray diffraction analysis

Y. Wu, P. Lin, G. Xie, J. Hu, and M. Cao, Department of Materials Science and

Engineering, Hohai University, Nanjing, 210098, China. Cited: *Mater. Sci. Eng. A,* 2006, Aug 25, **430**(1-2), p 34-39 [in English]. ISSN 0921-5093.

Quantitative analysis of pores of two types in a plasma sprayed coating. Quantitative microstructural analyses of thermally sprayed coatings are reviewed. Then a ceramic plasma sprayed coating is analyzed using light microscopy and image analysis. Globular pores and interlamellar flat pores are reconstructed from serial sections of a specimen and their volume and surface area histograms are estimated. The spatial distribution of pores is described using a method based on 3D distances and testing of complete spatial randomness is performed. Interpretations of results in terms of the physical background of the material are discussed.

Keywords: chemical analysis, globular pores, homogeneity, image analysis, interlamellar flat pores, microstructure, optical microscopy, plasma sprayed coating, random processes, sprayed coatings

P. Ctibor, R. Lechnerova, and V. Benes, Institute of Plasma Physics, Academy of Sciences of the Czech Republic, 182 21 Prague, Czech Republic. Cited: *Mater. Charact,* 2006, June, **56**(4-5 SPEC. ISS.), p 297-304 [in English]. ISSN 1044-5803.

Structural study near the film/substrate interface of a plasma sprayed tin coating on low carbon steel. The structure near the film/substrate interface of tin coatings deposited with the plasma spray technique on a low-carbon steel substrate is examined with scanning electron microscopy (SEM), x-ray diffraction (XRD), conventional transmission electron microscopy (CTEM), and high-resolution electron microscopy (HREM), focusing on the structural properties affecting the corrosion performance. This examination revealed the presence of several Fe-Sn phases, which ensure good adhesion of the coatings to the underlying steel. Furthermore, amorphous Sn or SnO_x were also detected in the coating, which, being in low concentration, have no effect on the coating properties.

Keywords: adhesion, amorphous materials, carbon steel, coating properties, coating techniques, high-resolution electron microscopy, plasma spray techniques, plasmas, scanning electron microscopy, substrate interface, surfaces and interfaces, thin films, tin, transmission electron microscopy, x-ray diffraction analysis

G. Vourlias, N. Pistofidis, G. Stergioudis, and E.K. Polychroniadis, Department of Physics, Aristotle University of Thessaloniki, GR 54124 Thessaloniki, Greece. Cited: *J. Alloy. Compd.,* 2006, June 8, **416**(1-2), p 183-187 [in English]. ISSN 0925-8388.

Structural characterization of basalt-based glass-ceramic coatings. There are a lot of technologically interesting characteristics of glass-ceramics, which are hard, wear-resistant, oxidation- and corrosion-resistant ceramic materials. In the present study, the production of the basalt-based glass-ceramic coating by atmospheric plasma spray technique and their structural characterization were reported. Basalt-based glass coating was performed on AISI 1040 steel substrate, which was precoated with Ni-5wt%Al by using plasma spray gun. Basalt coatings of the glass form were crystallized at 800, 900, and 1000 °C for 1 to 4 h in orders to transform to the glass-ceramic structure. The presence of augite [$(CaFeMg)SiO_3$], diopside [$Ca(Mg_{0.15}Fe_{0.85})(SiO_3)_2$], and aluminian diopside [$Ca(Mg,Al)(Si,Al)_2O_6$] crystalline phases formed in the basalt-based glass-ceramic coating layer was detected by x-ray diffraction analysis. Optical microscopy with micrometer was used for metallographic examinations. Differential scanning calorimeter was used for determining the crystallization temperature of glass form basalt-based coatings. Microhardness measurements were carried out on the basalt-based glass-ceramic coating layer with Vickers indenter. The hardness of coating layers is changing between 1009 and 1295 $HV_{0.05}$ depending on crystallization temperature and process times. It was found that, the higher the crystallization temperature, the more the crystalline phases were resulted. In addition, the lower the crystallization temperature and the longer the treatment time, the harder the coating layer became.

Keywords: basalt, basalt-based coatings, characterization, coatings, crystallization, crystallization temperature, differential scanning calorimetry, glass, glass ceramics, glass-ceramic coatings, optical microscopy, plasma applications, plasma spray coating, plasma spraying, structural characterization, x-ray diffraction analysis

S. Yilmaz, G. Bayrak, S. Sen, and U. Sen, Sakarya University, Engineering Faculty, Department of Metallurgical and Material Engineering, 54187 Sakarya, Turkey. Cited: *Mater. Des.,* 2006, **27**(10), p 1092-1096 [in English]. ISSN 0261-3069.

