Selected Abstracts of Thermal Spray Literature

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Applications

Bimetal Fabrication

Investigation of multilayer spray deposition of aluminum/steel bimetal. Multilayer spray deposition technology is used to fabricate aluminum/steel bimetal, and the factor of influencing the interface of aluminum/steel is discussed. It shows that multilayer spray deposition has many merits, for example: simple techniques, high adhesion strength, etc. The key of this technology is warming the substrate up. Hot rolling also can improve the adhesion strength between aluminum and steel.

Keywords: aluminum, joints (structural components), sprayed coatings

H.-L. Ning, Y.-P. Wang, F.-X. Huang, J.-S. Ma, Z.-T. Geng, and Z.-H. Chen, Dept. of Mat., Tsinghua Univ., Beijing 100084, China. Cited: *Gongneng Cailiao/J. Funct. Mater., 33*(2), April 2002, p 166-168 [in Chinese]. ISSN 1001-9731.

Biomaterial

A contribution to the production and characterization of new biomedical coatings: fluorohydroxyapatite coatings. In order to improve the osteointegration of the implant, the state-of-art specifies the use of coatings such as hydroxyapatite (HA; $Ca_5(PO_4)_3OH$). The research deals now with new materials and modification of HA, in order to improve the stability and mechanical properties of the coatings or more generally of the implant. A promising material is fluorohydroxyapatite (FHA, $Ca_5(PO_4)_3OH_{1-x}F_x$). This paper addresses the production and characterization of vacuum plasma sprayed fluorohydroxyapatite coating for orthopedic endoprosthesis. The spray trials have been carried out on Ti-6A-l4V alloy substrates preventively blasted with corundum. In order to improve adhesion of FHA to titanium substrates, two different titanium bond coats have been tested: the first with lower roughness and porosity named type A and the second with higher roughness and porosity named type B. A complete structural and mechanical characterization has been carried out: coating thickness, closed porosity and superficial porosity, microhardness, and roughness have been measured.

Keywords: adhesion, biomaterials, characterization, microhardness, organic coatings, orthopedics, plasma spraying, porosity, sprayed coatings, surface roughness, titanium alloys

G. Rizzi, R. Groppetti, L. Salvarani, and A. Scrivani, Biocoatings srl, 43040 Rubbiano di Solignano, Parma, Italy. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 93-96 [in English]. ISSN 1013-9826.

Preparation of thin histological sections for bone attachment and implant material analysis. Thin sections offer a means to assess the bone tissue type bone attachment to an implant surface. For homogeneous implant materials, where the phase composition is uniform along the surface, there are no preferential locations for bone attachment. For multiphase materials, such as calcium phosphate coatings, bone may preferentially interact with specific chemical phases. Thin histological sections of plasma sprayed calcium phosphate coatings were polished to a uniform thickness with an Accustop and viewed with transmission and reflection light microscopy. The polishing operation revealed the microstructure of the coating and provided a means of identifying the crystalline components within the coating. The use of such thin sections analyzed in reflective and transmission optical microscopy allowed observation of the coating structure while concurrently determining the bone type and apposition to the implant surface.

Keywords: calcium compounds, histology, implants (surgical), microstructure, optical microscopy, phase composition, phosphate coatings, plasma spraying

K.A. Gross, School of Physics and Materials Engineering, Monash Univ., Victoria, Vic. 3800, Australia. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 315-318 [in English]. ISSN 1013-9826.

Development of zirconia plasma sprayed coatings for dental implants and for knee prostheses. In the field of bone-prostheses production, two main sectors can be identified: dental applications and prosthetic applications for the rest of the human body (hip, knee, femur, etc). This paper addresses the study of biocompatible materials that could be used as coating of dental and knee prostheses. Namely the production and characterization of yttria partially-stabilized zirconia plasma spray coatings is considered. Used powder and obtained coatings have been fully characterized from the point of view of mechanical (adhesion and hardness), structural (thickness, porosity), and chemical-physical characteristics (chemical composition, phase presences). Colorimetric analysis as well as stability test in SBF have been carried out. Finally in vitro and in-vivo tests are in progress.

Keywords: adhesion, biocompatibility, composition, corrosion protection, dental prostheses, hardness, joint prostheses, plasma spraying, porosity, protective coatings, x-ray diffraction analysis, zirconia

A. Scrivani, A. Figueras, M. Garriga, and G. Rizzi, Dept. Industrial Engineering, Univ. Parma, Parma, Italy. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 515-518 [in English]. ISSN 1013-9826.

New approach to a cementless ceramic component for artificial knee joint. The cementless-type femoral component made of ceramics in artificial knee joint has not been applied as widely as the femoral head made of ceramics in artificial hip joint. The major reason for this situation is that the surface of ceramics has not enough ability for connecting with a living bone directly. So, the authors have been developing a composite material, "hydroxyapatite and titanium on zirconia" (HTOZ), which has zirconia ceramics as a substrate, arc spray coating of titanium as lower layer and flame spray coating of hydroxyapatite as upper layer. In this study, the authors estimated the basic mechanical properties, the biological safety properties, and the fixative ability with bone of this new composite material, which has been developed as a new cementless ceramic component for artificial knee joints. From this study, the authors concluded that HTOZ, which has high hardness and high strength held by zirconia ceramics and also has sufficient potential for connecting with living bone, is an excellent composite material for orthopedic implants.

Keywords: bone, hip prostheses, hydroxyapatite, implants (surgical), substrates, titanium, zirconia

S. Masuda, H. Kitano, J. Ikeda, Y. Yoshihara, K. Mukai, T. Shimotoso, and I. Noda, Bioceram Div., Kyocera Corp., Kyoto, Japan. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 577-580 [in English]. ISSN 1013-9826.

Buffer Coatings on Aluminum

Buffer coatings on aluminum alloys. If the objective is to replace components made of steel with aluminum alloys, sufficient resistance not only to wear and corrosion but also to mechanical and thermal stresses must remain guaranteed. Therefore, functional coatings were applied to the AlMg5 alloy by means of thermal spraying and were investigated. In order to be able to subsequently use aluminum alloys with such coatings for rolls in the paper and textile industries, tests were performed on a model test bench with combined mechanical and thermal loads. A buffer-coating system that consisted of NiCr 80/20 and WCCo 88/12 and was applied by means of high-velocity oxyfuel flame spraying proved to be most suitable in this case.

Keywords: aluminum alloys, corrosion resistance, mathematical models, thermal stress, wear resistance

E.H.H. Herold, K.-J. Matthes, G. Kolbe, and A. Hubner. Cited: *Weld. Res. Abroad, 48*(1), Jan 2002, p 33-36 [in English]. ISSN 0043-2318.

Praparation und charakterisierung thermisch gespritzter schichtsysteme auf aluminiumlegierungen [Preparation and characterization of thermally sprayed coating systems on aluminum alloys]. This article describes the preparation of thermally sprayed composite coatings applied to aluminum alloys and the investigation and characterization of selected specimens. The coatings were applied by HVOF or atmospheric plasma spraying onto an aluminum alloy substrate material. The article centers on the method of preparation used to prepare specimens of the different coatings applied, and on the evaluation of their microstructures using metallography and image analysis.

Keywords: aluminum alloys, characterization, composite materials, image analysis, metallographic microstructure, metallography, plasma spraying, substrates

A. Hubner, Otto-von-Guericke-Univ. Magdeburg, Inst. fur Fuge- und Strahltechnik, D-39016 Magdeburg, Germany. Cited: *Prakt. Metallogr./Pract. Metallogr., 39*(2), Feb 2002, p 70-81 [in German, English]. ISSN 0032-678X.

Catalyst Preparation

Catalyst preparation using plasma technologies. This paper discusses catalyst preparation using thermal and cold plasmas. In general, there are three main trends in preparing catalysts using plasma technologies: (1) plasma chemical synthesis of ultrafine particle catalysts, (2) plasma-assisted deposi-

tion of catalytically active compounds on various carriers, especially plasma spraying for the preparation of supported catalysts, (3) plasma-enhanced preparation or plasma modification of catalysts. Compared to conventional catalyst preparation, there are several advantages of using plasmas, including: (1) a highly distributed active species, (2) reduced energy requirements, (3) enhanced catalyst activation, selectivity, and lifetime, and (4) shortened preparation time. These advantages are leading to many potential applications of plasma prepared catalysts.

Keywords: charge carriers, deposition, plasma spraying, plasmas, synthesis (chemical)

C.-J. Liu, G.P. Vissokov, and B.W.-L. Jang, State Key Lab. for C1 Chemical Technology, Tianjin Univ., Tianjin 300072, China. Cited: Catalysis Today (Conf. Proc.), Jang, Reynolds, Boutonnet, and Spivey, Ed., 1 Aug 2000 (Washington, D.C.), *Catalysis and Plasma Technology, 72*(3-4), 15 March 2002, p 173-184 [in English]. ISSN 0920-5861.

Catalysis Today (Conf. Proc.). The proceedings contains 12 papers from the Conference on Catalysis Today. Topics discussed include: catalyst preparation using plasma technologies, low-temperature catalytic growth of carbon nanotubes under microwave plasma assistance, fused hollow cathode cold atmospheric plasma source for gas treatment, and involvement of catalyst materials in nonthermal plasma chemical processing of hazardous air pollutants.

Keywords: catalyst activity, catalyst deactivation, catalyst regeneration, chemical vapor deposition, deposition, electric arcs, electron microscopy, low temperature effects, Mössbauer spectroscopy, nanostructured materials, natural gas, plasma spraying, plasma torches, synthesis (chemical), thermodynamic stability, x-ray analysis

Jang, Reynolds, Boutonnet, and Spivey, Ed., 1 Aug 2000 (Washington, D.C.), *Catalysis and Plasma Technology, 72*(3-4), 15 March 2002, 109 pages [in English]. ISSN 0920-5861.

Chromium Speciation

Mechanistic studies of chromium speciation with thermospray. Thermospray (TSP) coupled with inductively coupled plasma-atomic emission spectroscopy (ICP-AES) or inductively coupled plasma-mass spectrometry (ICP-MS) has been developed as a nonchromatographic method for chromium speciation to quantitatively separate and determine two chromium oxidation states: Cr(III) and Cr(VI). The limits of detection can reach 0.5 ng/mL with ICP-AES detection and 50 pg/mL with ICP-MS detection. The basis for this speciation method is that Cr(III) can selectively and nearly quantitatively deposit inside a thermospray system as Cr_2O_3, while Cr(VI) does not. To fully understand the mechanism of this deposition process, four questions were investigated: Is aerosol formation necessary for the reaction to occur? Does the deposition occur in the aerosol or liquid regime? Does the deposit tend to be retained on the surface of the fused silica capillary? Can the reaction be predicted from thermodynamic calculations? These studies show that this reaction happens before solvent evaporates (i.e., the liquid regime). The high temperature inside the thermospray system is the major factor triggering this reaction. At the same time, the high pressure is important for its influence on the solvent boiling point, which affects the residence time (the time that the analyte spends in the solution before the solvent evaporates) and the kinetics of the reaction. The effects of the other parameters (vaporizer length, heating length, drawn tip, etc.) on the efficiency of the deposition reaction, represented as background residual signal (BRS), were also studied.

Keywords: aerosols, deposition, emission spectroscopy, evaporation, inductively coupled plasma, mass spectrometry, reaction kinetics, solvents

X. Zhang and J.A. Koropchak, Dept. of Chemistry and Biochemistry, Southern Illinois Univ., Carbondale, IL 62901-4409. Cited: *Appl. Spectrosc., 56*(9), Sept 2002, p 1152-1160 [in English]. ISSN 0003-7028.

Coatings for Engine Components

Bruhl foundry protects engine blocks with BASF powder coatings. The BASF powder coatings, which protect the engine blocks of the cars was discussed. Coatings give cars luster and protection and also protect the engines of the cars from corrosion. Scrap metal that is recyclable is used as the raw material. It consists of construction steel, rails, and compacted steel as well as pig iron. After a thorough cleaning of all parts and removal of all devices used in casting, the engine block was primed with powder coating for protection against corrosion. The coating withstands the heat and stress created by the rough driving, and it proves resistant to wear chemicals such as salt, engine oils, and brake fluids.

Keywords: coke, corrosion resistance, crankshafts, engine pistons, high temperature applications, industrial robots, iron scrap, lacquers, metal castings, pig iron, protective coatings, scrap metal reprocessing, smelting, steel scrap

J. Logan. Cited: *Prod. Finish. (London), 55*(3), March/April 2002, p 14-15 [in English]. ISSN 0032-9762.

Plasma sprayed bores for a greener future. The improvement in the performance of car engines achieved through plasma sprayed coatings on cylinder bores was discussed. The use of lightweight materials is becoming prevalent to reduce vehicle weight in order to improve performance, reduce fuel and oil consumption, and also to reduce emissions. The cast iron engines blocks were replaced with aluminum silicon versions because they have wear-resistant surfaces and have cast iron liners because of their good operating characteristics. Honing is the preferred machining technique because coating damage and the closure of pores can be prevented. A large range of coating types can be used for series production.

Keywords: abrasion, automobile engines, cast iron, chromate coatings, composition, compressive strength, corrosion resistance, crankcases, elasticity, honing, lubrication, molybdenum, optimization, oxidation, wear resistance

K. Harrison. Cited: *Prod. Finish. (London), 55*(3), March/April 2002, p 19-20 [in English]. ISSN 0032-9762.

Coatings for Gas Turbine Components

Up-to-date surface technology and mobile units for on-site coating of gas turbine compressor components. Erosion and corrosion attacks can initiate failures on highly stressed gas turbine compressor components that may lead from pitting corrosion and finally to blade ruptures with the typical severe damage. Aluminum-ceramic sacrificial coatings offer outstanding protection against erosion and corrosion and at the same time a significant efficiency improvement potential. The continuous development of processes and application methods made it possible to coat complete stacked rotors and stator shells with blades in situ. Today, there is equipment available to execute this service at virtually any place in the world under most difficult climatic conditions.

Keywords: aluminum compounds, binders, ceramic coatings, coating techniques, composition effects, erosion, gas turbines, process engineering, protective coatings, steel corrosion

P. Hagen, SermeTel Tech. Services (STS) GmbH, Heiligenhaus, Germany. Cited: *VGB PowerTech, 82*(4), 2002, p 62-64 [in English]. ISSN 1435-3199.

Sealing the gap: benefits of clearance control thermal spray coatings. The major benefits of clearance control in industrial gas turbine (IGT) coatings are increased engine efficiency and reduced fuel consumption. Although there are many types of coatings and methods to manufacture them, the operation of refurbishment of the seals must be simple, reliable and efficient. The article focuses on Sulzer Metco, which has developed its line of thermal spray materials and coating systems for use in turbine engine applications.

Keywords: fuel consumption, gas turbines, sealants

Cited: *Anti-Corros. Methods Mater., 49*(2), 2002, p 137-140 [in English]. ISSN 0003-5599.

Benefits of clearance control thermal spray coatings—sealing the gap. In response to customers' concerns regarding increasing demands on turbine operating temperatures and output efficiencies, Sulzer Metco has further developed its line of reliable thermal spray materials and coating systems. One result of this work is abradable coatings that are being used successfully in turbine engine applications for clearance control seals of gas leakage over the tips of the blades.

Keywords: abrasion, energy efficiency, fuel consumption, gas turbines, leakage (fluid), plasma spraying, sealing (closing), temperature, turbomachine blades

M. Dorfman, U. Erning, and J. Mallon, Sulzer Metco (US) Inc., Westbury, NY 11590. Cited: Technical Paper—Society of Manufacturing Engineers, FC02-219, 2002, Society of Manufacturing Engineers, p i+1-7 [in English]. ISSN 0161-1844.

Coatings for Rocket Engine Components

Robust low-cost liquid rocket combustion chamber by advanced vacuum plasma process. A project initiated at NASA-Marshall Space Flight Center (MMSFC) to combine three existing technologies to build and demonstrate an advanced liquid rocket engine combustion chamber was discussed. Technology developed in microgravity research to build cartridges for space furnaces was utilized to vacuum plasma spray (VPS) a functional gradient coating. The coating for the first time remained adhered to the combustion liner through a hot firing test.

Keywords: combustion chambers, plasma spraying, redox reactions, thermal barrier coatings

R. Holmes, S. Elam, T. McKechnie, and R. Hickman, George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, AL 35812. Cited: *39th Space Congress* (Conf. Proc.), 30 April-3 May 2002 (Cape Canaveral, FL), Canaveral Council of Technical Societies, 2002, p 25-35 [in English]. ISSN 0584-6099.

Fuel Cells

Electrochemical characterization of vacuum plasma sprayed thin-film solid oxide fuel cells (SOFC) for reduced operating temperatures. This paper focuses on the electrochemical characterization, such as current-voltage measurements, impedance spectroscopy, and long-term operation of completely plasma sprayed SOFC assemblies for a planar metallic substrate-

supported thin-film concept. The influence of the variation in operating conditions is presented. To determine the different resistances in the cells, the measured impedance spectra were fitted to an equivalent circuit. This enables further improvement of the electrochemical performance of the cells and allows the assembling of high performance SOFC stacks.

Keywords: current voltage characteristics, electric current measurement, electric impedance measurement, plasma spraying, solid oxide fuel cells, spectroscopy, thermal effects, thin films, vacuum applications, voltage measurement

M. Lang, T. Franco, G. Schiller, and N. Wagner, DLR, Inst. fur Technische Thermodynamik, D-70569 Stuttgart, Germany. Cited: *J. Appl. Electrochem., 32*(8), Aug 2002, p 871-874 [in English]. ISSN 0021-891X.

Thermal spray coatings for molten carbonate fuel cells separator plates. Molten salt corrosion at the wet seal of separator plates is one of the principal life-limiting factors of molten carbonate fuel cells (MCFC). The wet seal must therefore be coated with an aluminide layer that is commonly produced by ion vapor deposition (IVD) of Al followed by heat treatment. However, this coating only lasts approximately 20,000 h and not the 40,000 h expected for a cell life. Moreover, the IVD Al coating is also very expensive since only a few plates can be coated simultaneously due to size limitations of the existing commercial vacuum chambers employed in IVD. The need of heat treatment further increases costs, particularly since it requires long heating and cooling cycles in order to minimize distortion of the thin stainless steel plates. Thermally sprayed coatings constitute an alternative that requires neither containment nor heat treatment, and also provides the possibility of depositing materials more resistant to molten carbonates than plain aluminides. However, separator plates coated by thermal spray suffer distortion, due both to sand blasting (usually required prior to coating), and to the heat transfer process that occurs during the spraying process. In this work, commercially available coatings have been applied by plasma spray and high velocity oxyfuel (HVOF), employing alternative surface preparation methods. Moreover, substrate preheating and/or cooling during deposition were examined in order to eliminate substrate distortion. FeCrAl, and NiAl as well as a quasi-crystalline approximant alloy AlCoFeCr were deposited on AISI 310 foils, and after optimization the resulting coatings were characterized by means of scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS). The optimized coatings were then tested by immersion in a 62 mol% Li_2CO_3/38 mol% K_2CO_3 molten carbonate eutectic mixture at 700 °C and by electrochemical impedance spectroscopy. IVD Al coatings were also tested for comparison purposes. The results indicate that FeCrAl exhibits a higher molten-salt corrosion resistance than IVD aluminide coatings, whereas NiAl was attacked shortly after the beginning of the test. The QC approximant AlCoFeCr resisted 1000 h of attack, but its composition changed. Grinding of the substrate prior to coating resulted in good adhesion and substrate distortion was minimized by argon cooling during deposition.

Keywords: aluminum alloys, blasting, carbonate minerals, corrosion resistance, energy dispersive spectroscopy, fuel cells, heat transfer, heat treatment, molten materials, plasma spraying, quasi-crystals, scanning electron microscopy, stainless steel, substrates, vacuum applications, vapor deposition

A. Aguero, F.J.G. de Blas, M.C. Garcia, R. Muelas, and A. Roman, Inst. Nac. Tecnica Aeroespacial, Area de materiales Metalicos, Torrejon de Ardoz, Madrid 28850, Spain. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 578-585 [in English]. ISSN: 0257-8972.

Military Applications

Coating solutions for military applications. Coating solution advances are emerging in the commercial market as well as in the military arena. An overview is given on a variety of military coating applications and unique solutions utilizing thermal spray and electroplating processes.

Keywords: airframes, aluminum, bond strength (materials), corrosion protection, electroplating, gas turbines, kerosene, military applications, oxygen, pistons, plasma spraying

A. Gray, and E.R. Sampson, Praxair Surface Technologies Inc., Indianapolis, IN. Cited: *Adv. Mater. Process., 160*(5), May 2002, p 41-42 [in English]. ISSN 0882-7958.

Structural Steel Protection

Arc spraying is still the best for structural steel. A discussion on corrosion protection of structural steel at minimum cost by automated thermal spraying is presented. The features of all the four combinations of thermal spraying powder flame spraying, wire flame spraying, electric arc wire spraying or arc spraying, and electric arc powder spraying techniques known as plasma spraying, are discussed. The cost evaluation of thermal spraying techniques is done by evaluating surface area and required thickness.

Keywords: coating techniques, corrosion protection, cost effectiveness, electric arcs, feedstocks, melting, molten materials, nozzles, steel, surfaces

T. Lester, Metallisation Ltd., Dudley, West Midlands DY2 0XH, U.K. Cited: *Prod. Finish. (London), 55*(2), Feb 2002, p 19-20 [in English]. ISSN 0032-9762.

Superconducting Materials

Superconducting materials for electronic applications. Shielding elements were made of bulk material or thick films. The bulk route is determined by large-scale processing. After an axial or isostatic pressing of the fine-grained powder composed of BSCCO, Y-123, and Nd-123, the material was sintered/textured and annealed in special programs. Then the characterization of the materials and a measurement of magnetic fields were done with the help of a specially constructed measuring apparatus with Hall and SQUID sensors. The objective of the thick film route was to get large, coated superconducting work pieces of YBCO and BSCCO (plates or cylinders) with current density of $\geq$1000 kA/cm^2 (and/or a shielding effect of $\geq$1 mT). Thick films were made by plasma spraying and paste technology. Substrates used were ZrO_2, MgO, $SrTiO_3$, $BaZrO_3$, and others. In some cases the workpieces were treated with laser radiation. After laser and thermal treatment the surface was more dense, the cracks were cured and the current density was increased by more than two times.

Keywords: annealing, characterization, cracks, current density, electronic properties, large scale systems, laser applications, magnetic field measurement, plasma spraying, powders, sintering, substrates, textures, thick films, yttrium barium copper oxides

H. Altenburg, J. Plewa, W. Jaszczuk, M. Itoh, I. Brunets, A. Buev, and T. Vilics, Univ. Applied Sciences, Angew. Mat.wissenschaften, Bereich, Supraleiter-Keramik-Kristalle, 48565 Steinfurt, Germany. Cited: *Physica C: Supercond. Appl., 372-376*(suppl. 2), Aug 2002, p 1046-1050 [in English]. ISSN 0921-4534.

Targets for Magnetron Sputtering

Comparison of plasma sprayed and flame sprayed $YBa_2Cu_3O_{7-x}$ targets for rotatable magnetron sputtering. Rotatable magnetron sputter sources are standard equipment in large-scale sputter industry for the deposition of metals and metal oxides. The power input in a rotatable magnetron can be much higher compared to a planar magnetron, resulting in improved discharge characteristics and increased deposition speed. In order to develop rotatable magnetron deposition of $YBa_2Cu_3O_{7-x}$ (YBCO) on an industrial scale, the construction of large cylindrical YBCO targets using plasma and flame spraying was explored. Large cylindrical targets (ϕ 13 cm × 30 cm length) consisting of a stainless steel substrate coated with a 5 mm YBCO coating were fabricated. This paper describes the microstructure, mechanical, structural, thermal, and electrical characterization of the obtained coatings and the characteristics of the targets during magnetron sputtering.

Keywords: deposition, flame spraying, magnetron sputtering, mechanical properties, microstructure, plasma spraying, stainless steel, substrates, targets, thermodynamic properties

E. Georgiopoulos, J. Denul, A. Tsetsekou, C. Andreouli, I. De Roeck, G. De Winter, R. De Gryse, E. Bruneel, S. Hoste, and I. Van Driessche, Dept. Inorganic and Physical Chemistry, Ghent Univ., 9000 Gent, Belgium. Cited: *Physica C: Supercond. Appl., 372-376*(suppl. 2), Aug 2002, p 1221-1224 [in English]. ISSN 0921-4534.