Thermal Barrier Coating Systems

Application of thermography in the evaluation of early signs of failure of thermal barrier coating systems. For a number of years piezospectroscopy (Cr fluorescence) has been used to monitor the stress levels in the thermally grown oxide (TGO) that forms between the bondcoat and the thermal barrier coating (TBC) in TBC systems. The purpose of that work has been to observe early signs of failure and thus allow operators to schedule service intervals before failure of the TBC system occurred. This paper reports the use of thermography as an additional tool that can be used to assess the "health" of TBC systems. The technique consists of imaging the surface of the TBC coated specimen with a high spatial resolution infrared camera while the specimen is heated, and monitoring the temperature of the outer surface of the TBC. Conductive heating through the substrate and radiative heating incident on the TBC have been studied. Early results are encouraging, revealing a clear correlation between thermograms obtained using the conductive and radiative forms of heating, some of the stress maps obtained using piezospectroscopy and direct metallographic evidence. Examples of electron beam physical vapor deposited (EB PVD) and air plasma sprayed (APS) TBC systems have been studied as they were progressively aged. Cracking and disbonding associated with the TGO and/or TBC have been observed in places where thermography showed differential heating.

Keywords: correlation methods, electron beam physical vapor deposited, failure (mechanical), failure of thermal barrier coating systems, metallography, physical vapor deposition, spectroscopic analysis, thermal barrier coatings, thermally grown oxides, thermograms, thermography (imaging)

J. Nunn, S. Saunders, and J. Banks, Materials Centre, National Physical Laboratory, Teddington, Middlesex, TW11 0LW, U.K. Cited: *Mater. High Temp.,* **22**(3-4), p 385-392 [in English]. ISSN 0960-3409.

Characterization of bond coat in a thermal barrier coated superalloy used in combustor liners of aero engines. This paper deals with characterization of a thermal barrier coated (TBC) Supeni 263 superalloy, mostly employed for manufacturing combustion chamber of aero turbines, with respect to microstructure, residual stress, hardness, and with special emphasis in establishing the ductile to brittle transition temperature (DBTT) of the bond coat by using acoustic emission technique during room-temperature and high-temperature tensile tests. Results reveal that the residual stress was tensile in nature in the TBC layer and compressive in the bond coat as well as in the substrate. The DBTT of this bond coat is around 650 °C, which is in close proximity to the value reported in literature for CoCrAlY type of bond coat. Finite-element technique used for analyzing the equivalent stresses in the bond coat, at a particular load within the elastic limit of the composite specimens, revealed highest order of equivalent stress at 800 °C as the bond coat is ductile above 650 °C. Delamination of the bond coat and spallation of the TBC were evident at high stresses during high temperature (800 °C) fatigue.

Keywords: acoustic emissions, bond coats, combustion chambers, delamination, engines, fatigue of materials, hardness, microstructure, residual stresses, spallation, superalloys, tensile, thermal barrier coated, thermal barrier coatings

A.K. Ray, B. Goswami, M.P. Singh, D.K. Das, N. Roy, B. Dash, B. Ravi Kumar, A.K. Ray, G. Das, P. Karuna Purnapu Rupa, N. Parida, A. Das, J. Swaminathan, and E. Dwarakadasa, National Metallurgical Laboratory (CSIR), Jamshedpur, 831007, India. Cited: *Mater. Charact.,* 2006, Sept, **57**(3), p 199-209 [in English]. ISSN 1044-5803.

Detection of hydrogen in hidden and spalled layers of turbine blade coatings. Gas turbine blades are covered with an outer ceramic top coat and an inner metallic bond coat, namely a thermal barrier coating system (TBC). The stability of the TBC is strongly influenced by the thermally growing oxide (TGO) that forms between the top and bond coat during turbine operation. This work is focused on the role of hydrogen in the adhesion of the top coat after oxidation at 1100 °C in dry and wet air at various time steps between 75 and 1150 h. To obtain the essential hydrogen information from the TGO the nuclear reaction $^1H(^{15}N, \alpha\gamma)^{12}C$ is used with a unique scattering chamber (SDIBA). This equipment combines the defined exfoliation of the top coat by using a four-point bending mechanism followed by IBA. This allows the determination of hydrogen concentration depth profiles at the TGO and first results are presented.

Keywords: adhesion, concentration (process), desktop failure, gas turbine blades, gas turbines, hydrogen, hydrogen analysis, hydrogen depth profiles, spallation, thermal barrier coatings, turbomachine blades

H.E. Zschau, M. Dietrich, D. Renusch, M. Schutze, J. Meijer, and H.W. Becker, DECHEMA e.V., Karl-Winnacker-Institut, D-60486 Frankfurt am Main, Germany. Cited: *Nucl. Instrum. Methods Phys. Res., B,* 2006, Aug, **249**(1-2 SPEC. ISS.), p 381-383 [in English]. ISSN 0168-583X.