Targets for Spectroscopy

The production of sulfur targets for γ-ray spectroscopy. The production of thin sulfur targets for nuclear physics, either in elemental or in compound form, is problematic, due to low melting points, high vapor pressures, and high dissociation rates. Many sulfur compounds have been tried in the past without great success. In this paper, the authors report the use of spray coating molybdenum disulfide onto a thin carbon backing. The targets were of thickness 750 μg/cm^2 (~300 μg/cm^2 of sulfur) on 15 μg/cm^2 carbon backings, and withstood 4 pnA (~10 mW/cm^2) of deposited beam power for several days without apparent loss of sulfur content.

Keywords: deposition, gamma rays, melting, metallic films, molybdenum compounds, nuclear physics, spectroscopic analysis, sprayed coatings, sulfur

J.P. Greene, and C.J. Lister, Physics Division, Argonne National Laboratory, Argonne, IL 60439. Cited: 20th World Conf. International Nuclear Target Development Society (INTDS 2000), 2-6 Oct 2000 (Antwerp, Belgium), C. Ingelbrecht and P. Maier-Komor, Ed., Elsevier Science B.V., *Nucl. Instrum. Methods Phys. Res. A,* 480(1), 11 March 2002, p 79-83 [in English]. ISSN 0168-9002.

Feedstock

Atomization

Jet breakup of liquid metal in twin-fluid atomization. For melt disintegration in spray forming and metal powder production, the liquid metal typically is atomized by means of twin-fluid atomization e.g., with inert gases. The first stage of the atomization process is covered by the initialization and development of surface perturbations on the liquid jet surface that subsequently grow and finally lead to the breakup of the melt jet. The primary disintegration

process affects all further stages of the atomization process and hence influences the resulting spray characteristics. In this contribution, the influence of different material properties on the primary disintegration process of a metal melt in a free-fall atomizer configuration is investigated. Surface instabilities of liquid metal jets up to the primary breakup are analyzed experimentally as well as analytically. Results of a linear instability analysis are discussed and compared to evaluations of high-speed video images. In comparison of both results, the periodicity and main mechanism of the initialization process are analyzed.

Keywords: atomization, disintegration, drop breakup, image analysis, inert gases, jets, spraying

S. Markus, U. Fritsching, and K. Bauckhage, Univ. Bremen, SFB 372 Spray Forming, Bremen 28359, Germany. Cited: *Mater. Sci. Eng. A, 326*(1), 15 March 2002, p 122-133 [in English]. ISSN 0921-5093.

Undercooling and solidification of atomized liquid droplets. The overall analysis of the microstructures developed during atomized droplet solidification requires an understanding of the nucleation and growth kinetics that are operative during processing. Following the subdivision of a liquid volume into droplets, the basic nature of nucleation as a stochastic process and the activity of various catalysts play a major role in determining the droplet microstructure. Droplet thermal history under the influence of the external cooling rate and liquid undercooling is another important component of the solidification behavior and microstructure development in alloys and the particle incorporation modes that can be observed in composite processing. In addition, the kinetic competition near a phase transition can result in drastic microstructure changes that are sensitive to slight variations of the processing conditions. On a laboratory scale, the relevant processing/microstructure relationships can be simulated by controlled undercooling experiments on single droplets and droplet populations. The results that are obtained from these experimental simulations yield a valuable guideline for optimizing thermal spray processes and should be implemented into overall processing models.

Keywords: atomization, catalysts, computer simulation, cooling, growth kinetics, microstructure, nucleation, optimization, random processes, solidification, spraying

J.H. Perepezko, J.L. Sebright, P.G. Hockel, and G. Wilde, Forschungszentrum Karlsruhe, Inst. Nanotechnology, Karlsruhe 76021, Germany. Cited: *Mater. Sci. Eng. A, 326*(1), 15 March 2002, p 144-153 [in English]. ISSN 0921-5093.

Nanopowders

Solid-solution behavior of $Ce_xZr_{1-x}O_2$ nanopowders prepared by flame spray pyrolysis of solvent-borne precursors. A series of $Ce_xZr_{1-x}O_2$ nanopowders has been prepared via flame spray pyrolysis of metal precursors dissolved in the desired molar ratio in a flammable carrier solvent. This synthetic method relies on the near-instantaneous combustion of a fine aerosol mist of the precursor solution followed by rapid thermal quenching that limits both particle growth and phase separation. When $0.5 \leq X \leq 1$, the oxides have the cubic CaF_2 structure type with unit-cell parameters that decrease as the mole fraction of Ce^{4+} decreases. Such solid-solution behavior continues through $0 \leq X \leq 0.5$, although the oxides now possess a unit cell related to tetragonal-ZrO_2. For pure ZrO_2 ($X = 0$), the monoclinic phase dominates, although significant amounts of tetragonal ZrO_2 are also observed. The nanopowders have specific surface areas of 11-17 m^2/g, corresponding to average particle diameters of 50-85 nm. Direct observation with scanning electron and transmission electron microscopes confirms that the majority of the particles range from 50-100 nm. Upon heating the oxides at 1100 °C for 1 h, particle diameters increase to 100-220 nm, although the structures remain unchanged where $X \geq 0.1$.

Keywords: composition effects, flame spraying, heating, nanostructured materials, particle size analysis, phase composition, pyrolysis, scanning electron microscopy, solid solutions, solvents, surface properties, transmission electron microscopy

A.C. Sutorik and M.S. Baliat, Tal Materials, Inc., Ann Arbor, MI 48105. Cited: Cited: Proc. Int. Symposium on Metastable, Mechanically Alloyed and Noncrystalline Materials (ISMANAM), 24-29 June 2001 (Ann Arbor, MI), *Mater. Sci. Forum, 386-388,* 2002, p 371-376 [in English]. ISSN 0255-5476.

Dried particle plasma spray in-flight synthesis of spinel coatings. Powder particle diameters currently used for spraying are generally between 5 and 100 μm with a preferred size range around 40-60 μm. Future trends in plasma spraying involve the use of fine or ultrafine powders and the reduction of the number of steps between raw material preparation and coating. The use of nonsintered spray dried ceramic aggregates as feedstock material for plasma spraying has accordingly been investigated. Al_2O_3-based coatings were prepared by this route of dried particle plasma spray (DPPS). The microstructure and crystallographic phases of these deposits were characterized using scanning electron microscopy (SEM) equipped with energy dispersive spectrometry (EDS) and x-ray diffraction (XRD). Given the intimate mixing of the starting oxides, reactions occur during spraying leading to the formation of spinel ($MgAl_2O_4$ and/or $ZnAl_2O_4$) and zinc aluminum oxide ($Zn_4Al_{22}O_{37}$). The layered structure of the deposit is characteristic of conventional plasma sprayed coatings, but the features are smaller in size. Depending on the operating conditions (plasma characteristics and powder injection), two different melting modes of the particles were identified: the first leads to individual well-melted droplets that splash regularly even if generating some fingers, and the second leads to aggregates that are well melted on their outer parts and strengthened in their cores.

Keywords: aggregates, alumina, ceramic materials, energy dispersive spectroscopy, feedstocks, microstructure, scanning electron microscopy, synthesis (chemical), x-ray diffraction analysis

G. Bertrand, C. Meunier, P. Bertrand, and C. Coddet, LERMPS, UTBM, Belfort cedex 90010, France. Cited: *J. Eur. Ceram. Soc., 22*(6), June 2002, p 891-902 [in English]. ISSN 0955-2219.

Flame-made ceria nanoparticles. Flame spray pyrolysis (FSP) has been used to synthesize high-surface-area ceria from cerium acetate in acetic acid solution. With the addition of an iso-octane/2-butanol mixture to that solution, homogeneous CeO_2 nanoparticles were obtained. The specific surface area of the powders ranged from 240-101 m^2/g by controlling the oxygen dispersion and liquid precursor flow rates through the flame. Furthermore, for production rates from 2-10 g/h a constant average primary particle size could be obtained at selected process parameters. The ceria showed high crystallinity and primary particles with a stepped surface. The powder exhibited good thermal stability and conserved up to 40% of its initial specific surface area when calcinated for 2 h at 900 °C. This shows the potential of FSP made ceria for high-temperature applications as in three-way catalysts or fuel cells.

Keywords: acetic acid, addition reactions, catalysts, cerium compounds, crystalline materials, flame spraying, oxygen, pyrolysis, solutions, surface structure, synthesis (chemical), thermodynamic stability

L. Madler, W.J. Stark, and S.E. Pratsinis, Inst. Process Engineering, ETH Zurich, CH-8092 Zurich, Switzerland. Cited: *J. Mater. Res., 17*(6), June 2002, p 1356-1362 [in English]. ISSN 0884-2914.

Bismuth oxide nanoparticles by flame spray pyrolysis. Bismuth oxide nanostructured particles were made via the flame spray pyrolysis (FSP) of bismuth nitrate that had been dissolved in a solution of ethanol/nitric acid or in acetic acid. These self-sustaining spray flames produced tetragonal βBi_2O_3. The use of ethanol/nitric acid solutions resulted in a mixture of hollow, shelllike, and solid nanograined particles. The particle homogeneity was improved as the content of acetic acid in the precursor solution increased. Solid bismuth oxide nanoparticles were prepared consistent with percolation theory, accounting for the specific volume of the product and the precursor. Using pure acetic acid as the solvent, the effect of FSP variables on spray flame and product powder characteristics was investigated. The specific surface area of the Bi_2O_3 particles could be controlled over a range of 20-80 m^2/g by the liquid feed and oxygen gas flow rates for powder production rates of 6-46 g/h.

Keywords: acetic acid, bismuth compounds, ethanol, nitric acid, percolation (solid state), pyrolysis

L. Madler and S.E. Pratsinis, Inst. Process Engineering, ETH Zurich, CH-8092 Zurich, Switzerland. Cited: *J. Am. Ceram. Soc., 85*(7), July 2002, p 1713-1718 [in English]. ISSN 0002-7820.

Synthesis of magnetic nanocomposite particles. Carbon nanoparticles were synthesized using an arc-discharge apparatus. Magnetic-metal filled nanocapsules were segregated from nonmagnetic carbon particles using a magnet. TEM, XRD, EDS, and Raman scattering spectroscopic examination revealed that a magnetic iron particle, 10-50 nm in diameter, was encapsulated in each carbon nanocapsule. These magnetic-metal-filled carbon nanocapsules were then coated individually with amorphous silicate to provide additional oxidation protection. These nanocomposite particles ranging from 100 to 300 nm in diameter can be dispersed in water solution and aligned or spatially arranged by a magnet.

Keywords: carbon, electric arcs, energy dispersive spectroscopy, magnetic materials, nanostructured materials, oxidation resistance, protective coatings, Raman scattering, synthesis (chemical), transmission electron microscopy, x-ray diffraction analysis

C.P. Chen, T.H. Chang, and T.F. Wang, Dept. Materials Science and Engineering, National Dong Hwa Univ., Hualien, Taiwan. Cited: *Ceram. Int., 28*(8), 2002, p 925-930 [in English]. ISSN 0272-8842.

Synthesis of zinc oxide/silica composite nanoparticles by flame spray pyrolysis. Zinc oxide (ZnO)/silica (SiO_2) composite nanoparticles were made by flame spray pyrolysis. The effects of the Zn/Si ratio on particle properties were examined and compared with those of the pure ZnO and SiO_2 particles made at the same conditions. Polyhedral aggregates of nanosized primary particles were obtained in all experiments, The mixed-oxide primary particle size was smaller than that of pure oxides. The primary particles consisted of ZnO nanocrystals and amorphous SiO_2, as seen by high-resolution transmission electron microscopy (HR-TEM) and x-ray diffraction (XRD) analysis using the fundamental parameter approach. The XRD size of ZnO was controlled from 1.2-11.3 nm by the initial precursor composition and it was consistent with HR-TEM. The composite particles exhibited an excellent thermal stability and

little crystalline growth of ZnO (e.g., from 1.9-2.2 nm) was observed even after calcination at 600 °C.

Keywords: composite materials, crystal growth, flame spraying, particle size analysis, pyrolysis, silica, thermodynamic stability, transmission electron microscopy, x-ray diffraction, zinc oxide

T. Tani, L. Madler, and S.E. Pratsinis, Inst. Process Engineering, ETH Zurich, CH-8092 Zurich, Switzerland. Cited: *J. Mater. Sci., 37*(21), 1 Nov 2002, p 4627-4632 [in English]. ISSN 0022-2461.

Novel Materials

Lanthanum hexaaluminate—Novel thermal barrier coatings for gas turbine applications—Materials and process development. Lanthanum hexaaluminate (LHA) with a magnetoplumbite structure is a promising competitor to yttria partially stabilized zirconia (Y-PSZ) as a thermal barrier coating (TBC), since most zirconia coatings age significantly, including undesired densification at temperatures exceeding 1100 °C. The microstructure of calcined lanthanum hexaaluminate powders and thermally sprayed coatings show a platelet structure. The magnetoplumbite structure is characterized by the highly charged La^{3+} cation located in an oxygen position in the hexagonal close-packed structure of oxygen ions. Ion diffusion is strongly suppressed vertical to the crystallographic *c*-axis, thus hindering sintering densification. In contrast to the oxygen ion conducting zirconia, lanthanum hexaaluminate permits operating temperatures above 1300 °C because of its thermal stability and electrically insulating properties. This study describes the optimization of powder preparation for thermal spraying by spray drying and the development of parameters for atmospheric plasma spraying (APS) in order to produce homogeneous crystalline coatings with controlled microporosity and residual stresses. The phases were characterized by x-ray diffraction (XRD).

Keywords: calcination, densification, electric insulation, gas turbines, lanthanum compounds, metallographic microstructure, microporosity, residual stresses, sintering, sprayed coatings, thermodynamic stability, x-ray diffraction, zirconia

R. Gadow and M. Lischka, Inst. Manufacturing Technologies Cer, Univ. Stuttgart, Stuttgart D-70569, Germany. Cited: *Surf. Coat. Technol., 151-152,* 1 March 2002, p 392-399 [in English]. ISSN 0257-8972.

Lanthanum hexaaluminate—A new material for atmospheric plasma spraying of advanced thermal barrier coatings. One of the main application fields of the thermal spraying process is thermal barrier coatings (TBCs). Today, partially stabilized zirconia (YSZ or MSZ) is mainly used as a TBC material. At temperatures above 1000 °C, zirconia layers age distinctively, including phenomena shrinkage and microcrack formation. Therefore, there is a considerable interest in TBCs for higher-temperature applications. In this paper, lanthanum hexaaluminate, a newly developed TBC material with long-term stability up to 1400 °C, is presented. It ages significantly more slowly at these high temperatures than commercial zirconia-base TBCs. Its composition favors the formation of platelets, which prevent a densification of the coating by postsintering. It consists of La_2O_3, Al_2O_3, and MgO. Its crystal structure corresponds to a magnetoplumbite phase. Lanthanum hexaaluminate powders were produced using two different fabrication routes, one based on salts and the other one based on oxides. To optimize the granulate, various raw materials and additives were tested. The slurry was spray dried in a laboratory spray drier and calcined at 1650 °C. Using these two powders, coatings were produced by atmospheric plasma spraying (APS). The residual stresses of the coatings were measured by the hole-drilling method, and the deposition process was optimized with respect to the residual stresses in the TBC. The coatings were extensively analyzed regarding phase composition, thermal expansion, and long-term stability, as well as microstructural properties.

Keywords: additives, aging of materials, calcination, composition, crystal microstructure, densification, high-temperature applications, lanthanum compounds, microcracks, phase composition, powder metals, residual stresses, shrinkage, sintering, thermal barrier coatings, thermal expansion

R. Gadow, T. Schirmer, and C. Friedrich, Univ. Stuttgart, IFKB, Stuttgart, D 70569, Germany. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 592-598 [in English]. ISSN: 1059-9630.

Production/Preparation Technology

Direct synthesis of strontium titanate phosphor particles with high luminescence by flame spray pyrolysis. $SrTiO_3$:Pr,Al phosphor particles with high luminescence intensities were directly prepared by flame spray pyrolysis without post-treatment. They had better crystallinity than those prepared by general spray pyrolysis with post-treatment and solid-state reaction methods. In addition, they had complete spherical shape and narrow size distribution. On the other hand, the particles prepared by general spray pyrolysis had irregular shape, and poorer brightness than those prepared by solid-state reaction method, while the particles prepared by flame spray pyrolysis had comparable photoluminescence and cathodoluminescence intensities with those of particles prepared by solid-state reaction method. The photoluminescence intensity of $SrTiO_3$:Pr,Al particles prepared by flame spray pyrolysis was as much as 4.7 times higher than that of particles prepared by general spray pyrolysis.

Keywords: cathodoluminescence, ceramic materials, flame spraying, photoluminescence, pyrolysis, synthesis (chemical)

Y.C. Kang, D.J. Seo, S.B. Park, and H.D. Park, Advanced Materials Div., Korea Research Inst. Chemical Technology, Yusong-gu, Taejon 305-600, South Korea. Cited: *Mater. Res. Bull., 37*(2), 1 Feb 2002, p 263-269 [in English]. ISSN 0025-5408.

Nickel-coated Al_2O_3 powders. A heterogeneous precipitation method was employed to prepare nickel-coated-Al_2O_3 powders using Al_2O_3, $Ni(NO_3)_2{\cdot}6H_2O$ and NH_4HCO_3 as the starting materials. The coated powders were characterized by transmission electron microscopy, acoustic emission spectroscopy, and ζ-pH. Results showed that a continuous amorphous $NiCO_3{\cdot}2Ni(OH)_2{\cdot}2H_2O$ film uniformly coated the Al_2O_3 particles surface. After calcining at 400 °C for 2 h in air and reducing at 700 °C for 4 h in hydrogen atmosphere, $NiCO_3{\cdot}2Ni(OH)_2{\cdot}2H_2O$ was converted to nickel with size of about 20 nm, meanwhile, the continuous amorphous film become discontinuous.

Keywords: alumina, amorphous films, Auger electron spectroscopy, calcination, electrophoresis, ionic conduction, nickel, particle size analysis, precipitation (chemical), protective coatings, transmission electron microscopy

G.-J. Li, X.-X. Huang, J.-K. Guo, and D.-M. Chen, National Key Lab. of Advanced Composites, Beijing Inst. Aero. Materials, Beijing 100095, China. Cited: *Ceram. Int., 28*(6), 2002, p 623-626 [in English]. ISSN 0272-8842.

Preparation and characterization of Al_2O_3-TiO_2 powders by chemical synthesis for plasma spray coatings. This paper describes the preparation and characterization of the Al_2O_3-TiO_2 powders for plasma spray coatings. The Al_2O_3-TiO_2 powders were fabricated from an aqueous solution of aluminum nitrate and titanium ethoxide precursors using chemical synthesis. The powders were calcined at 650 °C for 1 h and then pellet samples were sintered at 1300 °C for 1 h in air. These powders were characterized by SEM, EDS, and x-ray diffraction. The results showed that the particle sizes of Al_2O_3-TiO_2 powders were found to be between 10 and 45 μm.

Keywords: alumina, calcination, energy-dispersive spectroscopy, particle size analysis, plasma spraying, scanning electron microscopy, solutions, sprayed coatings, synthesis (chemical), titanium compounds, x-ray diffraction analysis

E. Celik, Faculty of Engineering, Dept. of Metallurgical and Materials Engineering, Dokuz Eylul Univ., Bornova, Izmir 35100, Turkey. Cited: *J. Mater. Process. Technol., 128*(1-3), 6 Oct 2002, p 205-209 [in English]. ISSN 0924-0136.

Spray drying plants for manufacture of dustless powders—A technical note. The paper describes the methods and the equipment for production of free-flowing and dustless powders, which are often required for thermal spraying applications. The powders are made from a suspension including finely dispersed material to be agglomerated as a powder, the binder, and some other components (plasticizers, wetting agents, etc.). The binders added in the suspension play a particularly important role with regard to improving the particle size and stability. The paper also describes the alternative drying applications that can be realized using the different types of plants. The systems are described on the basis of two different types of feed product: (1) a liquid and (2) a powder.

Keywords: agglomeration, atomization, atomizers, drying, laminar flow, nozzles, particle size analysis, spraying

P. Bork, APV Anhydro, Soborg, Copenhagen, DK 2860, Denmark. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 578-583 [in English]. ISSN: 1059-9630.

Manufacturing

Substrate for Solid Oxide Fuel Cells

Development and characterization of vacuum plasma sprayed thin film solid oxide fuel cells. The vacuum plasma spraying (VPS) process allows the production of thin solid oxide fuel cells (SOFCs) with low internal resistances. This enables the reduction of the cell operating temperature without a significant decrease in power density. Consequently, the long-term stability of the cells can be improved and low-cost materials can be used. Different material combinations and spray parameter variations were applied to develop thin-film SOFCs, which were plasma sprayed in a consecutive deposition process onto different porous metallic substrates. The use of Laval nozzles, which were developed at the German Aerospace Center (DLR), and the use of conical F4V standard nozzles enable the fabrication of thin gastight yttria- and scandia-stabilized ZrO_2 (YSZ and ScSZ) electrolyte layers and of porous electrode layers with high material deposition rates. The optimization of the VPS parameters has been supported by laser Doppler anemometry (LDA) investigations. The development of the plasma-sprayed cells with a total thickness of approximately 100 μm requires an overall electrical and electrochemical characterization process of the single layers and of the completely plasma sprayed cell assembly. The plasma sprayed cell layers reveal high electrical conductivities. The plasma-sprayed cells show very good electrochemical performance and low internal resistances. Power densities of 300 to 400 mW/cm^2 at low operating temperatures of 750 to 800 °C were achieved. These cells can be as-

sembled to high-performance SOFC stacks with active cell areas up to 400 cm^2, which can be operated at reduced temperatures and good long-term stability.

Keywords: crystal microstructure, electric conductivity, electrochemical electrodes, electrochemistry, electrolytes, nozzles, porosity, solid oxide fuel cells, spectroscopic analysis, substrates, thin films, vacuum applications

R. Henne, S. Schaper, G. Schiller, and M. Lang, Inst. fur Technische Thermodynamik, Deutsches Zentrum F. Luft/Raumfahrt, D-70569 Stuttgart, Germany. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 618-625 [in English]. ISSN: 1059-9630.

Modeling

Influence of Process Parameters

Effects of anode nozzle geometry on thermal plasma characteristics generated by nontransferred torches for material processing. The thermal plasma characteristics produced by the nontransferred torches with various anode nozzle geometries, such as a tubular nozzle and a stepped nozzle, operating at an atmospheric pressure are calculated and measured by a numerical simulation and an optical emission spectroscopy, respectively. On the basis of the assumption of local thermodynamic equilibrium (LTE) and optically thin plasmas, the temperature distributions of argon thermal plasmas are determined by the Abel inversion and Boltzmann plot methods for the measured intensity of Ar I lines. On the other hand, their velocity distributions are deduced from the measured temperatures by means of power balance equations. For the numerical simulation, two-dimensional magnetohydrodynamic (MHD) equations are employed with a K-ε turbulence model. As a numerical scheme, the finite volume discretization and SIMPLE-like pressure correction algorithm are adopted in an unstructured triangular grid system for reflecting the complicated nozzle geometry. The thermal plasma properties produced with different nozzle types and sizes, such as tubular nozzles of various diameters and stepped nozzles of different step positions and diameters, are compared between the experimental and numerical results. Furthermore, from the obtained information on the effects of anode nozzle geometry on thermal plasma characteristics, the optimal design conditions of nozzle type and geometry are determined for the nontransferred plasma torches to be used as heat sources for material processing, such as plasma spraying, synthesis, and decomposition.

Keywords: anodes, atmospheric pressure, computer simulation, emission spectroscopy, finite volume method, magnetohydrodynamics, mathematical models, optical microscopy, plasma theory, plasma turbulence, temperature distribution, thermodynamic properties

T.H. Hwang, D.U. Kim, J.M. Park, S.S. Choi, and S.H. Hong, Dept. Nuclear Engineering, Seoul National Univ., Seoul 151-742, South Korea. Cited: *2002 IEEE International Conference on Plasma Science,* 26-30 May 2002 (Banff, Alberta, Canada), Inst. Electrical and Electronics Engineers Inc., p 117 [in English]. ISSN 0730-9244.