Femtosecond laser machining of single-crystal superalloys through thermal barrier coatings. Femtosecond laser machining of single-crystal superalloys coated with thermal barrier coatings (TBCs) has been investigated. The investigations were carried out in air using a titanium:sapphire laser system (λ = 780 nm) operating at a repetition rate of 1 kHz and delivering individual pulses of 150 fs in duration. The ablation threshold of 7 wt.% yttria-stabilized zirconia (7YSZ) has been measured to be 1.52 ± 0.21 J/cm^2. Microstructural investigations indicated a complete absence of conventional processing defects such as recast layers and microcracking in the vicinity of the machining area. The absence of machining-induced melting or delamination along interfaces of the TBC system demonstrates a significant advantage in comparison with conventional laser machining.

Keywords: ablation, delamination, interfaces (materials), machining, melting, metallographic microstructure, microcracking, microstructural investigations, scanning electron microscopy, single crystals, single-crystal superalloys, superalloys, thermal barrier coatings, titanium sapphire laser system

Q. Feng, Y.N. Picard, J.P. Mcdonald, P.A. Van Rompay, S.M. Yalisove, and T.M. Pollock, Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI 48109. Cited: *Mater. Sci. Eng. A,* 2006, Aug 25, **430**(1-2), p 203-207 [in English]. ISSN 0921-5093.

Grain-boundary grooving of plasma sprayed yttria-stabilized zirconia thermal barrier coatings. The focus of this study was to determine the mechanisms responsible for the microstructural changes of plasma sprayed 7 wt.% Y_2O_3-ZrO_2 thermal barrier coatings with annealing from 800 to 1400 °C. Mullins's thermal grooving theories have been applied to plasma sprayed TBCs to determine the dominant mass transport mechanism at various temperatures. Grain-boundary groove widths were measured as a function of annealing time and temperature using atomic force microscopy (AFM). The same collection of grains was analyzed after progressive heat treatments. Surface diffusion was found to be the dominant diffusion mechanism at 1000 °C, corresponding to the disappearance of intralamellar cracks at that temperature. At 1100 °C, both surface and volume diffusion were active. Volume diffusion, found to be the dominant diffusion mechanism at 1200 °C and above, was responsible for the sintering of interlamellar pores observed from AFM analysis of a single, progressively heat treated interlamellar boundary. Surface roughening was observed to coarsen with increased annealing time and disappear with increased annealing temperature.

Keywords: annealing, barrier coatings, coatings, diffusion, grain boundaries, intralamellar cracks, microstructure, Mullins's thermal grooving, plasma spraying, sintering

K.A. Erk, C. Deschaseaux, and R.W. Trice, Purdue University, School of Materials Engineering, West Lafayette, IN 47907. Cited: *J. Am. Ceram. Soc.,* 2006, May, **89**(5), p 1673-1678 [in English]. ISSN 0002-7820.

Heat conduction across thermal barrier coatings of anisotropic substrates. This article deals with the heat conduction across the interface between a thin isotropic thermal barrier coating and an anisotropic substrate by the boundary element method. To have excellent performance of protection, the settled temperature on the interface is crucial for the design of the thermal barrier coating. The finite-element method, although popular for engineering analysis, is not generally an ideal numerical tool for analysis of ultrathin media. As an effective alternative, the boundary element method may be applied for the analysis. For elements of general high orders, the present work applies a scheme to fully regularize the boundary integrals. At the end, some benchmark examples are investigated as illustrations of the veracity and applicability of the scheme.

Keywords: anisotropic substrate, anisotropy, boundary element method, finite-element method, heat conduction, interfaces (materials), isotropic thermal barrier coating, nearly singular integrals, substrates, thermal barrier coatings

Y.C. Shiah and Y.-X. Shi, Department of Aerospace Eng. and Systems Eng., Feng Chia University, Taichung, Taiwan. Cited: *Int. Commun. Heat Mass Transfer,* 2006, Aug, **33**(7), p 827-835 [in English]. ISSN 0735-1933.

Influence of insulation coating on thermal conductivity measurement by transient hot-wire method. The transient hot-wire method is widely used to determine the thermal conductivity of various media. It has been improved through the addition of an insulation coating to the wire. However, this coating could affect the accuracy of the thermal conductivity measurement. The temperature rise for the insulation-coated wire was calculated as a function of time by a Laplace transformation along with the expansion method outlined by Carslaw and Jaeger [Conduction of Heat in Solids (Oxford University Press, Oxford, 1959)]. The results of numerical simulations and experimental tests show that, for most engineering applications, the relative measurement errors of the thermal conductivity caused by the insulation coating are very small if the slopes of the temperature rise-logarithmic time diagrams are calculated for large time values. No correction to the insulation coating is necessary even for the conditions that the insulation coating thickness is comparable to the wire radius, and that the thermal conductivity of the insulation coating is lower than that of the measured medium.

Keywords: computer simulation, engineering applications, insulation-coated wire, Laplace transforms, logarithmic time diagrams, measurement errors, thermal barrier coatings, thermal conductivity, thermal expansion, thermal insulating materials, thermal variables measurement, transient hot-wire method

W. Yu and S.U.S. Choi, Energy Technology Division, Argonne National Laboratory, Building 335, Argonne, IL 60439. Cited: *Rev. Sci. Instrum.,* 77(7), p [in English]. ISSN 0034-6748.

In situ small-angle neutron scattering study of $La_2Zr_2O_7$ and $SrZrO_3$ ceramics for thermal barrier coatings. Ex and in situ (≤1300 °C) small-angle neutron scattering (SANS) experiments on annealed layers of air plasma sprayed $La_2Zr_2O_7$ and $SrZrO_3$ for thermal barrier coatings are presented. The deposits exposed at 1200 °C up to 100 h showed a stable microstructure of large pores. Medium-size (~10 to 50 nm) intragranular pores sinter during the exposure. The in situ SANS revealed that this process starts at 1000 °C. In contrast to $La_2Zr_2O_7$, the creation of nanopores starting at 900 °C was detected in the $SrZrO_3$ layer. These nanopores began to disappear at 1100 °C.

Keywords: annealing, ceramic materials, intragranular pores, lanthanum compounds, nanopores, neutron scattering, plasma spraying, porous materials, small-angle neutron scattering, thermal barrier coatings

P. Strunz, G. Schumacher, R. Vassen, A. Wiedenmann, and V. Ryukhtin, Research Centre Rez, 250 68 Rez near Prague, Czech Republic. Cited: *Scr. Mater.,* 2006, Sept **55**(6), p 545-548 [in English]. ISSN 1359-6462.

Integrity of detonation sprayed Cr_xC_y-NiCr coating under exposure to thermal cycling. Cr_xC_y-NiCr coatings with thickness in the range 200 to 250 μm were deposited by detonation spray coating on a nickel-base superalloy (IN718) substrate and subjected to thermal cycling. Each thermal cycle involved heating to 650 °C, the creep temperature of the IN718 substrate, followed by a dwell and then natural cooling to ambient temperature. With thermal cycling, the bulk of the coatings experienced preferential oxidation along the splat boundaries, contributing to an increase in porosity and cracking. Despite the development of porosity and cracks, no spallation of coatings was observed even after nearly 600 thermal cycles. The microhardness of coatings did not undergo significant change, owing to oxide formation and retention of the total carbide content of Cr_3C_2, Cr_7C_3 and $Cr_{23}C_6$. The wear behavior of the as-sprayed and thermally cycled coated samples was evaluated in abrasive and erosive wear modes. Wear measurements on as-sprayed and thermally cycled coatings showed virtually no deterioration in properties even after exposure to nearly 600 thermal cycles.

Keywords: abrasive wear, ceramic coatings, crack initiation, creep, detonation spray coating, erosive wear, microhardness, porosity, sprayed coatings, thermal cycling, thermally cycled coatings, wear of materials

J. George, P. Bhargava, D.S. Rao, and S.V. Joshi, Materials Science Centre, IIT Kharagpur, Kharagpur 721 302, India. Cited: *Adv. Appl. Ceram.,* 2006, June, **105**(3), p 148-152 [in English]. ISSN 1743-6753.

Investigation of strontium-niobium oxides for application to thermal barrier coatings. The authors have been trying to find new oxide compounds with large thermal expansion coefficients and low thermal conductivities by means of a material calculation technique. Among thousands of compounds in the databases, they found that there were some materials with low thermal conductivities and large thermal expansion coefficients in the group of strontium-niobium oxides. For example, $Sr_4Nb_2O_9$ has a thermal expansion coefficient of 14.5×10^{-6}/°C and thermal conductivity of 1.0 W/mK, although a slight amount of other phases appear during long-term annealing. These thermal properties are better than those of yttria-stabilized zirconia, which is the standard material for thermal barrier coatings. To prevent the precipitation of other phases, we prepared the solid solutions, $Sr_4Nb_{2-x}M_xO_9$. In this study, the thermal conductivities and thermal expansion coefficients of these solid solutions were measured, and their thermal stabilities were evaluated by long-term annealing.

Keywords: annealing, heat treatment, material calculation techniques, precipitation (chemical), solid solutions, strontium compounds, strontium-niobium oxides, thermal barrier coatings, thermal conductivity, thermal expansion, thermal expansion coefficients

M. Shida, K. Akiyama, I. Nagano, Y. Murakami, and S. Ohta, Advanced Technology Research Center, Mitsubishi Heavy Industries, Ltd., Kanazawa-ku, Yokohama, 236-8515, Japan. Cited: *Key Eng. Mater.,* 2006, **317-318,** p 517-520 [in English]. ISSN 1013-9826.