Modeling thermal spray coating processes: a powerful tool in design and optimization. Understanding the dependence of the microstructure of spray coatings on operating conditions of the thermal spray system is of great practical interest. To obtain good-quality coatings, the spray parameters must be selected carefully and, due to the large variety in process parameters, much trial and error goes into optimizing the process for each specific coating and substrate combinations. In this paper, a complete model of the high-velocity oxyfuel spray coating process is presented, including modeling three distinct subprocesses: spray parameters such as particle size, temperature, velocity, and impact points; particle impact and splat formation; and the coating microstructure.

Keywords: computer simulation, heating, impact testing, mathematical models, microstructure, optimization, particle size analysis, plasma spraying, quality control, temperature, velocity

J. Mostaghimi, R. Ghafouri-Azar, S. Chandra, and A. Dolatabadi, Center for Advanced Coating Technologies, Dept. of Mechanical and Industrial Engineering, Univ. Toronto, Toronto, Ontario, Canada. Cited: Technical Paper—Society of Manufacturing Engineers, FC02-224, 2002, Society of Manufacturing Engineers, p i+1-33 [in English]. ISSN 0161-1844.

Full-scale modeling of a thermal spray process. An attempt at the comprehensive simulation of a thermal spray process is made. The simulation tool consists of physical models and their computational realizations for major elements of the process such as: plasma torch, particle motion and heating, plasma-substrate and particle-substrate interaction, and formation of the deposited layer. Simulation results are compared with experimental data for LPPS. Using a simplified thermomechanical splat model and statistical model of particle deposition, some aspects of microstructure formation are studied. Influence of particle size, temperature, and speeds, as well as spray angle and stand-off distance, on the coating structure and surface texture is investigated. Influence of the motion control and process parameters on the coating porosity and microstructure is discussed. Examples of sensitivity analysis and coating optimization for those parameters are presented.

Keywords: computer simulation, deposition, mathematical models, metallographic microstructure, optimization, particle size analysis, plasma torches, porosity, statistical methods, textures

A.V. Zagorski and F. Stadelmaier, ALSTOM Power Technology, Baden-Daetwil CH5405, Switzerland. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 162-167 [in English]. ISSN 0257-8972.

Numerical analysis of the influence of coating porosity and substrate elastic properties on the residual stresses in high temperature graded coatings. The functionality and reliability of coated devices are strongly related to residual stresses of coatings. The major problem in thermal barrier coatings (TBCs) applied to gas turbine components is the failure by spallation of ceramic coating under thermal cycling processes. In order to prevent spallation and to improve the thermomechanical behavior of the TBC the interfacial stresses in the coating system should be reduced. To overcome this problem, it is desirable to introduce a graded layer between the metallic bond coat and the zirconia top coating. Therefore, a detailed study of the optimization of the gradient profile is necessary with respect to thermal stress relief. In this paper a numerical model of thermal stress distribution within a multilayered system which consists of a functionally gradient material (FGM) is presented. The structure of the graded coating system is made of a ceramic layer and a metallic layer, where between them there is an interlayer that is a graded composite made of the metal (NiCr-alloy) and the ceramic ($ZrO_2Y_2O_3$). The effects on residual stress distribution of elastic properties of the alloy substrate, the graded interlayer thickness and ceramic layer porosity were analyzed for the case of a fully graded TBC using a linear compositional profile for the FGM. This model will provide some insights regarding the development of a methodology for designing fail-safe graded coating systems used in high-temperature applications.

Keywords: ceramic materials, elasticity, functionally graded materials, mathematical models, multilayers, optimization, porosity, residual stresses, stress concentration, substrates, thermal cycling, thermal stress

V. Teixeira, Univ. Minho, IMAT-Inst. Materials, Physics Dept., Campus de Gualtar, Braga PT-4710-057, Portugal. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 79-84 [in English]. ISSN: 0257-8972.

Properties of Coatings

Numerical investigation of residual stress fields and crack behavior in TBC systems. Due to thermal expansion mismatch and bond coat (BC) oxidation, high residual stresses are induced in the thermal barrier coating (TBC), leading to failure by spalling and delamination. Using the finite-element method (FEM), an analysis of the stress distributions in TBC systems, which is a prerequisite for the understanding of failure mechanisms, was performed. As cracking usually occurs at or near the interfaces between BC/thermally grown oxide (TGO) and TBC/TGO depending on the processing mode of the TBC, cracks in the interface region were considered in the FE models in order to determine the loading conditions for their propagation and, thus, the failure criteria of the TBCs. Due to the mode mixity of these cracks, suitable methods are required for the determination of the fracture mechanics parameters needed for their assessment, such as the strain-energy release rate *G*. The modified crack closure integral method (MCCI) was found to be a very efficient tool that can be combined easily with an FE analysis and leads to highly accurate energy release rate values. Moreover, this method enables the determination of mode-dependent energy release rates. Using this tool and appropriate crack propagation criteria, TBC failure models could be developed and verified.

Keywords: crack propagation, delamination, finite element method, fracture mechanics, interfaces (materials), oxidation, stress concentration, thermal barrier coatings, thermal expansion

K. Sfar, J. Aktaa, and D. Munz, Forschungszentrum Karlsruhe, Inst. Materialforschung II, Karlsruhe D-76021, Germany. Cited: *Mater. Sci. Eng. A, 333*(1-2), Aug 2002, p 351-360 [in English]. ISSN 0921-5093.

Stress distributions in plasma sprayed thermal barrier coatings as a function of interface roughness and oxide scale thickness. During thermal cyclic loading, plasma sprayed thermal barrier coatings (TBCs) often show failure within the top coat close to the interface. In all cases, this results from crack propagation of pre-existing cracks near the bond coat (BC)-top coat interface. Stresses developing on a microscopic scale near the BC-TBC interface of plasma sprayed thermal barrier coatings govern crack growth in an initial phase of the failure process. Using a finite-element (FE) method the local dependence of stresses in the vicinity of this rough interface was investigated. Measurements of real roughness profiles provided geometrical parameters needed for the calculations. A significant difference in the stress distributions was found for peak-and-valley locations of the BC roughness profile. The effect of BC oxidation on stress development was more pronounced in the case of less roughness. Analytical fits of the FE results revealed how the parameters of roughness and the oxide thickness correlate with the stress levels. In the next stage of research these fits will serve as input data for a microstructural-based lifetime model.

Keywords: crack propagation, finite element method, interfaces (materials), microstructure, oxidation, plasma spraying, stress concentration, stresses, surface roughness, thermal cycling

M. Ahrens, R. Vassen, and D. Stover, Forschungszentrum Julich GmbH, Inst. Werkstoffe/Verfahren Energiet., Julich D-52425, Germany. Cited: *Surf. Coat. Technol., 161*(1), 1 Nov 2002, p 26-35 [in English]. ISSN 0257-8972.

Interfacial fracture property determination of coated systems: A finite-element study. A study was carried out to examine the interfacial fracture properties of the HOVF coating-steel composite system numerically in relation to indentation stress and strain fields. Based on the results, a novel method was established to quantify the adhesion strength of surface coated systems.

Keywords: adhesion, bond strength (materials), computer simulation, cracks, delamination, elastoplasticity, finite-element method, fracture, fracture toughness, interfaces (materials), mathematical models, tensile strength

H.Q. Li, X. Cai, and Q.L. Cheng, Key Lab. of the Min. of Education, Shanghai Jiao Tong Univ., Shanghai 200030, China. Cited: *J Mater. Sci. Lett., 20*(23), 1 Dec 2001, p 2167-2171 [in English]. ISSN 0261-8028.

Splats Cooling

Kinetic modeling of phase selection during nonequilibrium solidification of a tungsten-carbon system. A dynamic computational model developed within the context of the classical theory of phase evolution was applied to the tungsten-carbon (W-C) system to simulate the kinetics of phase selection during nonequilibrium solidification at 50% C between the thermodynamically stable WC and the metastable WC_{1-x} and W_2C. The kinetic variables used in the model are directly obtained from the free-energy formulations that characterize the stable and metastable equilibria among participating phases. The isothermal kinetic analysis suggests that at low to moderate undercoolings, thermodynamic stability prevails, while at deep undercoolings (~1000 K) the crystallization of W_2C completes faster than the more thermodynamically stable WC_{1-x} and almost as fast as WC. The nonisothermal kinetic analysis suggests that thermodynamic stability prevails under moderate to high cooling rates (e.g., 10^4 to 10^6 K/s); however, under ultrahigh cooling rates (e.g., 10^8 K/s), the crystallization of WC_{1-x} and W_2C completes at nearly the same undercooling as that of WC.

Keywords: crystallization, growth (materials), nucleation, plasma spraying, rapid solidification, thermodynamic stability, tungsten carbide

M.D. Demetriou, N.M. Ghoniem, and A.S. Lavine, Mechanical and Aerospace Engineering Dept., Univ. California, Los Angeles, CA 90095-1597. Cited: *Acta Mater., 50*(6), 2 April 2002, p 1421-1432 [in English]. ISSN 1359-6454.

Solidification modeling of plasma sprayed TBC: analysis of remelt and multiple length scales of rough substrates. A two-dimensional, finite-element model based on an enthalpy formulation, was developed to simulate a splat solidifying on a rough substrate (with an idealized, sinusoidal-shaped roughness) capturing the multiple-length scales seen in real coatings as well as different aspect ratios. The model was used to study the effects of substrate temperature, splat temperature, and roughness characteristics on the onset and extent of remelt. Remelt is studied since it is indicative of local heat-transfer conditions and might explain observed coating properties. Multiple splats were simulated using the two-dimensional model for short-time cooling coupled to a one-dimensional model for long-time cooling to predict substrate temperature rise prior to subsequent splat impacts. The presence of roughness promoted substrate remelting at conditions under which no remelting was observed for a smooth surface, suggesting that substrate roughness is an important parameter to include in splat-solidification studies. The effects of splat temperature and substrate temperature on remelt were consolidated into a single nondimensional parameter, which captured a number of critical phenomena including characterization of the onset of remelt with a nondimensional remelting point.

Keywords: aspect ratio, coatings, computer simulation, cooling, finite element method, mathematical models, microstructure, solidification, substrates, surface roughness, temperature, thermal barrier coatings

D.E. Wroblewski, R. Khare, and M. Gevelber, College of Engineering, Boston Univ., Boston, MA 02215. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 266-275 [in English]. ISSN 1059-9630.

Spray Deposition

Modeling and experimental observation of evaporation from oxidizing molybdenum particles entrained in a thermal plasma jet. A model describing the in-flight evaporation of particles injected into a high-temperature plasma jet issuing into surrounding air has been developed and incorporated into an earlier model that includes a detailed description of particle heating and melting. In addition to physical evaporation controlled by vapor diffusion and heat transfer, the evaporation due to the production of volatile oxides on the particle surface is also modeled. The effect of evaporation-induced mass transfer on heat flux to the particle surface is taken into consideration along with the effects of variable plasma properties and the modification of heat and momentum transfer due to noncontinuum effects experienced under plasma conditions. Computational results on molybdenum particles in an argon-hydrogen direct-current plasma spray system are developed and are qualitatively compared with experimental results.

Keywords: computational methods, diffusion, heat flux, high-temperature effects, mass transfer, melting, molybdenum, oxidation, plasma jets, plasma spraying

Y.P. Wan, J.R. Fincke, S. Sampath, V. Prasad, and H. Herman, GT Equipment Technologies Inc., Nashua, NH 03063. Cited: *Int. J. Heat and Mass Transfer, 45*(5), 8 Jan 2002, p 1007-1015 [in English]. ISSN 0017-9310.

An integrated model for interaction between melt flow and nonequilibrium solidification in thermal spraying. In this paper, a micro/macrointegrated model based on the VOF scheme is presented that accounts for free surface movement, thermal contact resistance, and fluid instability. A submodel is developed to include the nonequilibrium solidification phenomena at the solid/liquid interface. The melt flow is incorporated into the microscopic model through prescribing a velocity profile that is obtained from the interpolation of melt velocities on the macroscopic grids near the interface. To improve the efficiency of the integration between the melt flow and the microscopic model, a relational database is developed and applied to the integrated micro/macro model. Three velocity profiles, e.g., linear, parabolic, and cubic velocity profiles, are considered, and the results are compared with those obtained from the diffusion model.

Keywords: diffusion, heat resistance, interfaces (materials), interpolation, mathematical models, relational database systems, solidification, spraying

X.Y. Wang, H. Zhang, L.L. Zheng, and S. Sampath, Dept. Mechanical Engineering, St. Univ. New York at Stony Brook, Stony Brook, NY 11794-2300. Cited: *Int. J. Heat Mass Transfer, 45*(11), 2 April 2002, p 2289-2301 [in English]. ISSN 0017-9310.

On the importance of chemistry/turbulence interactions in spray computations. The importance of chemistry/turbulence interactions in spray computations was presented. The solution procedure combined the novelty of the application of the scalar Monte Carlo probability density function (PDF) method to the modeling of turbulent spray flames. The comparisons involving both gas-phase and droplet velocities, droplet size distributions, and gas-phase temperatures showed agreement with the experimental data. The results of Monte Carlo temperature distribution showed that the functional part of the PDF for the temperature fluctuations varied substantially from point to point.

Keywords: boundary conditions, combustion, computational fluid dynamics, diffusion, flame spraying, mathematical models, Monte Carlo methods, parallel processing systems, Prandtl number, probability density function, temperature distribution, turbulence, vaporization

M.S. Raju, M.S. 500, QSS, NASA Glenn Research Center, Cleveland, OH 44135. Cited: *Numer. Heat Transfer, B, 41*(5), May 2002, p 409-432 [in English]. ISSN 1040-7790.

Scaling analysis and prediction of thermal aspects of the plasma spraying process using a discrete particle approach. On the basis of a discrete particle approach, a scaling analysis was used to predict features of the thermal plasma spraying process. Correlations were obtained using the analysis, and they were subsequently used to predict two important features: the state of the particle at the moment of impact on the substrate, and the nature of solidification process. Limitations and restrictions were also identified in the development of the analysis that can be used to infer the resulting structure of coating. The correlations that were developed might be utilized in optimizing the thermal plasma spraying process, as well as in producing new types of coatings.

Keywords: deformation, deposition, flow of fluids, heat transfer, porosity, quality assurance, solidification, sprayed coatings, substrates, surface structure, thermal effects, thermal gradients

J. Lee and T.L. Bergman, Dept. of Mechanical Engineering, Yonsei Univ., Seoul, 120-749, South Korea. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 179-185 [in English]. ISSN 1059-9630.

Splat shapes in a thermal spray coating process: simulations and experiments. The authors studied the deposition of nickel particles in a plasma spray on a stainless steel surface using both experiments and numerical simulations. They developed a three-dimensional computational model of free-surface fluid flow that includes heat transfer and solidification and used it to simulate the impact of nickel particles. In our experiments, particles landing on a polished stainless steel surface at a temperature below 300 °C splashed and formed irregular splats, whereas those deposited on substrates heated above 400 °C formed round disk splats. Simulations showed that formation of fingers around the periphery of a spreading drop is caused by the presence of a solid layer. Droplets that spread completely before the onset of solidification will not splash. To sufficiently delay the instant at which solidification started in the simulations to obtain disk splats, the authors had to increase the thermal contact resistance between the droplet and the substrate by an order of magnitude. They measured the thickness of the oxide layer on the test surfaces used in their experiments and confirmed that heating them creates an oxide layer on the surface that increases the thermal contact resistance. They dem-

onstrated that the numerical model could be used to simulate the deposition of multiple droplets on a surface to build up a coating.

Keywords: computer simulation, deposition, flow of fluids, heat transfer, mathematical models, nickel, particles (particulate matter), plasma spraying, solidification, stainless steel, substrates, surface structure

M. Pasandideh-Fard, V. Pershin, S. Chandra, and J. Mostaghimi, Univ. Toronto, Dept. of Mechanical and Industrial Engineering, Toronto, Ontario M5S 3G8, Canada. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 206-217 [in English]. ISSN 1059-9630.

Volatilization of metal powders in plasma sprays. Ideally, plasma spraying of metal powders must take place within a narrow processing "window" where the particles become fully molten before they hit the substrate, but are not overheated to the point that substantial volatilization occurs. Metal evaporation in flight results in a decrease in the deposition efficiency. In addition, the emission of vapors leads to the formation of metal and oxide fumes that are undesirable from the viewpoints of both resource conservation and environmental control. This study examines the vaporization and fume formation in the plasma spraying of iron powders of different size ranges. The experimental part involves the determination of the population (number density) of metal atoms at different cross sections along the trajectory of the plasma jet, and the collection of the submicronic particles resulting from vapor condensation. The experimental results are compared with the projections of a mathematical model that computes the gas/particle velocity and temperature fields within the jet envelope, projects the rate of heat/mass transfer at the surface of individual particles, and determines the rate of volatilization that results in the formation of metal and metal oxide fumes.

Keywords: absorption spectroscopy, condensation, evaporation, heat transfer, iron, mathematical models, particles (particulate matter), plasma jets, plasma spraying, substrates, vapors, velocity

A. Vardelle, M. Vardelle, H. Zhang, N.J. Themelis, and K. Gross, Univ. Limoges, Lab., Sci. des Procedes Ceramiques, 87060 Limoges, France. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 244-252 [in English]. ISSN 1059-9630.

Numerical simulation and measurement of droplet velocity during high-velocity arc spraying. Droplet velocity is one of main factors influencing the coating properties. Based on the theories of gas dynamics and multiphase fluid mechanics, the velocity problems of the atomization gas and droplet during high-velocity arc spraying (HVAS) were modeled and solved by a numerical method, and experiments were carried out to measure the average velocity changes using aluminum and 3Gr13 wires. A good agreement between the numerical and experimental results was observed. The results show that the exit velocity of atomization gas maintains the original velocity (~690 m/s) for a certain distance, then decreases with increasing distance from the nozzle, and this corresponds to the interaction between expansion wave and compression wave after the supersonic velocity gas passing the Laval tube. The in-flight droplets experience an acceleration-deceleration velocity profile. The smaller droplets could reach higher maximum velocity at shorter flight distance. Beyond the flight distance where the maximum velocity is reached, the smaller droplets are decelerated rapidly due to their lower inertia force. On the other hand, the larger droplets do not exhibit a marked deceleration because of their high inertia force. And the droplet velocity is determined by Reynolds number. Simulation and measurement prove that the maximum velocities of aluminum and 3G13 droplets are greater than the velocity of sound during high velocity arc spraying.

Keywords: computer simulation, electric arcs, gas dynamics, measurements, nozzles, Reynolds number, velocity

X.-X. Zhu, B.-Sh. Xu, X.-B. Liang, and Z.-Y. Du, Armored Force Eng. Inst., Beijing 100072, China. Cited: *Hanjie Xuebao/Trans. Chin. Weld. Inst., 23*(1), Feb 2002, p 5-8 [in Chinese]. ISSN 0253-360X.

A self-consistent two-temperature model for the computation of supersonic argon plasma jets. This paper presents a two-temperature model for compressible plasma flows. This study concentrates on the behavior of the plasma jet in the expansion region. The conditions used correspond to the conditions of low-pressure plasma spraying, with slightly supersonic conditions with thermal and chemical nonequilibrium. The flow dynamics results are analyzed with different turbulence models and appear to be consistent with results previously published by the authors on the dynamics of low-temperature air jets and favor the Reynolds stress turbulence model. Chemical as well as thermal nonequilibrium are studied.

Keywords: argon, computational methods, mathematical models, plasma turbulence, stresses

Y. Bartosiewicz, P. Proulx, and Y. Mercadier, Plasma Research Center, CRTP, Univ. Sherbrooke (Quebec), Sherbrooke, Quebec, J1K2R1, Canada. Cited: *J. Phys. D: Appl. Phys., 35*(17), 7 Sept 2002, p 2139-2148 [in English]. ISSN 0022-3727.

The theoretical evaluation of powders transportation in plasma transferred-arc space under coaxial powder feeding condition. The powder's transportation in the plasma transferred arc space during the coaxial powder-feeding surface depositing process was theoretically evaluated. The axial acceleration and velocity of various particles in the arc column were described. According to the results of theoretical calculations, it was found that: (1) The powder's transporting velocity is much lower than the plasma fluid's. (2) The powder's axial transporting velocity presents "valley-shape distribution" along plasma arc column traverse section when surfacing current is greater than 100 A. When the arc current exceeding 100 A, the powders coming through the center field of arc column will transport slower than the powder through the outer-around field of arc column. It is in the field where the temperature is in the range of 9000 to ~11,000 K that the panicles can achieve its maximum axial acceleration in the argon plasma space. (3) For the given powder mass density, the smaller its size, the greater its acceleration and the greater its averaged transporting velocity will be in the arc space. (4) For the given powder size, the greater its mass density is, the smaller its acceleration and averaged velocity will be in the arc space.

Keywords: argon, plasma spraying, powders, thermal effects

X. Wang and W. Zhang, Center of Surface Coating and Technol., Tianjin Univ., Tianjin 300072, China. Cited: *China Weld., 10*(2), Nov 2001, p 104-110 [in English] ISSN: 1004-5341.

Wear

A generalized sliding wear model for inhomogeneous coatings. In this work, a recently proposed continuum mechanics based multiscale approach to study the sliding wear behavior of homogeneous coatings is generalized to components coated with an initially inhomogeneous material The approach is suitable for either single-phase or multiphase materials with and without porosities and relies on a representative volume element of the coated system and periodic unit techniques to incorporate explicitly second-phase particles or porosities. A wear relation is derived by expressing the rate of material removed in terms of an average ratcheting strain measure integrated along the sliding direction, and the average depth at which the inelastic deformation within the coating localizes. The model is used to investigate the sliding wear of a molybdenum coating containing 5% randomly distributed porosities.

Keywords: continuum mechanics, deformation, molybdenum, plasma spraying, porosity, sprayed coatings, strain measurement

W. Yan, E.P. Busso, and N.P. O'Dowd, Dept. Mechanical Engineering, Imperial College, London SW7 2BX, U.K. Cited: (Conf. Proc: Fourth European Mechanics of Materials Conf. Processes, Microstructures and Mechanical Properties EUROMECH-MECAMAT'2000, 26-29 June 2000, E. Aeby-Gautier, M. Clavel, and D. Dunne, Ed.). *J. Phys., 11*(4), Sept 2001, p Pr4257-Pr4264 [in English]. ISSN: 1155-4339.

Post-Processing

Grinding of Thermal Spray Coatings

Grinding of nanostructured ceramic coatings: surface observations and material removal mechanisms. Surface grinding of thermally sprayed nanostructured WC/12Co and Al_2O_3/13TiO_2 (*n*-WC/12Co and *n*-Al_2O_3/13TiO_2) coatings has been undertaken with diamond wheels and under various grinding conditions. This paper investigates the effects of the grinding parameters such as depth of cut, feedrate, wheel grit size, and bond materials on grinding forces, surface finish, and surface topography. Different from their consolidated counterparts, the coatings have large quantities of defects inherited from thermal spray process, which greatly influence the grinding process and ground coatings. The competing phenomenon between the effects on surface finish from both the thermal spray process and the grinding process is studied. Different surface topographies are observed, and their relationship with grinding conditions and material properties is investigated. Furthermore, the material-removal mechanisms in grinding are explored. The effects of grinding parameters, material properties, and the defects from thermal spray process on material removal mechanisms are discussed.

Keywords: diamond cutting tools, grinding (machining), nanostructured materials, surface roughness

X. Liu, B. Zhang, and Z. Deng, Dept. Mechanical Engineering, Univ. Connecticut, Storrs, CT 06269. Cited: *Int. J. Mach. Tools Manuf., 42*(15), Dec 2002, p 1665-1676 [in English]. ISSN 0890-6955.

Heat Treatment of Coatings

Effect of heat treatment on phase stability, microstructure, and thermal conductivity of plasma sprayed yttria-stabilized zirconia. The effects of the heat treatment on phase stability, microstructure, and thermal conductivity of plasma sprayed Y_2O_3-ZrO_2 (YSZ) was investigated. Changes in the thermal conductivity of the coating that occurred during heat treatment were interpreted with respect to microstructural evolution. A metastable tetragonal zirconia phase was the predominant phase in the as-sprayed coating. The thermal conductivity was found to increase after every heat treatment. Changes in the phase stability and microstructure were investigated using x-ray diffraction and transmission electron microscopy.