Low thermal conductivity plasma sprayed thermal barrier coatings with engineered microstructures. The solution precursor plasma spray (SPPS) process has been used to deposit ZrO_2-7wt.%Y_2O_3 thermal barrier coatings (TBCs) that contain alternate layers of low and high porosities (layered SPPS). The thermal conductivity of the layered SPPS coating is found to be lower than those of both a SPPS coating with distributed porosity and an air plasma sprayed coating of the same composition, in the temperature range 100 to 1000 °C. Analytical and object-oriented finite element (OOF) models have been used to analyze the experimental thermal conductivity data. The OOF model is better at describing the experimentally measured thermal conductivities than the analytical model, and the OOF model captures accurately the effect of real microstructures on the thermal conductivities of these plasma sprayed TBCs.

Keywords: air plasma sprayed coating, engineered microstructures, finite-element method, mathematical models, microstructure, object-oriented finite-element models, plasma spraying, porosity, thermal barrier coatings, thermal conductivity

A.D. Jadhav, N.P. Padture, E.H. Jordan, M. Gell, P. Miranzo, and E.R. Fuller Jr, Department of Materials Science and Engineering, The Ohio State University, Columbus, OH 43210. Cited: *Acta Mater.,* 2006, July, **54**(12), July 2006, p 3343-3349 [in English]. ISSN 1359-6454.

Microstructural and mechanical properties changes of a NiCoCrAlY bond coat with heat exposure time in air plasma sprayed Y_2O_3-ZrO_2 TBC systems. Changes in the microstructure and Young's modulus of NiCoCrAlY bond coat (BC) layer in a Y_2O_3 partially stabilized ZrO_2 thermal barrier coating system exposed at 1423 K up to 100 h have been studied. Under the as-sprayed condition, the BC layer consists of a fine mixture of β and γ′ phases. After heat exposure, the phases change in two different zones; in the zones adjacent to the TBC and substrate layers, a γ phase is present, and in the mid-zone between the two interfaces, a mixture of β and γ phases is present.

With an increase in exposure time, the BC microstructure transforms with time into a single γ phase. Young's modulus of the BC increases with increasing heat exposure time. In the as-sprayed state, the global effective Young's modulus of the BC is originally 178 GPa and with an increase in exposure time changes to 182, 186, and 192 GPa after 10, 50, and 100 h of heat exposure time, respectively. This observation is explained by the change in the microstructure from the γ' to the γ phase and the increase of existing γ phase, as the Young's modulus of the γ phase is higher than the β and γ' phases.

Keywords: bond coat, cermets, elastic moduli, exposure time, heat exposure, mechanical properties, microstructure, nickel alloys, phase transitions, thermal barrier coatings, thermal effects

M. Hasegawa and Y. Kagawa, Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo 153-8904, Japan. Cited: *Int. J. Appl. Ceram. Technol.,* 2006, July, **3**(4), p 293-301 [in English]. ISSN 1546-542X.

Modification of microstructure and electrical conductivity of plasma sprayed YSZ deposit through postdensification process. Yttria-stabilized zirconia (YSZ) coating (4.5 mol%) was deposited by atmospheric plasma spraying (APS) as an electrolyte for solid oxide fuel cells (SOFCs) applications. The posttreatment was employed using zirconium and yttrium nitrate solution infiltration to densify the coating microstructure for improvement of gas permeability. The deposition of YSZ through nitrate in voids of the coating was examined. Microstructure of the as-sprayed and densified coatings was characterized by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The effect of infiltrating treatment on coating microstructure and electrical conductivity was examined. The electrical conductivity of APS sprayed YSZ coating at the direction perpendicular to coating surface was much lower than that of bulk materials. Postdensification treatment improved the electrical conductivity of YSZ coating by about 25% compared with as-sprayed coating. It was found that the deposition of YSZ resulting from decomposition of nitrate in the lamellar interface gaps was different from that in vertical cracks in lamella owing to the orthogonal feature of those two types of gaps. The nanopores were formed in the deposited YSZ in nonbonded interface gaps while large pores were residued in vertical cracks in splats. The microstructural examination suggests that nanopores in the deposited YSZ in nonbonded interfaces in the coating were isolated from each other, which led to the significant reduction of gas permeability after densification. Moreover, the nanocontacts between lamellae resulted in high contact resistance and limit improvement of electrical conductivity of the coating after densification.

Keywords: atmospheric plasma spraying, cracks, densification, electric conductivity, gas permeability, interfaces (materials), microstructure, nanopores, plasma spraying, solid oxide fuel cells, yttria-stabilized zirconia coating, yttrium compounds, zirconia

X.-J. Ning, C.-X. Li, C.-J. Li, and G.-J. Yang, State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China. Cited: *Mater. Sci. Eng. A,* 2006, July 25, **428**(1-2), p 98-105 [in English]. ISSN 0921-5093.