Keywords: cooling, crystal microstructure, grain size and shape, high temperature effects, microcracks, morphology, nucleation, phase composition, phase diagrams, plasma spraying, porosity, thermal barrier coatings, thermal conductivity, transmission electron microscopy, x-ray diffraction analysis, zirconia

R.W. Trice, Y.J. Su, J.R. Mawdsley, K.T. Faber, A.R. De Arellano-Lopez, W.D. Porter, and H. Wang, Purdue Univ., School of Materials Engineering, West Lafayette, IN 47907. Cited: *J.Mater. Sci., 37*(11), 1 June 2002, p 2359-2365 [in English]. ISSN 0022-2461.

Role of heat treatments in the improvement of the sliding wear properties of Cr_3C_2-NiCr coatings. Thermal sprayed Cr_3C_2-NiCr coatings are widely used due to their excellent properties such as hardness and wear resistance, even at high temperatures or in corrosive environments. During thermal spraying, oxidation as well as Cr_3C_2 dissolution takes place. The present paper analyses the possibility of improving the sliding wear resistance of these coatings using heat treatments carried out at different temperatures in an inert atmosphere and in an oxidizing atmosphere. An enhancement of the sliding wear resistance attributed to the precipitation of Cr_3C_2 is demonstrated. Substantial differences are found in samples treated under the different atmospheres due to the role of the oxides formed on the tribological behavior of the coatings. Sliding wear tests were carried out using Ball-on-Disk equipment and the wear tracks were studied by scanning electron microscopy and scanning white light interferometry. A relationship between wear damage and energy dissipated during the sliding wear tests is found. In addition, the abrasive wear resistance of the coatings assessed by the Rubber Wheel test is reported.

Keywords: chromium compounds, dissolution, hardness, heat treatment, oxidation, scanning electron microscopy, tribology, wear resistance

J.M. Guilemany, J.M. Miguel, S. Vizcaino, C. Lorenzana, J. Delgado, and J. Sanchez, CPT (Thermal Spray Centre), Materials Engineering, Dept. d'Enginyeria Quimica, Barcelona E-08028, Spain. Cited: *Surf. Coat. Technol., 157*(2-3), 22 Aug 2002, p 207-213 [in English]. ISSN 0257-8972.

High-Velocity Oxyfuel Coatings

The effect of post-treatment of a high-velocity oxyfuel Ni-Cr-Mo-Si-B coating part 2: erosion-corrosion behavior. In this paper, a study of the erosion-corrosion characteristics of a Ni-Cr-Mo-Si-B coating applied by the high-velocity oxyfuel (HVOF) process on to an austenitic stainless steel (UNS S31603) substrate are reported. The coatings were studied in the as-sprayed condition, after vacuum sealing with polymer impregnation and after vacuum furnace fusion. The erosion-corrosion characteristics were assessed in an impinging liquid jet of 3.5% NaCl solution at 18 °C at a velocity of 17 m/s at normal incidence in two conditions: (1) free from added solids and (2) containing 800 ppm silica sand. The methodology employed electrochemical control and monitoring to facilitate the identification of the separate and interrelated erosion and corrosion contributions to the erosion-corrosion process. The rates of erosion-corrosion damage were drastically accelerated in the presence of the suspended solids. The application of cathodic protection significantly reduced the deterioration process. The study showed the effect of sealing with polymer impregnation did not significantly alter the erosion-corrosion behavior of the sprayed coating. However, there was a significant improvement in erosion-corrosion durability afforded by the postfusion process. The mechanisms by which the improved performance of vacuum-fused coatings is achieved are discussed.

Keywords: austenite, cathodic protection, cermets, corrosion resistance, electrochemical corrosion, metallographic microstructure, stainless steel, substrates, vacuum applications, wear of materials

T. Hodgkiess, A. Neville, and S. Shrestha, Dept. Mechanical Engineering, Univ. Glasgow, Glasgow S12 8QQ, U.K. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 656-665 [in English]. ISSN: 1059-9630.

Laser or Electron Beam Remelting

Optimization of an electron beam remelting of high-velocity oxyfuel sprayed alloys and carbides. Due to the lamella structure of the coating and the lack of metallurgical bonding, thermal sprayed coatings may have disadvantages such as low coating cohesive strength and low interface strength between the substrate and coating. It was considered that the electron beam remelting process is one of the most convenient processes to reduce or remove these disadvantages. The optimization of electron beam remelting process parameters and the evaluation of this process were investigated. Not only electron beam conditions, but also the thickness of copper substrate and electroplated nickel affect the penetration depth and the remelted width at the interface. Also, in order to reduce the number of pores and the unevenness of the surface morphology, it was found that relatively low fusing speed and homogeneous heating are preferable. Moreover, because the metallurgical bonding could dominate the interfacial strength, the interfacial shear strength is independent of the coating hardness. Thus, it is successful to deposit coatings, Stellite 6, nickel-base self-fused alloy 4 and WC-12Co with an adhesion strength value of approximately 350 MPa.

Keywords: adhesion, copper, electron beams, interfaces (materials), morphology, shear strength

H. Hamatani and Y. Miyazaki, Welding and Joining Laboratory, Nippon Steel Corp., Futtsu-city, Chiba 293-8511, Japan. Cited: *Surf. Coat. Technol., 154*(2-3), 15 May 2002, p 176-181 [in English]. ISSN 0257-8972.

Laser remelting of plasma sprayed NiCrAlY and NiCrAlY-Al_2O_3 coatings. Two types of plasma sprayed coatings (NiCrAlY and NiCrAlY-Al_2O_3) were remelted by a 5 kW cw CO_2 laser. With the increase of the laser power and the decrease of the traverse speed in the ranges of 200-700 W and 5-30 mm/s respectively, the melted track grew in width and depth. In the optimal range of laser parameters, a homogeneous remelted layer without voids, cavities, unmelted particles and microcracks was formed. On the surface of remelted layers, Al_2O_3 and $YAlO_3$ were detected. From the results of isothermal oxidation test, it was found that weight gains of laser-remelted coatings were obviously lower than those of only plasma sprayed, especially laser-remelted NiCrAlY-Al_2O_3 coatings. The effects of laser remelting and incorporation of Al_2O_3 second phase in the NiCrAlY matrix on high-temperature oxidation resistance were discussed.

Keywords: ceramic materials, oxidation resistance, plasma spraying, pulsed laser applications, remelting

Y. Wu, G. Zhang, B. Zhang, Z. Feng, Y. Liang, and F. Liu, Inst. of Metal Res., Chinese Acad. of Sci., Shenyang 110016, China. Cited: *J. Mater. Sci. Technol., 17*(5), Sept 2001, Chinese Society of Metals, p 525-528 [in English]. ISSN: 1005-0302.

Laser remelting of plasma sprayed thermal barrier coatings. A CO_2 continuous wave laser with defocused beam was used for remelting the surface of plasma sprayed ZrO_2-8wt.%Y_2O_3 (8YSZ)/Ni22Cr10AlY thermal barrier coatings (TBCs) on the GH536 superalloy substrate. Two main laser processing parameters, power and travel speed, were adopted to produce a completely remelted layer, and their effects on remelted appearance, remelting depth, density, and diameter of depression, space of segment crack, and remelted microstructure were evaluated. With the energy of 4.0-8.0 J/m^2, an appropriate laser processing for applicable remelted layer was suggested.

Keywords: laser applications, microstructure, plasma spraying, remelting, thermal insulation

G. Zhang, Y. Liang, Y. Wu, Z. Feng, B. Zhang, and F. Liu, Inst. of Metal Res., Chinese Acad. of Sci., Shenyang 110016, China. Cited: *J Mater. Sci. Technol., 17*(suppl.), Oct 2001, p S105-S110 [in English]. ISSN: 1005-0302.

Laser Surface Treatment

Crack-free surface sealing of plasma sprayed ceramic coatings using an excimer laser. Yttria-stabilized zirconia coatings are typically used in the aerospace industry as high-temperature thermal barriers. These coatings are normally applied by plasma thermal spray, which has an inherent problem of producing coatings containing a substantial amount of open or closed porosity. Surface sealing of plasma sprayed ceramic coatings with CO_2 and Nd:YAG lasers is always associated with the problem of cracking on melted layers. Although some attempts such as preheating have been used to overcome the problem, formation of cracking is still not prevented, especially in zirconia-based ceramic coatings. The present work investigates an alternative method of surface sealing of plasma sprayed 8 wt.% Y_2O_3-ZrO_2 coatings using an excimer laser. The results show that smooth, crack-free and crater-free sealing can be obtained. Effects of laser operating parameters on the sealing quality and involved mechanism are also discussed.

Keywords: carbon dioxide, ceramic coatings, cracks, excimer lasers, neodymium lasers, plasma spraying, porosity, zirconia

Z. Zhu, Corrosion and Protection Centre, UMIST, Manchester M60 1QD, U.K. Cited: Proc. European Materials Research Society 2001 Symposium, 5 June 2001 (Strasbourg), A. Giardini, J. Gonzalo, T. Szorenyi, and J. Perriere, Ed., Elsevier Science B.V., *J. Appl. Surf. Sci., 186*(1-4), 28 Jan 2002, p 135-139 [in English]. ISSN 0169-4332.

Processing

Clean Metal Spray Forming

Prediction of thermal history of preforms produced by the clean metal spray forming process. The clean metal spray forming (CMSF) process provides premium quality material for high-performance aircraft engine components. In this process, "clean" metal (metal free of oxides and other inclusions) is atomized via a scanning open atomizer, and the resultant spray is collected as a solid billet preform. Under a program jointly funded by industry and the U.S. Government, process models have been developed for the different stages of CMSF. The present paper focuses on models for the spray and deposition processes. The axisymmetric spray model has been benchmarked with experimental measurements of particle size distribution and mass distribution. It provides the input for the deposition model. A unique approach is used to make the deposition model both accurate and efficient. The models are discussed in detail and typical results presented.

Keywords: atomization, atomizers, deposition, inclusions, mathematical models, particle size analysis, spraying

R.S Minisandram, R.M. Forbes Jones, K.M. Kelkar, S.V. Patankar, and W.T. Carter Jr., Allvac an Allegheny Tech. Co., Monroe, NC 28110-5030. Cited: *Mater. Sci. Eng. A, 326*(1), 15 March 2002, p 184-193 [in English]. ISSN 0921-5093.

Cold Gas Dynamic Spraying

Cold spray technology. Cold gas-dynamic spray or cold spray is a process of applying coatings by exposing a metallic or dielectric substrate to a high-velocity jet of small particles accelerated by a supersonic jet of compressed gas. In this process, powder particles are accelerated by the supersonic gas jet at a temperature that is always lower than the melting point of the material, resulting in coating formation from particles in the solid state. As a result, the deleterious effects of high-temperature oxidation, evaporation, melting, crystallization, residual stresses, debonding, gas release, and other common problems for traditional thermal spray methods are minimized or eliminated.

Keywords: crystallization, debonding, evaporation, melting, oxidation, residual stresses, substrates, temperature, velocity

A. Papyrin and A., Ktech Corp., Albuquerque, NM. Cited: *Adv. Mater. Process., 159*(9), Sept 2001, p 49-51 [in English]. ISSN: 0882-7958.

Deformation microstructure of cold gas sprayed coatings. Cold gas spraying is a new coating technique, in which the formation of dense, tightly bonded coatings occurs only due to the kinetic energy of high-velocity particles of the spray powder. These particles are still in the solid state as they impinge on the substrate. Adiabatic heating after impingement can cause local shear instabilities and jet formation. The local microstructure is strongly dependent on local stress state and temperature rise. A variety of different microstructures is observed by transmission electron microscopy. The results are compared with modeling of the spray process.

Keywords: computer simulation, copper powder, jets, kinetic energy, microstructure, particles (particulate matter), plastic deformation, plastic flow, strain hardening, substrates, transmission electron microscopy, viscous flow

C. Borchers, T. Stoltenhoff, F. Gartner, H. Kreye, and H. Assadi, Dept. Materials Science Engineering, Tarbiat Modarres Univ., Tehran, Iran. Cited: *Dislocations and Deformation Mechanics in Thin Films and Small Structures* (Conf. Proc.), 17-19 April 2001 (San Francisco, CA), Vol 673, O. Kraft, K. Schwarz, S. Baker, L. Freund, and R. Hull, Ed., Materials Research Society, 2001, p P7.10.1-P7.10.6 [in English]. ISSN: 0272-9172.

Composite Materials

Manufacture of novel composites by spray forming. Silicon carbide, alumina, and tungsten carbide powders were added to the metal spray during spray forming of two different steels. For this purpose, a specially designed device was used that allows for the controlled injection of powder particles directly into the atomization zone where they mix with the metal droplets. After deposition, the resulting billets were characterized by micrography, hardness measurements, and wear resistance tests.

Keywords: addition reactions, alumina, atomization, deposition, forming, hardness, microstructure, silicon carbide, steel, tungsten carbide, wear resistance

J. Banhart and H. Grutzner, Inst. Manufacturing and Advanced Materials, Bremen, Germany. Cited: *J. Adv. Mater., 34*(2), April 2002, p 19-24 [in English]. ISSN 1070-9789.

Composite metal plates fabricated by spray deposition and gas scanning technique. A composite AlSn-steel bimetal plate was fabricated by spray deposition and gas scanning technique. The effects of process parameters such as scanning rate, preheating temperature of the substrate, and rolling temperature were studied. The structure of the bonding interface between the spray deposited aluminum alloy and the steel substrate was analyzed. The experimental results show that the best deposited plate can be obtained when the gas atomization pressure is 0.8-1.0 MPa, the spray distance is 300 mm, and the preheating temperature of substrate is 200 °C. After hot rolling at 220-230 °C, the composite bimetal plate with high density and superior interface bonding can be obtained.

Keywords: aluminum alloys, morphology, sprayed coatings, spraying, steel sheet

Y.-K. Xu, G.-Y. Chen, C. Tian, and Y.-C. Zhang, Inst. Metal Research, Chinese Academy of Science, Shenyang 110016, China. Cited: *Cailiao Kexue yu Gongyi/Mater. Sci. Technol., 9*(3), Sept 2002, p 243-246 [in Chinese]. ISSN 1005-0299.

A review on the various synthesis routes of TiC-reinforced ferrous-base composites. The major thrust underlying the processing of iron-base composites has been directed toward improving the wear resistance of steel or cast iron by incorporating some reinforcing phase, e.g., carbides, oxides, etc. The present article provides a review on the various synthesis routes of TiC-reinforced iron-base composites, i.e., powder metallurgy, conventional melting and casting, carbothermic reduction, combustion synthesis, aluminothermic reduction, electron beam radiation, laser surface melting, and plasma spray synthesis, highlighting the advantages and disadvantages associated with the different routes of synthesis.

Keywords: cast iron, iron powder metallurgy, laser applications, metal casting, metal melting, plasma spraying, radiation effects, reduction, steel powder metallurgy, synthesis (chemical), titanium carbide, wear resistance

K. Das, T.K. Bandyopadhyay, and S. Das, Dept. Metallurgical and Materials Engineering, Indian Inst. Technology, Kharagpur 721 302, India. Cited: *J. Mater. Sci., 37*(18), 15 Sept 2002, p 3881-3892 [in English]. ISSN 0022-2461.

Feasibility of plasma spraying in developing metal-matrix composite coatings: Modeling the heating of coated powder particles. Coated powder particles composed of a ceramic core and a metallic coating are being considered for plasma spray applications. The goal of using these powders is to produce particulate-reinforced metal-matrix composite coatings. In this work, the feasibility of plasma spray processing in producing these composite coatings is evaluated. A numerical model is presented to analyze the in-flight thermal behavior and physical state of moderate-size particles (10-30 μm radius) in arc-jet direct-current plasma under low loading conditions. The pairs of materials for the base and coating that are considered in this work are WC-Co, SiC-Ni, and SiC-Al. The plasma was taken to be atmospheric argon plasma. The study suggests that plasma processing is capable of melting the coating without excessive evaporation while retaining the base in the solid state over a range of particle sizes and base/coating proportions. Hence plasma processing appears suitable to develop particulate-reinforced metal-matrix composite coatings.

Keywords: ceramic materials, coatings, mathematical models, plasma spraying

M.D. Demetriou, A.S. Lavine, and N.M. Ghoniem, Mechanical and Aerospace Engineering Dept., Univ. California, Los Angeles, Los Angeles, CA 90095-1597. Cited: *J. Manuf. Sci. Eng., Trans. ASME, 124*(1), Feb 2002, p 58-64 [in English]. ISSN 1087-1357.

Use of plasma spraying in the manufacture of continuously graded and layered/graded molybdenum disilicide/alumina composites. Plasma spraying was used to produce continuously graded and graded/layered structures of molybdenum disilicide ($MoSi_2$) and alumina (Al_2O_3). These functionally graded materials (FGMs) were achieved by manipulating the powder hoppers and plasma torch translation via in-house created computer software. The resultant microstructures sprayed uniformly and were crack free. The interface between $MoSi_2$ and Al_2O_3 was continuous, and no evidence of debonding or cracking at the interface was found. The mechanical strength of these sprayed materials was evaluated using C-ring samples (in diametrical compression). Weibull analysis conducted on the C-ring data indicated that the continuously graded samples were slightly stronger and had a significantly narrower strength distribution than the graded/layered samples. Although the average strength values of both types of functionally graded samples were closer to those of monolithic $MoSi_2$, the fracture energy of the graded samples was significantly larger (~2-3×) compared with the monolithic materials. Scanning electron microscopy (SEM) conducted on the fracture surfaces of the FGMs illustrated a wavy and tortuous crack path through the composite cross section of the sample, with extensive crack kinking. This study has two important results. First, the authors demonstrated the ability to produce such functionally graded composite ceramic microstructures using a conventional plasma spraying process. Second, they quantified the improvements in mechanical performance provided by these FGMs over conventional monolithic materials.

Keywords: alumina, ceramic matrix composites, compressive strength, crack initiation, debonding, fracture testing, fracture toughness, functionally graded materials, microstructure, molybdenum compounds, plasma torches, scanning electron microscopy

R.U. Vaidya, R.G. Castro, M.I. Peters, D.E. Gallegos, and J.J. Petrovic, Materials Science and Technology Div., Los Alamos National Laboratory, Los Alamos, NM 87545. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 409-411 [in English]. ISSN 1059-9630.

Strength degradation of SiC fiber during manufacture of titanium-matrix composites by plasma spraying and hot pressing. Titanium-matrix composites (TMCs) reinforced with Sigma 1140+ SiC fiber have been manufactured by a combination of low-pressure plasma spraying (LPPS spray/wind) and simultaneous fiber winding, followed by vacuum hot pressing (VHP). Fiber damage during TMC manufacture has been evaluated by measuring fiber tensile strength after fiber extraction from the TMCs at various processing stages, followed by fitting of these data to a Weibull distribution function. The LPPS spray/wind processing caused a decrease in mean fiber strength and Weibull modulus in comparison with as-received fibers. A number of fiber surface flaws, primarily in the outer C layer of the fiber, formed as a result of mechanical impact of poorly melted particles from the plasma spray. Coarse feedstock powders promoted an increase in the population of fiber surface flaws, leading to significant reduction in fiber strength. The VHP consolidation promoted further development of fiber surface flaws by fiber bending and stress localization because of nonuniform matrix shrinkage, resulting in further degradation in fiber strength. In the extreme case of fibers touching, the stress concentration on the fibers was sufficient to cause fiber cracking. Fractographic studies revealed that low-strength fibers failed by surface flaw induced failure and contained a large fracture mirror zone. Compared with the more widely investigated foil-fiber-foil route to manufacture TMCs. LPPS/VHP resulted in less degradation in fiber strength for Sigma 1140+ fiber. Preliminary

results for Textron SCS-6 fiber indicated a much greater tolerance to LPPS/VHP damage.

Keywords: ceramic fibers, degradation, failure (mechanical), fractography, hot isostatic pressing, mechanical testing, metallic matrix composites, plasma spraying, silicon carbide, stress concentration, titanium metallurgy, Weibull distribution

K.H. Baik and P.S. Grant, Dept. Materials, Univ. Oxford, Oxford OX1 3PH, U.K. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci., 32*(12), Dec 2001, p 3133-3142 [in English]. ISSN 1073-5623.

Mo_5Si_3-B and $MoSi_2$ deposits fabricated by radio frequency induction plasma spraying. Induction plasma spray processing was used to produce free-standing parts of Mo_5Si_3-B composite and $MoSi_2$ materials. The oxidation resistance, up to 1210 °C, of the Mo_5Si_3-B composite was compared with $MoSi_2$, which is known to be resistant to high-temperature oxidation. The deposits were oxidized isothermally in air at atmospheric pressure. The structural performance of these materials under high-temperature oxidation conditions was found to depend on the boron content in the specimens. In particular, the composite containing 2 wt.% B exhibited excellent resistance to oxidation, as indicated by the specimen mass change, which was found to be near zero after the 24 h oxidation test.

Keywords: boron, composite materials, high-temperature effects, molybdenum compounds, oxidation resistance, powder metals

X. Fan and T. Ishigaki, TEKNA Plasma Systems, Inc., Sherbrooke, Que. J1L 1X7, Canada. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 611-617 [in English]. ISSN: 1059-9630.

Diagnostics and Control

Application of lock-in thermography for assessing the quality of thermally sprayed coats. The lock-in thermography procedure is presented. In order to prove its suitability as a testing method for thermally sprayed coats, investigations were conducted on various sprayed coats with intentionally produced defects. It was shown that pores, inclusions, and delaminations are easy to detect. Furthermore, the procedure is suitable for determining coat thicknesses. In this case, special calibration curves related to the material must be recorded beforehand.

Keywords: defects, delamination, inclusions, magnetic permeability, porosity, thermoanalysis, thermography (imaging)

B. Wielage, T. Schnick, and U. Hofmann. Cited: *Schweissen Schneiden/Weld. Cutting, 54*(3), 2002 p 157-160 [in English]. ISSN 0036-7184.

Calibration of a two-color imaging pyrometer and its use for particle measurements in controlled-air plasma spray experiments. Advances in digital-imaging technology have enabled the development of sensors that can measure the temperature and velocity of individual thermal spray particles over a large volume of the spray plume simultaneously using imaging pyrometry (IP) and particle streak velocimetry (PSV). This paper describes calibration, uncertainty analysis, and particle measurements with a commercial IP-PSV particle sensor designed for measuring particles in an air plasma spray (APS) process. Yttria-stabilized zirconia (YSZ) and molybdenum powders were sprayed in the experiments. An energy balance model of the spray torch was used to manipulate the average particle velocity and temperature in desired ways to test the response of the sensor to changes in the spray characteristics. Time-resolved particle data were obtained by averaging particle streaks in each successive image acquired by the sensor. Frame average particle velocity and temperature were found to fluctuate by 10% during 6 s acquisition periods. These fluctuations, caused by some combination of arc instability, turbulence, and unsteady powder feeding, contribute substantially to the overall particle variability in the spray plume.

Keywords: calibration, image sensors, imaging techniques, pyrometry, temperature measurement, velocity measurement, yttrium compounds, zirconia

S.P. Mates, D. Basak, F.S. Biancaniello, S.D. Ridder, and J. Geist, Metallurgy Division, National Inst. Standards Technology, Gaithersburg, MD 20899-8556. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 195-205 [in English]. ISSN 1059-9630.

Zur schichtdickenmessung an drahten mit mikrostrahl-rontgenfluoreszenz [Measurement of coating thickness on wires by microbeam x-ray fluorescence]. To maintain high quality in electronic assemblies, the thickness of solder coatings on wires is a parameter that must be monitored. The solder thickness has to be held within very tight limits. This calls for a continuously operating, contact-free thickness measurement method. With a new generation of XRF equipment that requires only a very small sampling area, wires with diameter down to 50 µm can be measured. Initial results with tin-, silver-, or nickel-coated wires from a normal process line show thickness variations, in some case quite substantial, and these can be determined with a statistical accuracy to less than 50 nm.

Keywords: electric wire, fluorescence, soldering alloys, statistical methods, thickness measurement, x-rays

V. Rossiger. Cited: *Galvanotechnik, 93*(9), Sept 2002, p 2262-2265+IV [in German]. ISSN 0016-4232.

Charakterisierung des hochgeschwindigkeitsflammspritzprozess mittels particle image velocimetry (PIV) [Characterization of HVOF (high-velocity oxyfuel) process using particle image velocimetry (PIV)]. High-velocity flame spraying is a widely used technique for application of coatings, especially ceramic types. Parameters set in using the method are mainly based on empirical experience. In order to improve the process and to expand the range of coatings able to be applied, data are necessary relating to the spray process itself. Using laser-based PIV as a measurement technique, values can be derived for the particle velocity, their dwell time in the expansion tube, and their temperature. Studies along these lines reveal that particle feed rote and distance of the gun from the work surface can vary widely, without significant effect on particle velocity.

Keywords: ceramic coatings, laser applications, particles (particulate matter), spraying, velocity measurement

Fr.-W. Bach, L. Engl, T. Rothardt, and L.A. Josefiak, Inst. Werkstoffkunde, Univ. Hannover, Hannover, Germany. Cited: *Galvanotechnik, 93*(9), Sept 2002, p 2374-2383+VI [in German]. ISSN 0016-4232.

Fluctuations of the core and the jet shape of an arc plasma spraying jet. The turbulence is one of the most attractive characteristics of the direct-current arc plasma spraying jet. A spectrum diagnostic system was built to investigate these effects with the aid of a high-speed digital camera. The fast Fourier transform (FFT) method was used to analyze the arc voltage and the light signals. The arc behavior and the power supply strongly influence the jet. There seems to be no laminar flow region in jet core. Moreover, the FFT analysis suggests that the jet fluctuations due to the arc voltage and arc restrike may be the dominant characteristics of the jet behavior. Snapshots of the jet show that the torch power also influences the jet fluctuations.

Keywords: Fast Fourier transforms, laminar flow, plasma spraying, plasma torches

W. Zhao, K. Tian, D. Liu, and H. Tang, Dept. of Eng. Mech., Tsinghua Univ., Beijing 100084, China. Cited: *Qinghua Daxue Xuebao/J. Tsinghua Univ., 42*(4), April 2002, p 442-445 [in Chinese]. ISSN 1000-0054.

Plasma jet imaging by CCD technology in rapid mold manufacturing. Plasma spraying, as an important enabling technology, is being applied to rapid mold manufacturing in order to reduce the development time and manufacturing cost. Due to the melting and in-flight states of powders being affected directly by the plasma jet, which ultimately determines the quality of the bulk deposit, there is an increasing interest in research on the diagnostics and control of plasma spray processing. This paper presents a compact, low-cost, and practical method for the real-time diagnosis of a plasma jet, which integrates CCD and computer-imaging technology. The collecting principle and methods were especially investigated, while the fake color processing of the jet image and jet shape under different process parameters were studied also, using an experimental system of real-time data collection by the present method. The current work is of paramount importance for further study of the closed-loop control of plasma spraying processes, which could turn plasma digitized manufacturing into reality.

Keywords: closed-loop control systems, feedback control, imaging techniques, mathematical models, plasma jets, plasma spraying, powders

J.P. Xu, J.C. Fang, and Z.G. Li, State Key Laboratory of PFSDMT, HUST, Wuhan 430074, Hubei, China. Cited: 10th Int. Manufacturing Conf. in China (IMCC 2002), X. Xu, Ed., *J. Mater. Process. Technol., 129*(1-3), 11 Oct 2002, p 250-254 [in English]. ISSN 0924-0136.

Control of average temperature in a spray deposition process. The spray forming process is a novel method of rapidly manufacturing tools and dies for stamping and injection operations. The process sprays molten tool steel from a set of arc spray guns onto a ceramic former to build up a thick steel shell. The volumetric contraction that occurs as the steel cools is offset by a volumetric expansion taking place within the sprayed steel, which allows the dimensionally accurate tools to be produced. To ensure that the required phase transformation takes place, the temperature of the steel is regulated during spraying. The paper describes the design and implementation of linear quadratic type controllers for the process and presents results from a simulation of the spray forming process.

Keywords: ceramic materials, computer simulation, deposition, dies, distributed parameter control systems, phase transitions, spray guns, spraying, stamping, tool steel, volumetric analysis

P. Pathirana, S. Duncan, and P. Jones, Dept. Engineering Science, Univ. Oxford, Oxford OX1 3PJ, U.K. Cited: *Proc. 2002 IEEE International Conference on Control Applications,* Vol 2, 18-20 Sept 2002 (Glasgow), Inst. Electrical and Electronics Engineers, 2002, p 1004-1009 [in English].

Diagnostics and control in the thermal spray process. The plasma spray process features complex plasma-particle interactions that can result in process variations that limit process repeatability and coating performance. This paper reports work on the development of real-time diagnostics and control for the plasma spray process. The strategy is to directly monitor and control those degrees of freedom of the process that are observable, controllable, and affect resulting coating properties. This includes monitoring of particle velocity and

temperature as well as the shape and trajectory of the spray pattern. Diagnostics that have been developed specifically for this purpose are described along with the demonstration of a closed loop process controller based on these measurements.

Keywords: closed loop control systems, degrees of freedom (mechanics), plasma diagnostics, plasma interactions

J.R. Fincke, W.D. Swank, R.L. Bewley, D.C. Haggard, M. Gevelber, and D. Wroblewski, Idaho Nat. Eng. and Environ. Lab., AC Idaho Falls, ID 83415-2211. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 537-543 [in English]. ISSN 0257-8972.

Feedstock Preparation

Plasma densification of agglomerated Cr_2O_3 powder for thermal spray coating. Double plasma flame treatments were carried out on spray dried Cr_2O_3 agglomerated powders to increase their apparent density. The powders that were subjected to the first densification treatment did not show the entirely melted state and were fully melted only after the second plasma treatment. Plasma densification resulted in powder size decreasing as well as apparent density of particles and also resulted in the fluidity increasing due to the powder melting and surface smoothing effects. However, some parts of the particles after the second treatment showed a hollowed structure, especially for a particle size above 30 μm. The influence of the thermal conductivity of powder and the gas pressure within aggregates exposed to the plasma flame in the particle densification process is discussed in detail. The powder density strongly influenced the structure of plasma sprayed coatings. The dense coatings with high hardness and high bond strength was achieved in the coatings produced from Cr_2O_3 powders after plasma densification.

Keywords: bond strength (materials), densification, density (specific gravity), fluidity, hardness, microstructure, morphology, plasma applications, powder metals, sprayed coatings, surfaces, thermal conductivity

B.K. Kim, D.W. Lee, and C.J. Choi, Korea Inst. of Machinery and Mat., Changwon, Kyungnam, South Korea. Cited: *Powder Metall., 44*(3), 2001, p 274-278 [in English]. ISSN: 0032-5899.

High-Velocity Oxyfuel Spray Parameters

Deposition and properties of high-velocity oxyfuel and plasma sprayed Mo-Mo_2C composite coatings. Molybdenum thermal spray coatings, dispersion strengthened by molybdenum oxides and molybdenum carbides, play an important role in industrial tribological applications. Traditionally, they have been prepared by plasma and wire flame spraying. High porosity and lower cohesion strength limit their application in situations where both galling and abrasion wear is involved. In this study, high-velocity oxyfuel (HVOF) deposition of molybdenum and molybdenum carbide coatings was attempted. Deposition was achieved for all powders used. Composition, microstructure, mechanical, and wear properties of the HVOF synthesized coatings were evaluated and compared with plasma sprayed counterparts. The HVOF coatings possessed a very good abrasion resistance, whereas plasma deposits performed better in dry sliding tests. Measurements showed a close relationship between the coating surface hardness and its abrasion resistance. Results also suggested correlation between molybdenum carbide distribution in the molybdenum matrix and the sliding friction response of Mo-Mo_2C coatings.

Keywords: composition, decarburization, friction, hardness, metallographic microstructure, molybdenum compounds, particle size analysis, plasma spraying, surface properties, wear of materials, wear resistance

L. Prchlik, J. Gutleber, and S. Sampath, Center for Thermal Spray Research, Dept. Materials Science and Eng., State Univ. New York, Stony Brook, NY 11794-2275. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 643-655 [in English]. ISSN: 1059-9630.

Hydroxyapatite Biomaterial

Comparative study of the synthesis and processing of hydroxyapatite. The HAp is a biomaterial applied as dense, porous, or coating bioceramics in the medical and odontological areas. The aim of this work was obtain hydroxyapatite with characteristics that allow its application as dense or porous bodies, and coating studying three methods of syntheses: precipitation, neutralization, and sol-gel in alcoholic media. Precipitation and neutralization showed the best results for thermal spraying stability, being thereafter reproduced in a pilot scale, in an open and closed system. Nitrogen atmosphere was used to avoid the formation of hydroxyapatite carbonate. The powders obtained by neutralization were used for coating titanium alloy substrate. Plasma spraying technique was used for deposition. On coating layer HAp was the main phase detected, showing a good adherence to the substrate. Porous ceramic bodies were obtained by gel casting foam with the HAp from the neutralization method in an inert atmosphere. The main techniques used on the characterization of powder, metallic substrates, coatings, porous, and dense ceramic bodies were: particle size distribution (PSD), scanning electron microscopy (SEM) and x-ray diffractometry (XRD). The HAp phase was detected as the majority in all conditions, and results are no cytotoxicity.

Keywords: coatings, particle size analysis, plasma spraying, porous materials, precipitation (chemical), processing, scanning electron microscopy, sol-gels, substrates, synthesis (chemical), titanium alloys, x-ray diffraction analysis

A. H. Bressiani and M. De Campos, Technological Research Center, Univ. Mogi das Cruzes, 08780-911 Mogi das Cruzes, S.P., Brazil. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 171-174 [in English]. ISSN 1013-9826.

Characterization of hydroxyapatite: before and after plasma spraying. Hydroxyapatite (HA) powder was characterized before and after plasma spraying using infrared spectroscopy and thermoanalytical techniques. Structural changes were observed from the infrared spectra for the plasma sprayed powder. These changes involved dehydroxylation and misoriented hydroxyl ions with different configurations. Dehydroxylation was accompanied by decreased intensities for the O-H stretching mode at 3571 cm^{-1} and the O-H librational mode at 633 cm^{-1}. A broad infrared band near 3400 cm^{-1} that was observed after spraying was attributed to the misoriented hydroxyl ions. The combined results from thermoanalytical techniques indicated that adsorbed water evolved in three stages below 500 °C and that the dehydroxylation of HA started as low as 700 °C. A weight gain of the plasma sprayed HA was observed above 500 °C in inert atmospheres. This result indicates a strong tendency of dehydroxylated HA to restore hydroxyls. The decrease in the decomposition temperature of HA after spraying was attributed to largely perturbed structures.

Keywords: characterization, decomposition, infrared spectroscopy, ions, plasma spraying, thermoanalysis

E. Park, R.A. Condrate Sr., D. Lee, K. Kociba, and P.K. Gallagher, St. Paul, MN 55113. Cited: *J. Mater. Sci.: Mater. Med., 13*(2), 2002, p 211-218 [in English]. ISSN 0957-4530.

High-pressure plasma spraying of hydroxyapatite powders. Thermal spray processes with their wide array of operating parameters are flexible manufacturing tools in the production of bioactive hydroxyapatite (HA) coatings. In this study, two spherical HA powders, namely, spray dried hydroxyapatite and spheroidized hydroxyapatite powders were sprayed with suitable parameters in a controlled atmosphere plasma spraying (CAPS) system. This unique system was operated in three distinct modes: High-pressure plasma spraying (HPPS), atmospheric plasma spraying (APS), and inert plasma spraying. The HPPS mode has three different pressure settings up to 250 kPa. The APS mode is operated at normal atmospheric pressure of 100 kPa (sea level), and the other modes utilized argon gas to provide the inert atmosphere during plasma spray. These were applied in order to assess the influence of chamber pressure and chamber atmosphere on the deposition of HA coatings. The microstructures and phase compositions of the plasma sprayed HA coatings are evaluated using standard x-ray diffraction (XRD) and electron microscopy techniques. These established the influence of the plasma spray parameters in the CAPS chamber. HPPS led to enhanced heating of the powder and dense HA coatings with a high content of the amorphous calcium phosphate phase. Small amounts of other calcium phosphates, tetracalcium phosphate and tricalcium phosphate were detected. Calcium oxide was not detected. Such coatings are useful for subsequent investigation of biological and mechanical properties where phase composition and porosity are deciding factors. It is found that the degree of melting of the HA powder can be controlled with CAPS system. This has the advantage of tailoring the final coating microstructure.

Keywords: argon electron microscopy, high pressure effects, lime, microstructure, phase composition, plasma spraying, powders, x-ray diffraction analysis

V. Guipont, M. Espanol, F. Borit, N. Llorca-Isern, M. Jeandin, K.A. Khor, and P. Cheang, Center for Plasma Processing C2P, Ecole Natl. Superieure Mines Paris, Evry Cedex 91003, France. Cited: *Mater. Sci. Eng. A, 325*(1-2), 28 Feb 2002, p 9-18 [in English]. ISSN 0921-5093.

Further studies on the effect of standoff distance on characteristics of plasma sprayed hydroxyapatite coating. Plasma spraying parameters are of crucial importance to the fabrication of high-quality hydroxyapatite (HA) coating for biomedical use. In the present work, an HA powder finer than that commonly used was plasma sprayed onto titanium substrate. The microstructures and the phase composition of the coatings were characterized using scanning electron microscopy and x-ray diffraction, respectively. Results have shown that the extent of melting of particles decreased, while the crystallinity of the HA increased with increasing standoff distance with power level of 40 kW. The reason was suggested to be that the molten particles began to cool and resolidify when the standoff distance exceed a certain value.

Keywords: hydroxyapatite, microstructure, phase composition, plasma spraying, substrates

Y.P. Lu, S.T. Li, R.F. Zhu, and M.S. Li, School of Materials Science and Engineering, Shandong Univ., Jinan 250061, China. Cited: *Surf. Coat. Technol., 157*(2-3), 22 Aug 2002, p 221-225 [in English]. ISSN 0257-8972.

Pulse repetition rate dependence of hydroxylapatite deposition by laser ablation. Hydroxylapatite (HA) is used as coating on metallic dental and or-

thopedic implants due to its similarity to the mineral part of bone. As an alternative to the commercial plasma spraying coating technique, pulsed laser deposition has been applied. In order to study the possibility of obtaining high-deposition rates by varying the pulse repetition rate, a HA target was ablated with an ArF laser at an energy density of 0.9 J/cm^2 in a water vapor pressure of 45Pa, and the material was deposited on a titanium substrate held at 460 °C. The coating thickness was measured by profilometry. The phases present in the coating were detected by x-ray diffraction. Their Ca/P ratios were determined by energy dispersive x-ray spectrometer, while their OH^- and CO_3^{2-} contents were evaluated by Fourier transform infrared. As the pulse repetition rate is increased from 20-80 Hz, the structural order of the coatings decreases, and, eventually, at 100 Hz the coatings become amorphous. When the time interval between pulses is too short, there is not enough time for the material to diffuse within the surface and accommodate in the structure before the material from the next pulse arrives. A long time between pulses also promotes the desorption of species from the substrate surface, preferentially CO_3^{2-}.

Keywords: desorption, diffusion, energy dispersive spectroscopy, Fourier transform infrared spectroscopy, laser pulses, plasma spraying, profilometry, pulsed laser deposition, vapor pressure, x-ray diffraction analysis, x-ray spectrometers

J.L. Arias, M.B. Mayor, J. Pou, B. Leon, and M. Perez-Amor, Dept. Fisica Aplicada, Univ. Vigo, E-36200, Vigo, Spain. Cited: *Vacuum, 67*(3-4), 26 Sept 2002, p 653-657 [in English]. ISSN 0042-207X.

Influence of Spray Parameters

In-situ particle temperature, velocity, and size measurements in the spray forming process. The structure and material properties of spray formed products depend directly on the thermal state of particles before they impact the substrate or on the already deposited layer. Monitoring particle temperature, velocity, and size can thus provide a unique tool for optimizing the material properties as well as controlling spraying conditions during deposition. In this paper, an optical-sensing device based on the principle of high-speed pyrometry, developed for on-line monitoring of particle temperature, velocity, and diameter of in-flight particles during thermal spraying conditions (e.g., plasma guns), is for the first time applied and examined in the spray forming process. Thermal radiation emitted by the particles is collected by a sensing head attached to the spray cone and transmitted through optical fibers to a detection cabinet located away from the dusty environment. Tests were carried out with different materials, spray pressures, and measurement positions to exhibit the efficiency of the measurement system in the spray forming process.

Keywords: deposition, heat radiation, optical sensors, optimization, particle size analysis, pyrometry, thermal effects

M. Krauss, D. Bergmann, U. Fritsching, and K. Bauckhage, SFB 372 Spray Forming, Univ. Bremen, Bremen 28359, Germany. Cited: *Mater. Sci. Eng. A, 326*(1), 15 March 2002, p 154-164 [in English]. ISSN 0921-5093.

A study of processing parameters in thermal sprayed alumina and zircon mixtures. A method of plasma spraying of alumina and zircon mixture to form ZrO_2 mullite composites has been proposed and developed. The feedstock is prepared by a combination of mechanical alloying, which allows formation of fine-grained, homogeneous solid-solution mixtures, followed by plasma spheroidization that yields rapid solidified microstructures and enhanced compositional homogeneity. The effects of ball-milling duration and milling media were studied. It was found that zirconia is a more efficient milling media and that increasing milling duration enhanced the dissociation of zircon. Flame spray and plasma spray processes were used to spheroidize the spray-dried powders. The temperature of the flame spray was found to be insufficient to melt the powders completely. The processing parameters of the plasma spray played an important role in zircon decomposition and mullite formation. Increasing the arc current or reducing secondary gas pressure caused more zircon to decompose and more mullite to form after heat treatment at 1200 °C for 3 h. Dissociation of zircon and the amount of mullite formed can be enhanced significantly when using the more efficient, computerized plasma spraying system and increasing the ball-milling duration from 4-8 h.

Keywords: alumina, ball milling, composite materials, heat treatment, mechanical alloying, microstructure, mixtures, rapid solidification, solid solutions, temperature, zirconia

Y. Li and K.A. Khor, School of Mechanical and Production Engineering, Nanyang Technological Univ., Singapore 639798, Singapore. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 186-194 [in English]. ISSN 1059-9630.

Thin alumina coating deposition by using controlled-atmosphere plasma spray system. This work dealt with the deposition of thin Al_2O_3 coating by using controlled-atmosphere plasma spray (CAPS) system. Low-porosity and low-roughness deposits resulted from the optimized spray conditions, i.e., plasma parameters, grit blasting, powder feed rate, and specimen rotation speed. Results showed that spray processing at a low pressure (LPPS) was highly beneficial for densifying the ceramic coatings. Thin coating thickness down to 10 μm and average surface roughness (R_a) ranged from 1.5-2.5 μm have been achieved on an original substrate R_a of 1.1 μm. The spray conditions were optimized particularly for a low power feed rate and a high specimen rotating speed to lower surface roughness. Moreover, a specific atmosphere/temperature-control device was developed to improve cooling efficiency in LPPS, which resulted in reduced microcracking in the deposits. Mechanical pull-off adhesion test was also carried out to evaluate these low-roughness thin coatings. Adhesion was shown to be satisfactory for direct coating of a low-roughness (R_a = 1.1 μm) AISI 316L substrate.

Keywords: adhesion, microcracking, plasma spraying, porosity, protective coatings, surface roughness

X.Q. Ma, F. Borit, V. Guipont, and M. Jeandin, Ecole Des Mines De Paris, Evry Cedex, France. Cited: *J. Adv. Mater., 34*(4), Oct 2002, p 52-57 [in English]. ISSN 1070-9789.

Microstructure and phase formation in spray-deposited Al-18%Si-5%Fe-1.5%Cu alloy. The aluminum alloy containing 18% Si, 5% Fe, and 1.5% Cu was spray deposited using convergent-divergent nozzle geometry. Nitrogen gas was used as atomization medium. Microstructure and phase constitution of oversprayed powders as well as spray deposit were studied. Spray-deposited alloy revealed 3-10 μm size particulates of primary silicon phase coexisting with rectangular shape intermetallic βAl_5SiFe and δAl_4Si_2Fe phases. This is in contrast to as-cast alloy that exhibit 90-150 μm size particulates of primary silicon phase and 120-500 μm size rods of Al-Fe-Si base intermetallic phases. X-ray diffraction results depicted presence of only δAl_4Si_2Fe phase in oversprayed powders, whereas spray-deposited alloy consisted both δAl_4Si_2Fe and βAl_5SiFe phases. Energy-dispersive x-ray analysis also corroborates the presence of the above intermetallic phases. These results have been discussed in light of the mechanisms involved in the spray deposition process.

Keywords: atomization, deposition, intermetallics, microstructure, rapid solidification, x-ray diffraction analysis

V.C. Srivastava, P. Ghosal, and S.N. Ojha, Materials Processing Division, National Metallurgical Laboratory, Jamshedpur 831 007, India. Cited: *Mater. Lett., 56*(5), Nov 2002, p 797-801 [in English]. ISSN 0167-577X.

Influence of arc voltage on temperature of plasma spraying jet. Turbulence is one of the most attractive characteristics of a direct-current arc plasma spraying jet. Most of the previous investigations believe that there is a laminar flow region in the core of the jet. A spectrum diagnosis system was built to investigate these effects by the aid of high-speed digital camera. The FFT (fast Fourier transform) method was applied to analyze the arc voltage and light signals. The influences of arc voltage behavior and power supply on the jet were described. It seems that there is no laminar flow region in the core of the jet. It was found from the graphs of FFT analysis that the jet fluctuation phenomenon due to the arc voltage behavior is the main factor to form the jet behavior.

Keywords: electric arcs, fast Fourier transforms, plasma turbulence, temperature, voltage control

W.-H. Zhao, D. Liu, K. Tian, and H.-Z. Tang, Tsinghua Univ., Beijing 100084, China. Cited: *Hanjie Xuebao/Trans. Chin. Weld. Inst., 22*(5), Oct 2001, Harbin Research Inst. Welding, p 24-26 [in Chinese]. ISSN: 0253-360X.

Low-Pressure Plasma Spray

Preparation and characterization of LPPS NiCoCrAlYTa coatings for gas turbine engine. NiCoCrAlYTa coatings have been deposited onto an aircraft gas turbine engine blade using a LPPS unit equipped with a computerized robot. Optimal processing conditions, including spray parameters, the trajectory of the robot, and the synchronized movements between the torch and the blade, have been developed for superior coating properties. The transferred-arc treatment, which provides the preheating and cleaning of the substrate surface, enhances the adherence of the coatings to a substrate. The resulting LPPS coatings show dense and uniform characteristics with ideal hardness, and good corrosion resistance to cycle oxidation.

Keywords: characterization, corrosion, engine mountings, inorganic coatings, plasma spraying, thermal effects

R.-J. Hong, K.-S. Zhou, D.-Z. Wang, H.-Z. Zhu, and Z.-Q. Kuang, Research Inst. of Non-ferrous Metals, Guangzhou 510651, China. Cited: *Trans. Nonferrous Met. Soc. China, 11*(4), Aug 2001, p 567-571 [in English]. ISSN 1003-6326.

Process study, microstructure, and matrix cracking of SiC fiber reinforced $MoSi_2$ based composites. SiC fiber reinforced SiAlON-$MoSi_2$ composites have been manufactured by a concurrent fiber winding and low-pressure plasma spraying (LPPS) technique to produce a multilayer, circumferentially fiber reinforced composite ring. The LPPS parameters for SiAlON-$MoSi_2$ powder were optimized by a two-level experimental design approach followed by further optimization, which provided a smooth sprayed surface, low matrix porosity, and high deposition efficiency. The microstructure of SiAlON-$MoSi_2$ matrix consisted of a lamellar structure built up of individual splats and a uniform distribution of discontinuous SiAlON splats throughout the $MoSi_2$ matrix. The spray/wind composites exhibited 2% porosity and well-controlled fiber distribution. High-temperature consolidation led to the forma-

tion of a thick reaction zone at the fiber-matrix interface by a chemical reaction between C coating and $MoSi_2$. Matrix cracking occurred in SiC_f (15 vol.%)/$MoSi_2$ after cooling from 1500 to 25 °C and was attributed to the large tensile residual stresses in the matrix developed on cooling because of coefficient of thermal expansion (CTE) mismatch between matrix and fiber. The addition of 40 vol.% SiAlON into the $MoSi_2$ effectively eliminated the matrix cracking by reducing the matrix-fiber CTE mismatch. Predictions of matrix cracking stress on the basis of residual stresses in the composites showed that the maximum permissible fiber volume fraction to avoid matrix cracking was 6% for SiC_f/$MoSi_2$ and 23% for SiC_f/SiAlON(40 vol.%)-$MoSi_2$.