Performance of high reflectance multiple-layered thermal barrier coating systems. A further increase in gas turbine engine temperature necessitates a continuous development and advancement of thermal barrier coatings. While tremendous effort has been devoted to developing new thermal barrier coating materials and processing methods in order to decrease the thermal conductivity, limited attention has been paid to radiative thermal transport through coatings. It is the purpose of this study to develop a new multiple-layered coating structure that can be used to effectively reduce both the radiative thermal transport as well as thermal conductivity and to demonstrate the mechanism and performance of the proposed multiple layered coating structure. Mathematical modeling based on multiple beam interference and simulation results are presented.

Keywords: coated materials, computer simulation, gas turbines, high reflectance, mathematical models, multiple beam interference, multiple layered, radiative thermal transport, reflection, thermal barrier coatings, thermal conductivity, wave interference

D. Wang, X. Huang, and P. Patnaik, Dept. of Mechanical and Aerospace Engineering, Carleton University, Ottawa, Ontario, Canada. Cited: *Can. Metall. Quart.,* 2005, Oct, **44**(4), p 515-522 [in English]. ISSN 0008-4433.

The role of transient oxides during deposition and thermal cycling of thermal barrier coatings. High-temperature coating systems, consisting of a Rene N5 superalloy, a Ni-23Co-23Cr-19Al-0.2Y (at.%) bond coating (BC), and a partially yttria-stabilized zirconia (PYSZ) thermal barrier coating (TBC), were thermally cycled to failure for three different preoxidation treatments performed for 1 h at 1373 K and a partial oxygen pressure (pO_2) of 20 kPa, 100 Pa, and 0.1 Pa, respectively. These pretreatments resulted in the formation of different thermally grown oxide (TGO) layers prior to TBC deposition with respect to the presence of the transient oxides $NiAl_2O_4$, θ-Al_2O_3, and $Y_3Al_5O_{12}$ at the TGO surface. The TGO microstructures after TBC deposition and thermal cycling were investigated with a variety of analytical techniques and compared with those after preoxidation. For all preoxidation treatments, a double-layered TGO developed on the BC during thermal cycling. The TGO adjacent to the TBC consisted of small Zr-rich oxide crystallites embedded in an Al_2O_3 matrix when the TGO surface after preoxidation comprising $Y_3Al_5O_{12}$ plus α-Al_2O_3. When the TGO surface constituted of θ-Al_2O_3, the Zr-rich oxide crystallites were embedded in a $NiAl_2O_4$ spinel layer after thermal cycling. Zr was absent in the oxide layer when the TGO surface prior to TBC deposition was composed of $NiAl_2O_4$ spinel. The TGO contiguous to the BC consisted in all cases of α-Al_2O_3 with $Y_3Al_5O_{12}$ crystallites. The roughness of the α-Al_2O_3/BC interface increased for a higher density of Y-rich oxide protrusions (i.e., pegs) along this interface.

Keywords: crystalline materials, deposition, NiCoCrAlY bound coatings, partially yttria stabilized zirconia, superalloys, thermal barrier coatings, thermal cycling, thermally grown oxide, transient oxides, zirconia

T.J. Nijdam and W.G. Sloof, Department of Materials Science and Engineering, Delft University of Technology, 2628 AL Delft, Netherlands. Cited: *Mater. High Temp.,* **22**(3-4), p 551-559 [in English]. ISSN 0960-3409.

Tribology

Comparative study of the friction and wear behavior of plasma sprayed conventional and nanostructured WC-12%Co coatings on stainless steel. Conventional and nanostructured WC-12%Co coatings were deposited on 1Cr18Ni9Ti stainless steel substrate using air plasma spraying. The hardness of the coatings was measured, while their friction and wear behavior sliding against Si_3N_4 at room temperature and elevated temperatures up to 400 °C was comparatively studied. The microstructures and worn surface morphologies of the coatings were comparatively analyzed as well by means of x-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive x-ray analysis (EDXA). It was found that the as-sprayed WC-12%Co coatings were composed of WC as the major phase and W_2C, WC_{1-x}, and W_3Co_3C as the minor phases. The plasma sprayed nanostructured WC-12%Co coating had much higher hardness and refined microstructures than the conventional WC-12%Co coating. This largely accounted for the better wear resistance of the nanostructured WC-12%Co coating than the conventional coating. Besides, the two types of WC-12%Co coatings showed minor differences in friction coefficients, though the nanostructured WC-12%Co coating roughly had slightly smaller friction coefficient than the conventional coating under the same sliding condition. Moreover, both the conventional and nanostructured WC-12%Co coatings recorded gradually increased wear rate with increasing temperature, and the nanostructured coating was less sensitive to the temperature rise in terms of the wear resistance. The worn surfaces of the conventional WC-12%Co coating at different sliding conditions showed more severe adhesion, microfracture, and peeling as compared to the nanostructured WC-12%Co coating, which well conformed to the corresponding wear resistance of the two types of coatings. The nanostructured WC-12%Co coating with a wear rate as small as 1.01×10^{-7} mm^3/Nm at 400 °C could be promising candidate coating for the surface-modification of some sliding components subject to harsh working conditions involving elevated-temperature and corrosive medium.