Keywords: crack initiation, interfaces (materials), microstructure, molybdenum compounds, plasma spraying, porosity, powder metals, residual stresses, silicon carbide, tensile stress, thermal expansion, volume fraction

K. H. Baik and P.S. Grant, Oxford Ctr. for Adv. Mat. and Comp., Dept. Materials, Univ. Oxford, U.K. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 584-591 [in English]. ISSN: 1059-9630.

Nanostructured Materials

Nanostructured zirconia coating prepared by atmospheric plasma spraying. In this paper, a nanostructured zirconia coating fabricated by atmospheric plasma spraying (APS) is described. The microstructure and phase composition of the coating was characterized with scanning electron microscopy, transmission electron microscopy, x-ray diffraction, and Raman Spectroscopy. In addition, the bonding strength between the nanostructured zirconia coating and stainless steel substrate has been measured. It is found that the as-sprayed zirconia coating exhibited a bimodal distribution with small grains (60-80 nm) and large grains (70-120 nm), the latter is the main microstructure of the coating. The coating is composed of tetragonal zirconia; it was found that the monoclinic zirconia existing in the starting powders transformed into tetragonal phase during plasma spraying.

Keywords: bonding, crystal microstructure, nanostructured materials, phase composition, phase transitions, plasma spraying, Raman spectroscopy, scanning electron microscopy, substrates, transmission electron microscopy, x-ray diffraction analysis, zirconia

H. Chen and C.X. Ding, Shanghai Inst. Ceramics, Chinese Academy of Sciences, Shanghai 200050, China. Cited: *Surf. Coat. Technol., 150*(1), 1 Feb 2002, p 31-36 [in English]. ISSN 0257-8972.

Microstructure development of Al_2O_3-13wt.%TiO_2 plasma sprayed coatings derived from nanocrystalline powders. The development of constituent phases and microstructure in plasma sprayed Al_2O_3-13wt.%TiO_2 coatings and reconstituted nanocrystalline feed powder was investigated as a function of processing conditions. The microstructure of the coatings was found to consist of two distinct regions; one of the regions was completely melted and quenched as splats, and the other was incompletely melted with a particulate microstructure retained from the starting agglomerates. The melted region predominantly consisted of nanometer-sized γAl_2O_3 with dissolved Ti^{4+}, whereas the partially melted region was primarily submicrometer-sized αAl_2O_3 with small amounts of γAl_2O_3 with dissolved Ti^{4+}. The ratio of the splat microstructure to the particulate microstructure and thus the ratio of the γAl_2O_3 to αAl_2O_3 can be controlled by a plasma spray parameter, defined as the critical plasma spray parameter (CPSP). This bimodal distribution of microstructure and grain size is expected to have favorable impact on mechanical properties of nanostructured coatings, as has been observed before.

Keywords: agglomeration, alumina, crystal microstructure, grain size and shape, nanostructured materials, phase transitions, plasma spraying, quenching, titanium dioxide

Y.H. Sohn, L. Shaw, E. Jordan, M. Gell, and D. Goberman, Dept. Metallurgy and Materials Engineering, Inst. Materials Science, Univ. Connecticut, Storrs, CT 06269. Cited: *Acta Mater., 50*(5), 14 March 2002, p 1141-1152 [in English]. ISSN 1359-6454.

Near-nanostructured WC-18%Co coatings with low amounts of non-WC carbide phase: part I. synthesis and characterization. Near-nanostructured WC-18%Co coatings, with low amounts of non-WC carbide phases, have been synthesized using high-velocity oxyfuel (HVOF) thermal spraying under spraying conditions of varying fuel chemistry, fuel-oxygen ratio, and powder particle size. The results show that the temperature the particles experience during spraying depends on the preceding parameters. Compared to available published results on WC-Co system coatings, nanostructured WC-18%Co coatings, synthesized in these experiments, contain very low amounts of non-WC carbide phase (<10 vol%). This is comparable to that of the conventional WC-12%Co coating, prepared in the present study for comparison purposes. Regardless of whether the binder phase in the agglomerated feedstock powder particles melt or not, the WC particles do not appear to experience significant growth as a result of the spraying. The size of WC particles remains in the 200-500 nm range, consistent with that present in the feedstock powder. The as-received near-nanostructured WC-18%Co feedstock powder exhibits morphological characteristics that lead to low amounts of non-WC carbide phases in the coatings. The microstructure and phase constitution of the coatings depend on particle size of the feedstock powder and flame characteristics of the fuels during spraying. A higher particle temperature causes more decomposition of the WC phase, but reduces porosity in the coatings; this occurs with higher flame temperature and smaller particle sizes. Propylene fuel produces less decomposition of the WC phase despite the higher flame temperature and, thus, provides the best combination of dense coating with low amount of non-WC phase.

Keywords: carbides, characterization, decomposition, morphology, nanostructured materials, particle size analysis, phase composition, porosity, sprayed coatings, synthesis (chemical), thermal effects.

J. He, Y. Liu, Y. Qiao, T.E. Fischer, and E.J. Lavernia, Dept. Chem. Biochem. Engineering Materials Science, Univ. California, Irvine, CA 92687-2575. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci., 33*(1), Jan 2002, p 145-157 [in English]. ISSN 1073-5623.

Plasma spray forming of nanostructured composite coatings. The nanostructured composite coating is obtained via plasma spraying with Al_2O_3-13wt.%TiO_2 powder. Brittle and hard lamellas result from melted nanostructured powders. The ductile nanostructured matrix forms from unmelted nanostructured particles. Through the adjustment of constituent and nanostructure, hardness/strength and toughness/ductility can be balanced and the overall properties of the nanostructured composite coating can be achieved.

Keywords: hardness, mechanical properties, nanostructured materials, plasma spraying

X. Jiang, E.H. Jordan, L. Shaw, and M. Gell, Inst. Surface Technology, Central South Univ., Changsha 410083, China. Cited: *J. Mater. Sci. Technol., 18*(3), May 2002, p 287-288 [in English]. ISSN 1005-0302.

The spray forming of nanostructured aluminum oxide. Nanostructured ceramics and their composites possess improved properties such as tensile strength, fatigue strength, hardness, and wear resistance. Freestanding, near-net-shape, nanostructured Al_2O_3 components can be synthesized via plasma spray forming. In this study, plasma spray parameters were optimized, and an innovative substrate cooling technique was developed to retain nanosize Al_2O_3 in the spray deposit. Nanosize Al_2O_3 particles were partially melted and trapped between the fully melted coarser, micrometer-size Al_2O_3 grains. Densification of the spray-deposited Al_2O_3 occurred via solidification and sintering. A similar processing approach can be adopted for fabrication of near-net shapes of a variety of nanostructured materials (metals, ceramics, and intermetallics) and their combinations by selecting suitable powder-treatment and plasma spray parameters.

Keywords: ceramic materials, crystal microstructure, densification, grain size and shape, hardness, nanostructured materials, plasma spraying, powders, synthesis (chemical), tensile strength, wear resistance

A. Agarwal, T. McKechnie, and S. Seal, Plasma Process, Huntsville, AL 35811. Cited: *JOM, 54*(9), Sept 2002, p 42-44 [in English]. ISSN 1047-4838.

Development and implementation of plasma sprayed nanostructured ceramic coatings. A broad overview of the science and technology leading to the development and implementation of the first plasma sprayed nanostructured coating is described in this paper. Nanostructured alumina and titania powders were blended and reconstituted to a sprayable size. Thermal spray process diagnostics, modeling, and Taguchi design of experiments were used to define the optimum plasma spray conditions to produce nanostructured alumina-titania coatings. It was found that the microstructure and properties of these coatings could be related to a critical process spray parameter (CPSP), defined as the gun power divided by the primary gas flow rate. Optimum properties were determined at intermediate values of CPSP. These conditions produce limited melting of the powder and retained nanostructure in the coatings. A broad range of mechanical properties of the nanostructured alumina-titania coatings were evaluated and compared to the Metco 130 commercial baseline. It was found that the nanostructured alumina-titania coatings exhibited superior wear resistance, adhesion, toughness, and spallation resistance. The technology for plasma spraying these nanostructured coatings was transferred to the U.S. Navy and one of their approved coating suppliers. They confirmed the superior properties of the nanostructured alumina-titania coatings and qualified them for use in a number of shipboard and submarine applications.

Keywords: adhesion, alumina, nanostructured materials, plasma spraying, powder coatings, titanium dioxide, toughness, wear resistance

M. Gell, E.H. Jordan, Y.H. Sohn, D. Goberman, L. Shaw, and T.D. Xiao, Dept. Metallurgy and Materials Engineering, Univ. Connecticut, Storrs, CT 06269. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 48-54 [in English]. ISSN: 0257-8972.

Processing and characterization of nanocrystalline iron aluminide coatings prepared by thermal spraying of milled powders. This paper presents the first results of an ongoing research which was set up to investigate the possibility of processing an ultrafine grain Fe-40Al (Zr, B) alloy using a thermal spraying route. The coating produced here by high-velocity oxyfuel (HVOF) thermal spraying of milled powder had a highly metastable microstructure, inherited from the initial milling, that was characterized essentially by the nanometer grain size of its FeAl phase. The hardness of this nanocrystalline

coating was 35% higher than that of a conventional coating obtained from atomized powder and close to that of a fully dense bulk material having a micrometer grain size.

Keywords: coating techniques, grain size and shape, iron alloys, microstructure, scanning electron microscopy, transmission electron microscopy, x-ray diffraction analysis

T. Grosdidier, H.L. Liao, S. Lenhard, A. Tidu, and S. Revol, LERMPS, Univ. TBM, 90010 Belfort Cedex, France. Cited: (Conf. Proc: Fourth European Mechanics of Materials Conf. Processes, Microstructures and Mechanical Properties EUROMECH-MECAMAT'2000, 26-29 June 2000, E. Aeby-Gautier, M. Clavel, and D. Dunne, Ed.). *J. Phys., 11*(4), Sept 2001, p Pr411-Pr418 [in English]. ISSN: 1155-4339.

Shock synthesis of nanocrystalline high-pressure phases in semiconductors by high-velocity thermal spray. Shock synthesis of nanocrystalline silicon, germanium, and CdTe was accomplished using high-velocity thermal spray. Silicon or germanium powders were injected into a high-energy flame, created by a thermal spray gun, where the particles melt and accelerate to impact on a substrate. The shock wave generated by the sudden impact of the droplets propagated through the underlying deposits, which induces a phase transition to a high-pressure form. The decompression of the high-pressure phase results in the formation of several metastable phases, as evidenced by transmission electron microscopy and x-ray diffraction studies. The peak pressure is estimated to be approximately equals 23 GPa with a pulse duration of 1-5 ns. Transmission electron microscopy revealed that the metastable phases of silicon with a size range of 2-5 nm were dispersed within Si-I. In germanium, a metastable phase, ST-12, was observed. This is a decompression product of Ge-II that possesses the β-Sn type of structure. In the case of CdTe, a fine dispersion of hexagonal CdTe particles, embedded in cubic-CdTe with an average size of 2 nm was obtained.

Keywords: high-pressure effects, phase transitions, semiconducting silicon, spray guns, substrates, synthesis (chemical), transmission electron microscopy, x-ray diffraction

R. Goswami, J. Parise, H. Herman, S. Sampath, R. Gambino, Y. Zhu, and D. Welch, Center for Thermal Spray Research, Dept. Materials Sci. and Eng., SUNY at Stony Brook, Stony Brook, NY. Cited: *Microcrystalline and Nanocrystalline Semiconductors 2000* (Conf. Proc.) 27-30 Nov 2000 (Boston, MA), Vol 638, P. Fauchet, J. Buriak, L. Canham, N. Koshida, and B. White, Jr., Ed., Materials Research Society, 2001, p F1511-F1516 [in English]. ISSN: 0272-9172.

Production of glass microspheres using the plasma spraying method. The production of glass microspheres by the plasma spraying method was discussed. Argon was used as the plasma forming gas. The influence of the operating parameters of the plasma gun was investigated on the granular composition of microspheres. The plasma gun parameters were a working voltage of 30 V and a current strength of 350-450 A.

Keywords: composition, nanostructured materials, plasma guns, plasma spraying, synthesis (chemical)

V.S. Bessmertnyi, V.P. Krokhin, A.A. Lyashko, N.A. Drizhd, and Zh.E. Shekhovtsova, Belgorod Univ. Consum. Co-op., Belgorod, Russian Federation. Cited: *Glass Ceram. (Steklo Keram.), 58*(7-8), July/Aug 2001, p 268-269 [in English]. ISSN: 0017-100X.

Plasma Spray Forming

Spray forming and subsequent forging of γ-titanium aluminide alloys. Spray forming experiments with a binary Ti-48.9Al (at.%) alloy and an advanced γTiAl alloy with the composition Ti-47Al-4(Nb, Mn, Cr, Si, B) (at.%), designated as γ-TAB, were carried out. Subsequently, the spray formed materials were forged. The sprayed-and-forged conditions were characterized in terms of microstructure, porosity, and impurity content. Tensile properties were evaluated at room and elevated temperatures. Upon forging, the microstructures turned from nearly lamellar to near-γ with a grain size of 4.9 μm (Ti-48.9Al) and from duplex to near-γ; with a grain size of 2.2 μm (γ-TAB) owing to dynamic recrystallization. The porosity of the spray formed materials almost vanished after forging. The room-temperature (RT) tensile strength was improved due to the significant microstructural refinement. The sprayed-and-forged γ-TAB alloy sustains an elongation of 120% at 800 °C indicating the possibility of superplastic forming. The results are discussed in comparison with conventionally P/M-processed and hot isostatically pressed materials of the same composition.

Keywords: composition, crystallization, forging, grain size and shape, impurities, microstructure, plastics forming, porosity, tensile strength

G. Wegmann, R. Gerling, F.-P. Schimansky, and J.-X. Zhang, Inst. Materials Research, GKSS Research Centre, Geesthacht 21502, Germany. Cited: *Mater. Sci. Eng. A, 329-331,* June 2002, p 99-105 [in English]. ISSN 0921-5093.

Plasma spray forming. The technology of plasma spray forming (PSF) is introduced, and the technical processes of plasma spray for fabricating parts and molds are investigated emphatically in this paper. The technological characteristics of PSF are summarized, including original prototype fabrication and surface treatment, post-treatment of a formed workpiece and demolding methods. Also, some important factors affecting the qualities of workpiece formed by plasma spraying have been analyzed and evaluated in detail based on experiments. Finally, some experiments of PSF have been carried out.

Keywords: machining, plasma jets, plasma spraying, surface treatment

W.J. Xu and J.C. Fang, College of Mechanical Engineering and Automation, HQU, Quanzhou 362011, Fujian, China. Cited: 10th Int. Manufacturing Conf. in China (IMCC 2002), X. Xu, Ed., *J. Mater. Process. Technol., 129*(1-3), 11 Oct 2002, p 288-293 [in English]. ISSN 0924-0136.

10th International Manufacturing Conference in China (IMCC 2002). The proceedings contains 138 papers from the *Journal of Materials Processing Technology.* Topics discussed include: study on the friction coefficient in grinding; high-speed cutting of Inconel 718 with coated carbide and ceramic inserts; analysis of the rotary ultrasonic machining mechanism; thermal aspects in the face grinding of ceramics; plasma spray forming; a new shaping model for green ceramic balls; and immersive virtual product development.

Keywords: adaptive control systems, brittleness, computer software, ferrites, friction, fuzzy control, granite, heat conduction, image processing, kinematics, lapping, machining, molecular dynamics, sawing, silicon wafers, thermocouples

X. Xu, Ed. Cited: *J. Mater. Process. Technol., 129*(1-3), 11 Oct 2002, 670 pages [in English]. ISSN 0924-0136.

Preheating of Substrate

Splat morphology and microstructure of plasma sprayed cast iron with different preheat substrate temperatures. A cast iron coating is a prime candidate for the surface modification of aluminum alloys for antiwear applications because cast iron is inexpensive and exhibits superior wear resistance arising from the self-lubricating properties of graphite. In the present study, fundamental aspects of a plasma sprayed cast iron coating on an aluminum alloy substrate, including (1) the effects of preheat substrate temperature on the splat morphology, (2) the formation of a reaction layer and pores, and (3) the splat microstructure, were investigated in low-pressure plasma spraying. With an increasing substrate temperature, the splat morphology changes from a splash type to a disk and star shape. Deformed substrate ridges, mainly resulting from the slight surface melting, are recognized adjacent to the splat periphery at high substrate temperatures. The flattening ratio of disk splats decreases with substrate temperature because the ridges act as an obstacle for splat expansion. A reaction layer composed of iron, aluminum, and oxygen is ready to form at high substrate temperatures, which, along with the deformed ridges, improves the adhesive strength of splats. However, the pores appear at the splat interface at low substrate temperatures, which hinder the formation of a reaction layer. The amount of graphitized carbon increases in cast iron splats with an increase in substrate temperature.

Keywords: aluminum alloys, cast iron, interfaces (materials), microstructure, morphology, oxygen, plasma spraying, pressure effects, substrates, surface treatment, temperature, thermal effects

M.F. Morks, Y. Tsunekawa, M. Okumiya, and M.A. Shoeib, Toyota Technological Inst., Nagoya, Japan. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 226-232 [in English]. ISSN 1059-9630.

Radiofrequency Induction Plasma Spraying

In-flight treatment of metallurgical silicon powder by RF thermal plasma: elaboration of hydrogenated silicon deposit on a substrate. A plasma deposition process of metallurgical grade silicon powders was used in order to combine purification and deposition processes onto different kinds of substrate with a high deposition rate (approximately equals 100 μm/min). The calibrated silicon particles, previously ($50 \leq \phi \leq 120$ μm) are injected axially in the plasma and dragged by a carrier gas flow. Laser Doppler granulometry (LDG) analysis has been undertaken in order to measure the residence time τ; of the particles in the plasma which is approximately 12 ms for 30 cm long trajectories and an evaporation rate close to 30%. The decrease in particle size is due to the melting and evaporation reactions, which lead to the purification process. EDX and ICP analyses show that under optimized experimental conditions, dense and pure silicon deposits are obtained on a ceramic substrate.

Keywords: approximation theory, energy dispersive spectroscopy, evaporation, hydrogenation, optimization, plasma theory, powders, purification

M. Benmansour, E. Francke, D. Morvan, J. Amouroux, and D. Ballutaud, Lab. de Genie des Procedes Plasmas, Univ. Pierre et Marie Curie, ENSCP, 75231 Paris, France. Cited: "Thin Film Materials for Photovolt E-MRS," *Thin Solid Films* (Conf. Proc.), 5-8 June 2001 (Strasbourg), Vol 403-404, A. Slaoui, J. Poortmans, A. Jager-Waldau, and C. Brabec, Ed., Elsevier Science B.V., p 112-115 [in English]. ISSN 0040-6090.

Influence of plasma gas composition on the adhesiveness of RF thermal plasma sprayed hydroxyapatite/titanium composite coatings. Influence of plasma gas composition on the adhesiveness of radiofrequency (RF) thermal plasma sprayed (TPS) hydroxyapatite (HA)/titanium composite coatings was investigated. The bond strength of coatings was measured using autograph-

testing machine in which iron rods were bonded to both coated and noncoated sides of each specimen with epoxy glue. The results show that radiofrequency thermal plasma spraying (RF-TPS) with N_2 added plasma gas allows the formation of HA/Ti composite coatings with excellent adhesion to the titanium substrates.

Keywords: biomaterials, electrophoresis, etching, flame spraying, implants (surgical), microstructure, plasma spraying, scanning electron microscopy, sprayed coatings, surface roughness, x-ray diffraction analysis

M. Inagaki, Y. Yokogawa, and T. Kameyama, National Inst. AIST, Nagoya, Japan. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 47-50 [in English]. ISSN 1013-9826.

The deformation and cooling of ceramic particles sprayed with a thermal radiofrequency plasma under atmospheric conditions. Common thermal spray techniques use the strong acceleration of powder particles to produce dense ceramic coatings with high bond strength. The residence time of the powder particles within the plasma jet is correspondingly low, and only relatively small particles can be molten. In this work, on the contrary, an inductively coupled radiofrequency (RF) inductively coupled plasma (ICP) torch was used to spray large oxide/ceramic powder particles under atmospheric conditions. The slow plasma flow of a RF plasma leads to large residence times of the powder particles, so that the powder size of the feedstock can be 100 μm and more. It was observed that these particles will not be strongly accelerated in the plasma and that their velocity at the moment of impact is in the range of 10 to 20 m/s. Ceramic coatings were ICP sprayed with a low porosity and a high bond strength, similar to direct-current (DC) or high-velocity oxyfuel (HVOF) sprayed coatings. The morphology of ICP-sprayed particles on smooth steel surfaces, as a function of the surface temperature, is described and compared with DC plasma sprayed splats. Furthermore, the degree of deformation was measured and determined by different models, and the pronounced contact zones formed between the pancake and the substrate were investigated. The ICP-sprayed ceramic coatings show some special properties, such as the absence of metastable crystalline phases, which are common in other spray technologies.

Keywords: alumina, cooling, deformation, inductively coupled plasma, metallographic microstructure, morphology, plasma spraying, plasma torches, porosity, surface properties, thermodynamic stability

B. Dzur, H. Wilhelmi, and G. Nutsch, Technische Univ. Ilmenau, Plasma und Oberflachentechnik, D-98684 Ilmenau, Germany. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 637-642 [in English]. ISSN: 1059-9630.

Evaporation of zirconia powders in a thermal radiofrequency plasma. Incomplete evaporation of high-melting solid precursors, such as zirconia (ZrO_2), is a major problem in the application of plasma-flash evaporation processes to powder synthesis and production of high-performance coatings. The evaporation of zirconia powders injected into a thermal radiofrequency (RF) plasma is investigated by using optical emission spectroscopy (OES) and laser Doppler anemometry (LDA) to study evaporation rates and particle velocities. Model calculations are compared with the results of the process diagnostics. Axial emission profiles confirm the influence of the particle size on the evaporation behavior. Line-integrated side-on emission profiles are used to assess the rate of evaporation.

Keywords: evaporation, mathematical models, nanostructured materials, particle size analysis, powder metals, spectroscopic analysis, zirconia

P. Buchner, H. Schubert, J. Uhlenbusch, and M. Weiss, Inst. fur Laser und Plasmaphysik, Heinrich-Heine-Univ. Dusseldorf, D-40225 Dusseldorf, Germany. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 666-672 [in English]. ISSN: 1059-9630.

Deposition and characterization of $Y_3Al_5O_{12}$ (YAG) films and powders by plasma spray synthesis. YAG powders and coatings were developed for the first time by a novel precursor plasma spraying technique using the radiofrequency (RF) induction plasma technique. The x-ray diffraction of the as-sprayed coating confirms the presence of YAG, H-YAP, or O-YAP or a mixture of the above depending on the spray conditions. ^{27}Al MAS NMR of the YAG coating corroborates the x-ray results. Transmission electron microscopy studies on the coatings confirm that the coating consists of nanostructured particles. The successful spraying of these complex oxide coatings proves that chemistry of phase formation can be controlled in the plasma, thus opening up new avenues in material synthesis.

Keywords: decomposition, nanostructured materials, nuclear magnetic resonance, plasma spraying, powder coatings, powders, synthesis (chemical), x-ray diffraction analysis, yttrium compounds

S.D. Parukuttyamma, J. Margolis, H. Liu, J.B. Parise, C.P. Grey, S. Sampath, P. Gouma, and H. Herman, Center for Thermal Spray Research, Dept. Materials Science and Eng., State Univ. New York at Stony Brook, Stony Brook, NY 11794-2275. Cited: *Solid-State Chemistry of Inorganic Materials III* (Conf. Proc.), 27-30 Nov 2000 (Boston, MA), Vol 658, M. Geselbracht, J. Greedan, D. Johnson, and M.A. Subramanian, Ed., Materials Research Society, 2001, p GG6291-GG6296 [in English]. ISSN: 0272-9172.

Reactive Spraying

Induction plasma reactive deposition of tungsten carbide from tungsten metal powder. Experimental results on the primary carburization reaction between the tungsten powder and methane in the induction plasma, and the secondary carburization of the deposit on substrate at high temperature are reported. Optical microscopy and scanning electron microscopy were used to examine the microstructures of starting tungsten powder, carburized powder, and deposit. X-ray diffraction analysis, thermal gravimetric analysis and microhardness measurement were used to characterize the structures and properties of the powder and the deposit. It is found that the primary carburization reaction in the induction plasma starts from the surface of tungsten particles when the particles are melted. Tungsten particles are partially carburized inside the reactive plasma. Complete carburization is achieved through the secondary carburization reaction of the deposit on substrate at high temperature.

Keywords: carburizing, deposition, methane, powder metals, tungsten, tungsten carbide

X.L. Jiang and M.I. Boulos, Central South Univ., Changsha 410083, China. Cited: *Acta Metall. Sin., 14*(5), Oct 2001, p 352-358 [in English]. ISSN: 1006-7191.

Stability of Thermal Spray Process

The long-term stability of plasma spraying. The wear state of the different gun parts can affect the reproducibility of the plasma spray process. Indeed, this may influence the plasma characteristics and the energy transfer to the sprayed particles resulting in significant changes in the coating attributes. In this contribution, results from a detailed investigation on the stability of plasma spraying are presented. Specifically designed diagnostic tools were used to study the evolution of key parameters of a plasma spray process during a long-term experiment. A comprehensive analysis was carried out on the collected set of data, with an emphasis on the correlation that may exist among the data. Results show significant variations in the particle state and gun characteristics with spraying time. These variations are reflected in the microstructure of the sprayed coatings. The investigation also gives some indication about how the spray process could be controlled.

Keywords: characterization, data acquisition, data reduction, electrodes, energy transfer, fast Fourier transforms, morphology, optical correlation, plasma guns, plasma stability, plasma torches, surfaces

L. Leblanc and C. Moreau, National Research Council Canada, Boucherville, Que. J4B 6Y4, Canada. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 380-386 [in English]. ISSN 1059-9630.

Thermal Barrier Coating Topcoats

Thermal barrier coatings for gas-turbine engine applications. Hundreds of different types of coatings are used to protect a variety of structural engineering materials from corrosion, wear, and erosion and to provide lubrication and thermal insulation. Of all of these, thermal barrier coatings (TBCs) have the most complex structure and must operate in the most demanding high-temperature environment of aircraft and industrial gas-turbine engines. Thermal barrier coatings, which comprise metal and ceramic multilayers, insulate turbine and combustor engine components from the hot gas stream, and improve the durability and energy efficiency of these engines. Improvements in TBCs will require a better understanding of the complex changes in their structure and properties that occur under operating conditions that lead to their failure. The structure, properties, and failure mechanisms of TBCs are herein reviewed, together with a discussion of current limitations and future opportunities.

Keywords: ceramic coatings, corrosion resistance, durability, energy efficiency, erosion, failure analysis, gas turbines, lubrication, multilayers, thermal insulation, wear resistance

N.P. Padture, M. Gell, and E.H. Jordan, Dept. Metallurgy, Univ. Connecticut, Storrs, CT 06269-3136. Cited: *Science, 296*(5566), 12 April 2002, p 280-284 [in English]. ISSN 0036-8075.

High-temperature properties of plasma sprayed coatings of YSZ/NiCrAlY on Inconel substrate. Eleven-layered functionally gradient thermal barrier coatings (TBCs) were sprayed on Inconel substrate by varying the feeding ratio of YSZ/NiCrAlY in 0.1 intervals in the range of 0-1 linearly as well as nonlinearly (concave and convex type). The performance of the coatings was evaluated in terms of high-temperature fatigue, oxidation resistance, and bond strength. The fatigue behavior and the oxidation resistance were governed by the oxidation of aluminum in the NiCrAlY bond coating. The bond strength was determined by continuity of the composition and the microstructure between the layers. The linearly sprayed TBCs showed the highest endurance at high-temperatures among the coatings investigated, indicating that the linear feeding technique can be used for the high-temperature applications.

Keywords: bond strength (chemical), composition, fatigue of materials, feeding, high temperature operations, oxidation resistance, sprayed coatings, substrates, thermal barrier coatings

Y.-S. Song, I.-G. Lee, D.Y. Lee, D.-J. Kim, S. Kim, and K. Lee, Dept. Materials

Engineering, Daelin College of Technology, Anyang 431-715, South Korea. Cited: *Mater. Sci. Eng. A, 332*(1-2), July 2002, p 129-133 [in English]. ISSN 0921-5093.

Plasma spray deposition and high temperature characterization of ZrB_2-SiC protective coatings. Refractory metal borides are the object of special interest for aerospace applications requiring properties of chemical and mechanical resistance in ultrahigh temperature, such as nose and leading edges of re-entry space vehicles. The main objective of the research is the fabrication and characterization of plasma sprayed zirconium diboride-silicon carbide composite coatings and free-standing components for high-temperature applications. High- and low-pressure plasma sprays in a controlled atmosphere were selected as manufacturing techniques for the deposition of ceramic coatings. Fine ZrB_2 and SiC precursors were agglomerated and preconsolidated into spherical, hollow powders for better flowability and silicon carbide thermal protection during the interaction with the plasma. Coatings and free-standing tubular specimens were fabricated and tested for high-temperature behavior. Thermogravimetric analysis, surface morphology investigation and high-temperature x-ray diffraction showed that the addition of approximately 25% SiC induces a mechanism of self-protection of the ceramic material during heat treatment in oxidizing environments up to approximately 2100 K.

Keywords: aerospace applications, ceramic materials, heat treatment, high temperature properties, oxidation, plasma spraying, plasmas, x-ray diffraction analysis, zirconium compounds

C. Bartuli, T. Valente, and Tului, Dept. of Chemical and Materials Engineering, Univ. 'La Sapienza', Rome, Italy. Cited: *Surf. Coat. Technol., 155*(2-3), 17 June 2002, p 260-273 [in English]. ISSN 0257-8972.

Phase evolutions of plasma sprayed ceria and yttria-stabilized zirconia thermal barrier coating. The phase evolution of plasma sprayed CYSZ coating was observed during deposition and after isothermal heat treatments. It was observed that the reduction of tetravalent cerium to trivalent cerium occurred in an in-flight particle and in a spraying bead. However, the partial re-oxidation from the Ce^{3+} to the Ce^{4+} of the bead occurred by the additional heat input from plasma plume and the subsequent overlying layers. The remnant trivalent cerium cation and resultant oxygen vacancy stabilized the cubic phase in the as-sprayed coating. This resulted in higher cubic phase content in the as-sprayed coating. During isothermal aging, phase separation occurred due to the diffusion of stabilizing elements.

Keywords: aging of materials, heat treatment, phase separation, phase transitions, Raman spectroscopy, temperature, thermal barrier coatings, x-ray diffraction analysis, x-ray photoelectron spectroscopy, zirconia

H. Choi, H. Kim, and C. Lee, Division of Materials Science and Engineering, Ceramic Process Research Center, Hanyang Univ., Seoul, South Korea. Cited: *J. Mater. Sci. Lett., 21*(17), 1 Sept 2002, p 1359-1361 [in English]. ISSN 0261-8028.

Thermal barrier coatings: Improving thermal protection. A report on thermal barrier coatings (TBCs) to improve thermal protection and increase the life of industrial gas turbines, aircraft engines, and marine diesels was presented. Repeatable coating microstructures were obtained with powder development concepts, gun designs, controllers, and work-handling systems. Parameters affecting coating performance and the need to develop these parameters to obtain quality powders for coating were also analyzed.

Keywords: adhesion, aircraft engines, ceramic materials, closed-loop control systems, gas turbines, laser pulses, marine applications, particle size analysis, plasma guns, powder coatings, sprayed coatings, thermal conductivity, thermal insulating materials

M. Dorfman and C. Dambra, Sulzer Metco (US) Inc., Westbury, NY 11590. Cited: *Sulzer Tech. Rev., 83*(4), Dec 2001, p 10-13 [in English]. ISSN: 0039-4912.

Properties

Adhesion of Thermal Spray Coatings

Quantification of plasma sprayed coating adhesion using pulsed laser induced decohesion technique. The aim of the present study is to compare a laser ultrasonic technique with a conventional indentation test for the determination of intrinsic properties and the adhesion of alumina coatings, of different thicknesses (30-350 μm), deposited on stainless steel substrates by atmospheric plasma spraying (APS). For this purpose, a pulsed Nd:YAG laser is used to irradiate the coated specimens, and the ultrasonic waves generated by the laser are recorded at the epicenter using a laser interferometer. In the thermoelastic regime, the good agreement between the experiment and computation allows determination of the longitudinal wave velocity as well as the Young's modulus of the oxide coatings versus the porosity. For a critical value of the laser energy, breakdown at the coating/substrate interface occurs. An analytical model connected the acoustic waveforms with the length of the interfacial cracks and the time delay of the debonding. The critical tensile stress at the interface is calculated using a numerical model, and the practical adhesion defined by the laser technique was compared with indentation test results.

Keywords: adhesion, elastic moduli, interfaces (materials), interferometers, neodymium lasers, plasma spraying, pulsed laser deposition, stainless steel, substrates, ultrasonic waves

G. Rosa, R. Oltra, C. Coddet, S. Costil, and M.-H. Nadal, LRRS, UMR 5613 CNRS, Univ. Bourgogne, 21078 Dijon, France. Cited: *Surf. Eng., 17*(6), 2001, p 472-476 [in English]. ISSN 0267-0844.

Influence of laser surface preparation on adhesion of thermally sprayed coatings. Laser treatment was used to prepare substrate surfaces for thermal spray deposition. The interaction between aluminum and titanium alloys and short Nd:YAG laser pulses was investigated. In particular, the topography of laser treated surfaces has been observed and analyzed using scanning electron microscopy, atomic force microscopy, and laser profilometry. The coating/substrate adhesion was quantified for various surface preparation parameters by means of tensile tests and Rockwell indentations for Al_2O_3-13wt.%TiO_2 coatings. The influences of the laser energy density and the time interval between the laser treatment and the plasma spraying were studied. Compared with conventional degreasing and grit blasting, laser treatment produces better adhesion. The mechanisms of adhesion after laser treatment were investigated by transmission electron microscopy and electron energy loss spectrometry for a pure copper coating on a pure aluminum substrate. It appears that the adhesion is facilitated by metallurgical bonding.

Keywords: adhesion, aluminum alloys, atomic force microscopy, electron energy loss spectroscopy, laser applications, neodymium lasers, plasma spraying, profilometry, scanning electron microscopy, surface treatment, tensile testing, titanium alloys, transmission electron microscopy

J. Michler, G. Barbezat, and F. Folio, Alstom Power, GFHD, CH-5242 Birr, Switzerland. Cited: *Surf. Eng., 17*(6), 2001, p 490-494 [in English]. ISSN 0267-0844.

Effect of substrate hardness on the delamination strength of WC-Co coating deposited by high-velocity flame spraying method. WC-Co cermet was coated on the steel substrates (JIS: SKD5, SKD62 and SS400) with different hardness by two types of spraying methods using high-velocity oxygen fuel (HVOF) and high-pressure high-velocity oxygen fuel (HP-HVOF). Tensile tests as well as edge-indent tests were carried out to obtain interfacial fracture toughness G_{C12} and delamination energy E_d, respectively. The G_{C12} and E_d of the coatings deposited on the SS400 substrate with smaller hardness revealed larger values, and the G_{C12} and E_d of the coatings deposited by HP-HVOF were higher than that by HVOF with the same hardness of substrate. The reason can be that the sprayed powder with higher speed more easily shot into the soft substrate than the hard substrate so that the mechanical bond effect along interface between coating and substrate was stronger.

Keywords: bond strength (materials), cobalt, delamination, deposition, flame spraying, fracture toughness, hardness, interfaces (materials), sprayed coatings, substrates, tensile strength, tungsten compounds

D. Zhang, M. Kato, K. Nakasa, and X. Cing, Dept. Mech. Eng., Hiroshima Univ., Kagamiyama, Higashi-Hiroshima, Japan. Cited: *Zairyo/J. Soc. Mater. Sci., Jpn., 50*(11), Nov 2001, p 1262-1268 [in Japanese]. ISSN: 0514-5163.

Atmospheric Plasma Spray Coatings

Some properties of atmospheric air and inert gas high-pressure plasma sprayed ZrB_2 coatings. This work was aimed at developing a plasma spraying process for the deposition of ZrB_2 coatings. The ZrB_2 powder was prepared by a spray-drying technique and characterized by x-ray diffraction (XRD), scanning electron microscopy (SEM), electron microprobe analysis (EMPA), and laser granulometry. X-ray diffraction revealed the presence of ZrO_2 in the coatings deposited by atmospheric plasma spray (APS), while ZrB_2 was only present in the coatings deposited by inert plasma spray (IPS). The microhardness increased from 900 to over 1500 HV by increasing the spraying pressure over the atmospheric one. The coatings were submitted to pin-on-disk testing, and their behavior was compared to the WC-Co and TiO_2 + Al_2O_3 coatings, sprayed by high-velocity oxyfuel (HVOF) and APS, respectively. The characterization results showed that the ZrB_2 coatings, deposited by IPS, were good electrical conductors and they compared favorably with the reference coatings, in terms of tribological performance.

Keywords: inert gases, microhardness, plasma spraying, scanning electron microscopy, x-ray diffraction analysis, zirconium compounds

M. Tului, F. Ruffini, F. Arezzo, S. Lasisz, Z. Znamirowski, and L. Pawlowski, ENSCL, Villeneuve d'Ascq 59652, France. Cited: *Surf. Coat. Technol., 151-152,* 1 March 2002, p 483-489 [in English]. ISSN 0257-8972.

Cermet Coatings

Manufacturing silicon carbide cermet coatings by means of high-velocity oxyfuel flame spraying. Composite powders with silicon carbides (SiC) were developed for the manufacture of wear-resistant and corrosion-resistant protective coats by means of high-velocity oxyfuel flame spraying. It was possible to embed the SiC particles in ductile matrix alloys in order to prevent their disintegration. The matrices used were nickel, nickel-base, cobalt-base, and stellite alloys. Tests relating to high-velocity oxyfuel flame spraying with differ-

ent systems were performed after the manufacture of agglomerated, sintered, and mechanically mixed composite powders. The porosities, SiC contents, and structures of the coatings were analyzed, and their wear and corrosion resistances were examined in cyclic wear tests and in aging tests. In this respect, the main influencing quantity was the SiC content, which proved to be dependent on the spraying parameters.

Keywords: cobalt alloys, corrosion resistance, ductility, flame research, mechanical testing, nickel alloys, oxygen, porosity, powder metals, silicon carbide, sprayed coatings, wear resistance

B. Wielage, J. Wilden, and T. Schnick. Cited: *Schweissen Schneiden/Weld. Cutt., 54*(5), 2002, p 254-259 [in English]. ISSN 0036-7184.

Development of surface-modifying technologies by thermal spraying of process rolls in steel production process. Research and development of surface modification for process rolls have been carried out to improve the quality and productivity of steel strip sheets, as well as to prolong the span of service life of the rolls. To apply to bridle rolls that control strip tension in processing lines, thermal spray coating techniques of providing wear resistance, slip resistance, and corrosion resistance have been developed. These coatings are WC-cermet coating, provided with roughness-control technology, and multicoating, sprayed with WC-powder including undercoat with sealing technology. As for the conductor rolls that have conductive function at the plating section, self-fluxing alloy coating added with WC-cermet, which can prevent WC particles from peeling by the flattening of the particles, was developed. This WC self-fluxing alloy coating has excellent corrosion resistance and wear resistance. Through the investigation of ways to reduce and prevent the manganese buildup, a thermally sprayed coating with eminent manganese buildup resistance has been developed for hearth rolls that convey steel strip sheets in a continuous annealing furnace. These activities have made the process rolls more reliable and their span of service-life longer.

Keywords: annealing, corrosion resistance, rolling, sealing (finishing), service life, spraying, steel sheet, steelmaking furnaces, surface roughness, surface treatment, tensile stress, wear resistance

S. Midorikawa, T. Yamada, and K. Nakazato. Cited: *Kawasaki Steel Tech. Rep.,* Nov 2001, p 57-63 [in English]. ISSN: 0388-9475.

Coating-Substrate Interaction

Study on the morphology and action of the interface between nickel-base self-fluxing alloy coating and steel substrate. The interface morphology between WC enhanced nickel-base self-fluxing alloy coating and 38CrMoAl steel substrate, which were fabricated, respectively, by oxyacetylene flame spray welding, plasma spraying + oxyacetylene flame remelting, plasma spraying + remelting in electric furnace, was investigated. The results show that the composition diffusion between the coatings and substrate occurs during the coatings melting process, which mainly is iron element in substrate diffusing into the melted coating. The composition diffusion has definitive influence on the interface morphology. When the temperature of substrate surface is high enough, there will be amount of iron element diffusing into the coating, and a thin and dense layer of iron-nickel solution phase forms at the interface between the coating and substrate. So the adherent strength will be improved remarkably and the coating will have excellent antispall property.

Keywords: alloys, interdiffusion (solids), morphology, scanning electron microscopy, sprayed coatings

X.-H. Xiang, X. Mu, Z.-Y. Liu, and S.-Z. Li, School of Mechanical Engineering, South China Univ. Technol., Guangzhou 510640, China. Cited: *Hanjie Xuebao/Trans. Chin. Weld. Inst., 23*(3), June 2002, p 45-48 [in Chinese]. ISSN 0253-360X.

Microstructure and modeling of the high-temperature deformation behavior of thermal barrier coated superalloys. The present study describes the application of hot deformation experiments and microstructure investigations in order to predict the deformation behavior of uncoated and thermal barrier coated superalloys NiCr22Co12Mo9 and CoCr22Ni22W14. Estimating parameters such as dislocation density and carbide spacing by transmission electron microscopy (TEM), the hot tensile, creep, and relaxation behavior has been connected with the evolution of microstructure. The results of mechanical tests and the TEM investigations have been used as input data into two models (an effective stress model and a modified constitutive model by Kocks-Mecking), which describe the deformation behavior. The deterioration in the creep properties of the alloy NiCr22Co12Mo9 as a result of coating was a result both of the degraded state of the $M_{23}C_6$-precipitate in the substrate metal and of the weakening of the solid-solution hardening and precipitation hardening mechanisms responsible for the creep strength of the material, in the region of the boundary surface.

Keywords: computer simulation, creep, crystal microstructure, deformation, dislocations (crystals), hardening, solid solutions, substrates, tensile testing, transmission electron microscopy

U. Martin, H. Oettel, and U. Muhle, Inst. Physical Metallurgy, Freiberg, Univ. Mining/Technology, Freiberg D-09596, Germany. Cited: *Mater. Sci. Eng. A, 319-321,* Dec 2001, p 388-392 [in English]. ISSN 0921-5093.

Corrosion and Electrochemical Behavior

The lifetime assessment of hot-dip 5% Al-Zn coatings in chloride environments. Batch-type hot-dip zinc and 5% Al-Zn coatings were investigated for comparison of their corrosion resistance, electrochemical behavior and microstructures. The 5% Al-Zn coatings possess prominent electrochemical passivation behavior. Intermetallics formed mainly between iron, aluminum, and zinc adhering to the substrate were identified with energy-dispersive x-ray analysis and are believed to be responsible for the passivation phenomena observed in the electrochemical polarization. The 5% Al-Zn coatings exhibit much better corrosion resistance than the conventional hot-dip galvanizing steels under salt-spray tests. Although the corrosion potential of both coatings increases toward the noble potential as the immersion time increases, 5% Al-Zn coatings are always nobler than hot-dip zinc coatings.

Keywords: corrosion resistance, electrochemical corrosion, galvanized metal, intermetallics, passivation, substrates, x-ray analysis, zinc

H.C. Shih, J.W. Hsu, C.N. Sun, and S.C. Chung, Dept. Materials Science/Engineering, National Tsing Hua Univ., Hsinchu 300, Taiwan. Cited: *Surf. Coat. Technol., 150*(1), 1 Feb 2002, p 70-75 [in English]. ISSN 0257-8972.

Oxidation behavior of γTiAl coated with zirconia thermal barriers. The applicability of the thermal barrier coating concept, which is an established concept for nickel-base alloys, was investigated for the first time for γTiAl. As potential bond coats, the following surface treatments were applied: aluminum-diffusion coating, aluminum-diffusion coating combined with short-term preoxidation in air, short-term preoxidation in oxygen of a rough surface finish γTiAl sample without aluminide coating. For the purpose of lowering the temperature of the γTiAl substrate surface, and thus, to prolong the lifetime, a zirconia thermal barrier coating (TBC) was applied on top of the above-mentioned modified TiAl surfaces. Oxidation resistance of the modified γTiAl alloys/TBC systems was evaluated by isothermal oxidation tests at 900 °C for 100 h in air. Whatever the pretreatment conditions, the TBC was adherent to the oxide scale after 100 h oxidation, which was not the case for untreated γTiAl.

Keywords: aluminum compounds, chemical bonds, diffusion coatings, oxidation, oxidation resistance, surface treatment, thermal barrier coatings, zirconia

V. Gauthier, F. Dettenwanger, and M. Schutze, Karl Winnacker Institut, Dechema e.V., D-60486 Frankfurt am Main, Germany. Cited: *Intermetallics, 10*(7), July 2002, p 667-674 [in English]. ISSN 0966-9795.

Corrosion behavior of high-velocity oxyfuel sprayed and Nd-YAG laser-remelted high-chromium, nickel-chromium coatings. Thermal spray processes are widely used to deposit high-chromium, nickel-chromium coatings to improve high-temperature oxidation and corrosion behavior. However, despite the efforts made to improve the present spraying techniques, such as high-velocity oxyfuel (HVOF) and plasma spraying, these coatings may still exhibit certain defects, such as unmelted particles, oxide layers at splat boundaries, porosity, and cracks, which are detrimental to corrosion performances in severe operating conditions. Because of the process temperature, only mechanical bonding is obtained between the coating and substrate. Laser remelting of the sprayed coatings was studied in order to overcome the drawbacks of sprayed structures and to markedly improve the coating properties. The coating material was high-chromium, nickel-chromium alloy, which contains small amounts of molybdenum and boron (53.3% Cr, 42.5% Ni, 2.5% Mo, 0.5% B). The coatings were prepared by HVOF spraying onto mild steel substrates. A high-power, fiber-coupled, continuous-wave Nd:YAG laser equipped with large beam optics was used to remelt the HVOF-sprayed coating using different levels of scanning speed and beam with (10 or 20 mm). Coating that was remelted with the highest traverse speed suffered from cracking because of the rapid solidification inherent to laser processing. However, after the appropriate laser parameters were chosen, nonporous, crack-free coatings with minimal dilution between coating and substrate were produced. Laser remelting resulted in the formation of a dense oxide layer on top of the coatings and full homogenization of the sprayed structure. The coatings as sprayed and after laser remelting were characterized by optical and electron microscopy (OM, SEM, respectively). Dilution between coating and substrate was studied with energy dispersive spectrometry (EDS). The properties of the laser-remelted coatings were directly compared with properties of as-sprayed HVOF coatings.

Keywords: bonding, chromium, corrosion, defects, heat treatment, high temperature operations, laser applications, neodymium lasers, optical microscopy, scanning electron microscopy, substrates, thermooxidation

J. Tuominen, P. Vuoristo, T. Mantyla, S. Ahmaniemi, J. Vihinen, and P.H. Andersson, Tampere Univ. Technology, Inst. Materials Science, FIN 33101 Tampere, Finland. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 233-243 [in English]. ISSN 1059-9630.

The preparation and properties of iron-base self-fluxing alloy spray-welding coatings with different rare earths and chromium content. This investigation studied the effects of rare earths (RE) and chromium on the high-temperature oxidation resistance and aqueous corrosion resistance of iron-base self-fluxing alloy coatings. Four coatings were prepared through smelting-atomizing and oxide-acetylene flame spraying. The properties of the coatings were evaluated by cyclic oxidation tests, weight-loss experiments,

electrochemical impedance spectroscopy (EIS), potentiodynamic scanning technique, scanning electron microscopy (SEM), and electron dispersive x-ray analysis (EDAX). The addition of RE greatly enhanced the oxidation resistance of the coatings. This effect was attributed to the fact that RE changed the ion diffusion patterns of the coatings in the process of scale forming, resulting in more protective scales with high adhesion. The increase of chromium content in the coatings enhanced the corrosion resistance of the coatings in nitric acid solution, but in hydrochloric acid and sulfuric acid solutions the result was reversed. Rare earth addition had a beneficial effect in sulfuric acid and nitric solutions, but in hydrochloric acid, the samples with RE had a corrosion rate slightly higher than that of the samples without RE addition. These results are explained by the effect that the addition of RE minimized the cathodic area of the coatings.