Keywords: adhesion, air plasma spraying, conventional coatings, deposition, elevated temperature, friction, hardness, microstructure, morphology, nanostructured coatings, nanostructured materials, peeling, plasma spraying, stainless steel, surface treatment, wear of materials, wear resistance

X.-Q. Zhao, H.-D. Zhou, and J.-M. Chen, State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, 730000, China. Cited: *Mater. Sci. Eng. A,* 2006, Sept 15, **431**(1-2), p 290-297 [in English]. ISSN 0921-5093.

Effects of CeO_2 on friction and wear characteristics of Fe-Ni-Cr alloy coatings. The effects of rare earth oxide CeO_2 on the microstructure and wear resistance of thermal sprayed Fe-Ni-Cr alloy coatings were investigated. The powders of Fe-Ni-Cr alloy with the addition of CeO_2 were flame sprayed on to a 1045 carbon steel substrate. The coatings were examined and tested for microstructure feature, compositions, and phase structure. Tribological properties of coatings were tested under reciprocating sliding test. The results were compared with those for coatings of the alloy without CeO_2. The comparison indicated that the addition of rare earth oxide CeO_2 could refine and purify the microstructure of coatings, and increase the microhardness of the coatings. As a result, by CeO_2 addition, the friction coefficient of the coatings was decreased slightly and the wear resistance of the coatings was enhanced significantly.

Keywords: bond strength (chemical), carbon steel, carbon steel substrate, cerium compounds, coatings, composition, flame spraying, friction coefficient, microhardness, microstructure, nickel alloys, rare earth elements, rare earth oxide, tribological properties, wear resistance

Z. Zhang, Z. Wang, B. Liang, and P. La, State Key Laboratory of New Nonferrous Metal Materials, Lanzhou University of Technology Lanzhou, 730050 Gansu, China. Cited: *Tribol. Int.,* 2006, Sept, **39**(9), p 971-978 [in English]. ISSN 0301-679X.

The friction and wear properties of PTFE composite-thermal spray metallic binary coatings. Cu-Al alloy and Mo coatings were deposited on a low-carbon steel substrate using an atmospheric plasma spray machine. Pure

PTFE and PTFE metal powder composites were deposited on the metallic coatings. Studied and compared are PTFE-metal coatings and PTFE composite-metal coatings filled with different metal powders with the proportion of 10% (mass). Mass loss and coefficient of friction were measured under dry reciprocating sliding tests. The worn surfaces of samples were observed by microscopy. The influence of additives on the wear resistance was assessed.

Keywords: friction, friction coefficient, plasma spraying, polytetrafluoroethylenes, powder metals, substrates, wear, wear of materials

M. Shi, F. Miyazawa, S. Tobe, and T.A. Stolarski, Zhejiang University of Technology, Zhejiang 310014, China. Cited: *Mater. Trans.,* 2005, Jan, **46**(1), p 84-87 [in English]. ISSN 1345-9678.

Rolling contact fatigue of alumina ceramics sprayed on steel roller under pure rolling contact condition. The rolling contact fatigue of sprayed alumina ceramics with a nominal composition of Al_2O_3-2.3 mass%TiO_2 was studied with a two-roller test machine under a pure rolling contact condition with oil lubricant. The influence of undercoating of sprayed Ni-base alloy on the rolling contact fatigue was investigated. The failure mode of all sprayed rollers was spalling caused by subsurface cracking. The undercoating did not contribute to the improvement of the rolling contact fatigue life. The elastic modulus of the alumina sprayed layer evaluated with the nanoindentation method was around 85 GPa. The depths of the observed subsurface cracks corresponded approximately to the depths where the orthogonal shear stress or the maximum shear stress calculated with two-dimensional FEM became maximum.

Keywords: alumina, alumina ceramics, coating techniques, contact angle, cracks, failure analysis, finite-element method, indentation, nanoindentation, nickel alloys, oil lubrication, rolling contact fatigue, shear stress, spraying, stress analysis

M. Fujii, A. Yoshida, J. Ma, S. Shigemura, and K. Tani, Department of Mechanical Engineering, Okayama University, Naka, Okayama, 700-8530, Japan. Cited: *Tribol. Int.,* 2006, Sept, **39**(9), p 856-862 [in English]. ISSN 0301-679X.

Tribological behavior of plasma spray coatings for marine diesel engine piston ring and cylinder liner. High-temperature wear characteristics between plasma spray coated piston rings and cylinder liners were investigated to find the optimum combination of coating materials using the disc-on-plate reciprocating wear test in dry conditions. The disc and plate represented the piston ring and the cylinder liner, respectively. Coating materials studied were Cr_2O_3-NiCr, Cr_2O_3-NiCr-Mo, and Cr_3C_2-NiCr-Mo. Plasma spray conditions for the coating materials were established adjusting stand-off distance to obtain a coating with a porosity content of ~5%. It was found that a dissimilar coating combination of Cr_2O_3-NiCr-Mo and Cr_3C_2-NiCr-Mo provided the best antiwear performance. The addition of molybdenum was found to be beneficial to improve the wear resistance of the coating. Hardness differences between mating surfaces were also important factors in determining the wear characteristics, so that it should be controlled below 300 in Vickers hardness under dry conditions. Adhesive wear accompanying with metal transfer was a dominant wear mechanism for dry conditions.

Keywords: abrasives, adhesives, ASTM G 133, cast iron, CV cast iron, gray cast iron, lubricants, marine engines, piston rings, plasma spray coatings, plasma spraying, solid lubricants, sprayed coatings, tribology

J.-H. Hwang, M.-S. Han, D.-Y. Kim, and J.-G. Youn, Materials Research Department, Hyundai Industrial Research Institute, Hyundai Heavy Industries Co. Ltd., Dong-gu, Ulsan, 682-792, South Korea. Cited: *J. Mater. Eng. Perform.,* 2006, June, **15**(3), p 328-335 [in English]. ISSN 1059-9495.

Tribological property of plasma sprayed TiO_2 coating. The sliding wear property of plasma sprayed TiO_2 coatings with porosity of 4.2 and 5.4% mating against silicon nitride ball were comparatively investigated with a reciprocating tribometer under dry conditions. The results indicate that the wear resistance of the TiO_2 coating with lower porosity is superior, which is attributed to its homogeneous microstructure and improved microhardness. The morphologies of the wear tracks of the two TiO_2 coatings, as well as wear debris reveal the pore is the main location wear occur. The coefficients of friction of the two TiO_2 coatings decrease with the increase of applied load, while the wear rates increase, which is attributed to the difference of the dependence of microhardness on load between the coating and the Si_3N_4 ball. No apparent dependence of wear resistance on sliding speed was found on these two coatings.

Keywords: coatings, friction and wear, microhardness, microstructure, plasma spray, plasma spraying, silicon nitride, sliding speed, TiO_2 coatings, titanium dioxide, tribology, wear resistance

S.W. Lee, H. Du, H. Chen, and B.Y. Hur, Department of Materials Engineering, Sun Moon University, Asan, South Korea. Cited: *Key Eng. Mater.,* **317-318,** p 377-380 [in English]. ISSN 1013-9826.

Tribological properties of flame sprayed Fe-Ni-RE alloy coatings under reciprocating sliding. Fe-Ni-RE self-fluxing alloy powders were flame sprayed onto 1045 carbon steel. The tribological properties of Fe-Ni-RE alloy coatings under dry sliding against SAE52100 steel at ambient conditions were studied on an Optimol SRV oscillating friction and wear tester in a ball-on-disc contact configuration. Effects of load and sliding speed on tribological properties of the Fe-Ni-RE coatings were investigated. The worn surfaces of the Fe-Ni-RE alloy coatings were examined with a scanning electron microscopy (SEM) and an energy-dispersive spectroscopy (EDS). It was found that the Fe-Ni-RE alloy coatings had better wear resistance than the SAE52100 steel. An adhered oxide debris layer was formed on the worn surface in friction. Area of the friction layer varied with variety of sliding speed, but did not vary with load. The oxide layer contributed to decreased wear, but increased friction. Wear rate of the material increased with the load, but dramatically decreased at first and then slightly decreased the sliding speed. The friction coefficient of the material was 0.40 to 0.58, and decreased slightly with the load, but increased with sliding speed at first, and then tended to be a constant value. Wear mechanism of the coatings was oxidation wear and a large amount of counterpart material was transferred to the coatings.

Keywords: energy dispersive spectroscopy, Fe-Ni-RE coatings, friction, friction coefficient, iron alloys, protective coatings, reciprocating sliding, scanning electron microscopy, tribology, wear debris layer, wear of materials

Z. Zhang, Z. Wang, and B. Liang, The Mechanical Department, Lanzhou Polytechnical College, Lanzhou, Gansu 730050, China. Cited: *Tribol. Int.,* 2006, Nov, **39**(11), p 1462-1468 [in English]. ISSN 0301-679X.