Keywords: acetylene, adhesion, atomization, chromium, flame spraying, hydrochloric acid, inorganic coatings, oxidation resistance, scanning electron microscopy, smelting, spectroscopic analysis, sulfuric acid, synthesis (chemical), welding, x-ray diffraction analysis

Y.L. Cheng, C.Q. Zheng, Z. Zhang, F.H. Cao, J.F. Li, J.Q. Zhang, and J.M. Wang, Dept. Chemistry, Zhejiang Univ., Hangzhou 310027, China. Cited: *J. Mater. Sci., 37*(21), 1 Nov 2002, p 4589-4595 [in English]. ISSN 0022-2461.

Corrosion resistance of thermal sprayed film of zinc, aluminum, zinc-aluminum alloy against atmosphere corrosion. Corrosion resistance of the thermal sprayed coatings of zinc, aluminum, and Zn-15Al alloy exposed in the atmosphere for 22 years at Tokyo and Sapporo were evaluated by the electrochemical anodic polarization measurements, scanning electron microscopy observation, and electron probe microanalysis, comparing with the as-sprayed specimen. These coatings showed excellent resistance against the atmospheric corrosion for more than 20 years. Among the three kinds of metals, zinc was the most superior comparing with that of zinc-aluminum alloy and aluminum. Corrosivity of the atmosphere caused by sulfur and chlorine was larger at Sapporo than at Tokyo. The fact suggests that the influence of the airborne salinity and the air pollution substances is more severe at the coast of Japan Sea rather than the coast of Pacific Ocean.

Keywords: air pollution, aluminum, anodic polarization, atmospheric corrosion, electrochemistry, salinity measurement, sprayed coatings, zinc alloys

H. Nuriya, T. Suzuki, K. Ishikawa, and Y. Kitamura, College of Industrial Technology, Nihon Univ., Narashino 275-8575, Japan. Cited: *Zairyo-to-Kankyo/ Corros. Eng., 51*(9), 2002, p 404-409 [in Japanese]. ISSN 0917-0480.

Corrosion of High-Velocity Oxyfuel Coatings

Corrosion of Ni-Al high velocity oxyfuel (HVOF) thermal spray coating by fly ash and synthetic biomass ash deposits. Corrosion of a thermal spray (HVOF) Ni-Al coating has been investigated at 600 °C under both biomass generated fly ash and synthetic biomass ashes and has been monitored as a function of reaction time for up to 1000 h. Detailed microstructural and compositional analyses have been carried out to investigate the hot corrosion mechanism. Various microstructural defects and compositional inhomogeneities are found to play an important role in the initiation of hot corrosion. Deposition of molten reactants from the ashes creates the aggressive environment. Molten salts cause initial rapid hot corrosion via fluxing reactions between planar interlamellar porosity resulting in debonding of the surface lenticular splats followed by subsequent slow dissolution. Comparison between the performance of the coating in the fly ash and the synthetic ashes provides information for improved laboratory corrosion tests.

Keywords: composition, density (specific gravity), deposition, elastic moduli, fly ash, hardness, microstructure, nickel alloys, porosity, sprayed coatings, thermodynamic properties, yield stress

J.A. Hearley, C. Liu, J.A. Little, and A.J. Sturgeon, Dept. Materials Science and Metallurgy, Cambridge CB2 3QZ, U.K. Cited: *Brit. Corros. J., 36*(2), 2001, p 111-120 [in English]. ISSN: 0007-0599.

Erosion and Abrasion Resistance

The effect of heat treatment on the structure and abrasive wear resistance of autocatalytic NiP and NiP-SiC coatings. A systematic study on the relationships between the structure and abrasive wear resistance of autocatalytic nickel-phosphorus coatings (particle-free and SiC composite) with different phosphorus contents (i.e., 2.5-10.2 wt.% P) and under different thermal treatments (i.e., 300, 400 and 500 °C) has been performed. The phase structure, composition, and properties of the coatings could be controlled by changing the phosphorus content of the nickel-phosphorus matrix and by performing thermal treatments. The improvement in abrasive wear behavior of the nanocrystalline (i.e., $\leq$6.0 wt.% P) coatings with heat treatment temperature up to 400 °C was related to (1) the formation of a metastable equilibrium phase and (2) precipitation of Ni_3P compound. At higher thermal treatments (500 °C), a change in the deformation mechanisms (Orowan mechanism) determined by the coarsening of Ni_3P precipitates was associated with the decrease in abrasive wear resistance of the coatings. In addition, for the NiP-SiC coatings after annealing at 500 °C, Ni_3Si was formed and the adhesion between the reinforcement and the matrix was enhanced.

Keywords: adhesion, annealing, nanostructured materials, nickel compounds, phase composition, precipitation (chemical), reinforcement, silicon carbide, wear resistance

I. Apachitei, F.D. Tichelaar, J. Duszczyk, and L. Katgerman, Laboratory of Materials Science, Delft Univ. Technology, Delft, AL 2628, Netherlands. Cited: *Surf. Coat. Technol., 149*(2-3), 15 Jan 2002, p 263-278 [in English]. ISSN 0257-8972.

Erosion characteristics of silicon-carbide-coated C/C materials in arc-heated high enthalpy air flow. Silicon-carbide (SiC)-coated C/C materials are one of the most promising candidates for application to the highest temperature region of reusable reentry vehicles. SiC has good high-temperature properties, but oxidation mechanism and utilization limitation in high-temperature range are not clearly understood. In order to prevent oxygen attack through surface microcracks, glass sealing is usually applied as a final production procedure. In this investigation, however, SiC-coated C/C materials without glass coating are selected as specimens. This would provide advantages in analysis because thermochemical behavior on the surface becomes simpler than in glass sealed SiC coating. Two kinds of heating facilities are used in this investigation. One is a xenon lamp facility for obtaining static heating characteristics. Another type of facility is an arc-heated wind tunnel, which is a constrictor-type arc heater facility of NASDA and a magnetoplasmadynamic heating facility of IRS. One of the research objectives is to make comparisons of these facilities as a tool of reentry heating simulation. For this purpose, same materials were tested at all of these facilities. Heating conditions were parametrically changed in order to investigate erosion mechanism of the coating materials. The research is particularly focused on the erosion-rate dependence on pressure/temperature and active-passive transition characteristics.

Keywords: computer simulation, enthalpy, high-temperature properties, magnetoplasma, materials testing, microcracks, oxidation, plasma heating, pressure effects, protective coatings, reentry, silicon carbide, surface chemistry, wind tunnels, xenon

T. Yoshinaka, M. Auweter-Kurtz, G. Hilfer, H.-D. Speckmann, A. Sakai, and Y. Morino, National Space Development Agency of Japan, Tsukuba, Ibaraki 305-8505, Japan. Cited: *Acta Astronautica, 50*(3), Feb 2002, Elsevier Science Ltd., p 149-158 [in English]. ISSN 0094-5765.

Erosion resistance of TiO_2 thermal spraying coating in ClO_2 liquid medium. Based on chemical reaction kinetics, the corrosion rate and lifetime of TiO_2 thermal spraying coating corrosion rate meet chemical kinetics equation of $V_L = KC^{1.1}$ (mm/a) and the constant of corrosion reaction rate $K = 128 \exp(-30{,}842.88/RT)$. It provided the theory for erosion resistance of TiO_2 thermal spraying coating in ClO_2 liquid medium.

Keywords: chlorine compounds, corrosion resistance, reaction kinetics, spraying, titanium dioxide

L. Feng, A. Lei, and Q. Jin, Qiting, Xi'an Univ. Technology, China. Cited: *Chung-kuo Tsao Chih/China Pulp Paper, 21*(2), March 2002, p 23-26 [in Chinese]. ISSN 0254-508X.

The hot erosion behavior of high-velocity oxyfuel chromium carbide-metal cermet coatings sprayed with different powders. The high-velocity oxyfuel (HVOF) sprayed chromium carbide-metal cermet coatings have shown some attractive behavior, which makes them superior to arc sprayed iron-base coatings in preventing erosion. While their hot erosion behavior and its dependence on carbide/metal matrix proportion have been investigated, the detail study of the hot erosion behavior being dependent on the spraying methods and the starting powder characteristics has been somewhat limited. This work was undertaken to understand the influence of powder type on the hot erosion behavior of HVOF coatings. A series of hot erosion tests was carried out on eight chromium carbide-metal cermet coatings using a nozzle-type elevated-temperature erosion tester. The morphology of specimens was examined by light microscopy and scanning electron microscopy (SEM) with energy-dispersive spectroscopy (EDS). The composition of starting powders and deposited coatings was analyzed using EDS. It was found that among the eight HVOF chromium carbide-metal cermet coatings tested the composite powder sprayed coatings had nearly the same composition as the starting powders, while the blend powder sprayed coatings had lower chromium and higher nickel contents than the starting powders. This means that more chromium carbide particles had lost during spraying the blend powders, as compared with spraying the composite powders whose composition almost remained the same. The composite powder sprayed coatings also showed higher microhardness and finer microstructure, lower porosity, and oxide rate, which account for their higher erosion resistance than the blend powder sprayed coatings.

Keywords: chromium compounds, composition, deposition, energy dispersive spectroscopy, erosion, microhardness, microstructure, nozzles, optical microscopy, porosity, powders, scanning electron microscopy

B.Q. Wang and Z.R Shui, FBE Technology Centre, Metalspray United, Midlothian, VA 23112. Cited: *Wear, 253*(5-6), Sept 2002, p 550-557 [in English]. ISSN 0043-1648.

Fatigue and Fracture

Thermal fatigue failure induced by delamination in thermal barrier coating. The paper presents the experimental and theoretical investigation on the thermal fatigue failure induced by delamination in thermal barrier coating system. Laser heating method was used to simulate the operating state of thermal barrier coating (TBC) system. The nondestructive evaluation such as acoustic emission (AE) detection was used to study the evolution of TBC system damage. Micro-observation and AE detection both revealed that fatigue crack was in two forms: surface crack and interface delamination. It was found that interface delamination took place in the period of cooling or heating. Heating or cooling rate and temperature gradient had an important effect on interface delamination cracking propagation. A theoretical model on interface delamination cracking in TBC system at operating state is proposed. In the model, a membrane stress *P* and a bending moment *M* are designated the thermal loads of the thermal stress and temperature gradient in TBC system. In this case, the coupled effect of plastic deformation, creep of ceramic coating as well as thermal growth oxidation (TGO) and temperature gradient in TBC system was considered in the model. The thermal stress intensity factors (TSIFs) in non-FGM (functional gradient material) thermal barrier coating system are analytically obtained. The numerical results of TSIFs reveal some same results as obtained in experimental test. The model is based on fracture mechanics theory about heterogeneous materials, and it gives a rigorous explanation of delaminations in TBC system loaded by thermal fatigue. Both theoretical analysis and experimental observation reveal an important fact: delaminations are fatigue cracks that grow during thermal shocks due to compressive stresses in the loading, this loads the delaminations cracks in mixed I and II mode.

Keywords: bending moments, crack propagation, cracks, creep, delamination, failure analysis, fatigue of materials, fracture mechanics, laser applications, plastic deformation, stress-intensity factors

Y.C. Zhou and T. Hashida, Fracture Research Inst., Tohoku Univ., Sendai 980-8579, Japan. Cited: *Int. J. Fatigue, 24*(2-4), 2002, p 407-417 [in English].

Thermal fracture of interfaces in precracked thermal barrier coatings. Thermal barrier coatings (TBCs) make it possible to operate gas turbines, aircraft engines, and diesel engines at higher temperatures, thus enabling significant improvements in the performance of these systems. In this paper, the effect of introducing surface cracks into plasma sprayed TBCs is studied. The resistance of these precracked coatings to interfacial fracture was determined both experimentally and analytically. In the experiments performed, beam-shaped specimens, with crack densities varying from 0-42 cracks/in., were subjected to a high heat flux generated by a 1.5 kW CO_2 laser for a time interval of 4 s followed by natural convection cooling. In each case, the surface temperature that resulted in interface crack initiation was determined. Similarly, the final interfacial crack length corresponding to the different crack densities was measured as a function of maximum surface temperature. In all cases, it was shown that increasing crack density resulted in decreased interfacial cracking at the end of the thermal shock procedure. A numerical model of the experiment was developed using the finite-element method, and it was used to study the effect of the laser-heating process on an interface crack in a precracked TBC system. The analytical results confirmed and explained the experimentally observed behavior.

Keywords: crack initiation, finite element method, fracture, heat flux, interfaces (materials), laser beam effects, mathematical models, plasma spraying, thermal effects

K. Kokini, A. Banerjee, and T.A. Taylor, School of Mechanical Engineering, Purdue Univ., West Lafayette, IN 47907-1288. Cited: *Mater. Sci. Eng. A, 323*(1-2), 31 Jan 2002, p 70-82 [in English]. ISSN 0921-5093.

Fatigue behavior of a 4140 steel coated with a NiMoAl deposit applied by HVOF thermal spray. The fatigue behavior of a quenched-and-tempered AISI 4140 steel has been investigated in three different conditions: as-polished, as-grit blasted with Al_2O_3 particles, and as-coated, after grit blasting, with a deposit of Ni-Al-Mo alloy (Metco 447) of approximately 300 μm in thickness, applied by HVOF thermal spraying. It has been determined that after grit blasting with particles of 20 mesh (83 μm) at a pressure of 345 kPa, a significant decrease in the fatigue properties of the material takes place. It has also been observed that such particles are retained at the substrate surface during blasting and become stress concentrators that enhance the nucleation of fatigue cracks. The latter give rise to a decrease in the fatigue strength of the blasted material. Further coating of the grit-blasted specimens with a deposit of Metco 447 of approximately 300 μm thick, applied by HVOF thermal spraying, leads to a further reduction in the fatigue strength of the material. Under these conditions, the fatigue cracks are also nucleated at the alumina particles retained after blasting. It is believed that such a further decrease is mainly associated with two different causes. Firstly, the extensive fracture and delamination of the coating from the substrate, which has been observed from the microscopic analysis. Secondly, the possible existence of tensile residual stresses in the substrate, in the vicinity of the substrate-deposit interface, which would assist in the propagation of the fatigue cracks nucleated at the alumina particles. The fatigue properties of the steel substrate in the three different conditions investigated has been described in terms of the simple parametric relationship earlier proposed by Basquin.

Keywords: blasting, crack propagation, cracks, delamination, fatigue of materials, fracture, nucleation, quenching, residual stresses, spraying, strength of materials, stress concentration, tensile stress

K. Padilla, A. Velasquez, J.A. Berrios, and E.S. Puchi Cabrera, School of Metallurgical Engineering/Materials Science, Faculty of Engineering, Univ. Central de Venezuela, Los Chaguaramos, Caracas 1045, Venezuela. Cited: *Surf. Coat. Technol., 150*(2), 15 Feb 2002, p 151-162 [in English]. ISSN 0257-8972.

Study of thermal fatigue of H13 die steel with various surface treatments. Surfaces of die-casting dies are subjected to very severe conditions of cyclical thermal and mechanical load and chemical and mechanical wear. Dies mostly fail due to a combination of heat checking, erosion, corrosion, and soldering. It is conceivable that appropriate surface treatments and coatings have a favorable influence on the temperature-dependant performance of the surface of the die. The objective of this study was to examine various surface treatments and coatings, including shot peening, nitriding, nitrocarburizing, laser hardening and remelting, electrospark alloying (deposition), and plasma spraying under thermal fatigue conditions. Thermal cycling tests were conducted by alternate dipping of treated samples in an LM24 melt and in water. Results and their analyses are presented in this paper. The best thermal fatigue resistance was shown by the specimen that had a double treatment of laser hardening plus electrospark deposition.

Keywords: coatings, corrosion, die casting, laser applications, plasma spraying, surface treatment

V.V. Ivanov, I.R. Paine, and P.J. Revnyuk, Univ. Auckland, Auckland, New Zealand. Cited: *High-Temp. Mater. Process., 21*(1-2), June 2002, p 65-78 [in English]. ISSN 0334-6455.

Fracture characteristics of thermal barrier coatings after tensile and bending tests. Uniaxial tension and four-point bending tests were conducted on two-layer (nonfunctionally graded material) plasma sprayed rectangular specimens, boasting a new, functionally graded material (FGM) layer. The top coat layer was composed of stabilized yttria-zirconia (YSZ), and the bond coat layer was NiCrAlY. The FGM was composed of five layers: 100% YSZ; 80% YSZ + 20% NiCrAlY; 60% YSZ + 40% NiCrAlY; 40% YSZ + 60% NiCrAlY; and 20% YSZ + 80% NiCrAlY. Fracture in the thermal barrier coating (TBC) system was examined by scanning electron microscopy (SEM), which showed that vertical multiple cracking first occurred in the top coat, followed by propagation of interface cracking between the top and bond coats. Spallation of non-FGM coatings occurred in tensile/bending experiments, but not for the FGM-coated specimens, with only localized delamination observed along the interface between FGM layers and the substrate. For specimens prepared with a gun-substrate distance of approximately 120 mm and gun operating power of approximately 32.5 kW, the interface fracture toughness, evaluated by a shear lag model for the uniaxial tensile test, was 0.94 and 0.67 MPa $\cdot$ $m^{1/2}$ for type A and B coatings, respectively. Here, types A and B correspond to an average roughness of the bond coat surface of 12.8 and 6.8 μm, respectively. The interface fracture toughness evaluated by the Suo-Hutchinson model was 1.05-1.27 and 1.0-1.17 MPa $\cdot$ $m^{1/2}$ for type A and B coatings, respectively. The results are very close to data obtained by the blister test method. For specimens prepared with a gun-substrate distance of 125-130 mm and gun operating power of approximately 38.5 kW, the interface fracture toughness, evaluated by the Suo-Hutchinson model for four-point bending, was 4.26-7.21 MPa $\cdot$ $m^{1/2}$.

Keywords: bending (deformation), cracks, delamination, fracture toughness, functionally graded materials, interfaces (materials), scanning electron microscopy, spalling, substrates, tensile testing

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Mechanisms of fatigue failure in thermal spray coatings. The aim of this experimental study was to ascertain the fatigue failure modes of thermal spray coatings in rolling/sliding contact. These failure modes outline the design requirements of thermal spray coatings for high-stress tribological applications including impact and point or line contact loading. Recently, a number of scientific studies have addressed the fatigue performance and durability of thermal spray coatings in rolling/sliding contact, but investigations on the mechanisms of these failures are seldom reported. The understanding of such failure mechanisms is, however, critical in optimizing the generic design of these overlay coatings. This study takes a holistic approach to summarize the results of ongoing research on various cermet (WC-Co) and ceramic (Al_2O_3) coatings deposited by detonation gun (D-Gun), high-velocity oxyfuel (HVOF), and high-velocity plasma spraying (HVPS) techniques, in a range of coating thickness (20-250 μm) on various steel substrates to deliver an overview of the various competing failure modes. Results indicate four distinct modes of fatigue failure in thermal spray cermet and ceramic coatings: abrasion, delamination, bulk failure, and spalling. The influences of coating process, thickness,

materials, properties of substrate materials, and prespray conditions on these fatigue failure modes are also discussed. A modified four-ball machine was used to investigate these failure modes under various tribological conditions of contact stress and lubrication regimes in conventional steel and hybrid ceramic contact configurations. Results are discussed in terms of pretest and posttest surface examination of rolling elements using scanning electron microscopy (SEM), electron probe microscopy analysis (EPMA), and surface interferometry, as well as subsurface observations using x-ray diffraction (XRD), residual stress analysis, and dye-penetrant investigations.

Keywords: cermets, defects, failure (mechanical), fatigue of materials, interferometry, plasma spraying, porosity, residual stresses, scanning electron microscopy, spalling, stress analysis, x-ray diffraction analysis

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Interfacial fatigue crack propagation in nickel-base superalloy protective coatings. It is important to control the interface strength of coatings and composite materials, a feature that has been noted for many years. However, how can interface strength be evaluated and controlled? In order to explore this aspect, subcritical fatigue crack growth behavior was investigated along the interface of a CoNiCrAlY coated nickel-base superalloy. According to the traditional fatigue test methodology, fatigue crack propagation tests were carried out, using double cantilever beam specimens. The resistance to the fatigue crack propagation was successfully evaluated by a fracture mechanics approach. Particular attention was given to the effects of surface finish of the substrate as a coating parameter, the test temperature, and long-term thermal aging after the coating.

Keywords: adhesion, cobalt compounds, composite materials, crack propagation, cracks, fatigue of materials, fatigue testing, fracture mechanics, interfaces (materials), nickel alloys, strength of materials, surface structure

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Effect of high-temperature protective coatings on fatigue lives of nickel-base superalloys. This study concerns *M*CrAlY coatings (*M* is nickel, cobalt or both) sprayed by a vacuum plasma spraying process for protection against high-temperature corrosion and oxidation of gas turbine components, such as turbine blades and duct segments. The effect of high-temperature protective coatings on fatigue lives of nickel-base superalloys were investigated at high temperature under push-pull loading and rotary bending and then compared with uncoated superalloys, such as equiaxed IN738LC, unidirectional solidified CM247LC and single-crystal CMSX-2. The high-cycle fatigue lives of *M*CrAlY-coated superalloys at high temperature under push-pull loading showed an inferior performance when compared with the uncoated superalloys. This was because the crack-initiation site was different. The high-cycle fatigue cracks of nickel-base superalloys initiated at casting cavities that were exposed on the specimen surface, whereas the high-cycle fatigue cracks of *M*CrAlY-coated specimens initiated at interface defects, such as small pores and grid residue, between the *M*CrAlY coating and the substrate and grew into the *M*CrAlY coating, and then into the substrate. Similarly, the rotary bending fatigue properties of *M*CrAlY-coated superalloys at high temperature showed an inferior performance when compared with the uncoated superalloys. This is because of a high stress due to the higher Young's modules of the *M*CrAlY coating (in comparison with the substrate) being induced at the *M*CrAlY coating surface. The crack-initiation site was on the specimen surface in both cases of the nickel-base superalloys and the *M*CrAlY-coated superalloys, respectively. As a result, it was considered that, for rotary bending tests, the fatigue life reduction was due to the high stress that originated from the difference of elastic constants between the *M*CrAlY coating and the superalloy. Consequently, in fatigue life design it is necessary to take account of the stress levels in a coating layer.

Keywords: cobalt, corrosion protection, crack initiation, fatigue of materials, gas turbines, high-temperature effects, high-temperature properties, nickel alloys, oxidation, plasma spraying, protective coatings, single crystals

Y. Itoh, M. Saitoh, K. Takaki, and K. Fujiyama, Toshiba Corp., Power and Indust. Syst. R & D Ctr., Yokohama, 230-0045, Japan. Cited: *Fatigue Fract. Eng. Mater. Struct., 24*(12), Dec 2001, p 843-854 [in English]. ISSN: 8756-758X.

Dauerfestigkeit auftragge-schweisster und auftraggespritzter Bauteile bei mechanischen Ermudungsbelastungen [Fatigue strength of surface-welded and surface-sprayed components subjected to mechanical fatigue loads]. Investigations were conducted into the influence of different weld and spray surfacing technologies on the fatigue strength of components. In this case, mathematical fatigue-strength models were used in order to calculate the fatigue loads and take account of the mechanical characteristics of the surface-welded and surface-sprayed coatings and of defects in the coating. The validity of the models was confirmed experimentally. Technological recommendations which take the fatigue-strength criterion into consideration are presented.

Keywords: calculations, fatigue of materials, hardfacing, loads (forces), mathematical models, strength of materials, tensile strength, tensile stress

P. Adamiec and J. Dziubinski, Silesian Technical Univ., Gliwice, Poland. Cited: *Schweissen und Schneiden/Welding and Cutting, 53*(12), Dec 2001, p E270-E275+E790-E795 [in German, English]. ISSN 0036-7184.

Friction and Wear

Tribological properties of arc sprayed coatings obtained from FeCrB- and FeCr-based powder wires. The technology of wear-resistant coatings and new powder wire composites has been developed. New coatings with low porosity and small grains were obtained by arc spraying of FeCrB + Al and FeCr + Al + C powder wires in a steel cover. A modified arc spraying torch was used. The initial phase contents of coatings and their changes in the subsurface region during friction processes were studied by x-ray diffractometry (XRD). Wear tests with the block-on-ring configuration at boundary lubrication and friction in an abrasive-oil mixture under normal pressure at 5 MPa have been performed. Results for sprayed coatings of both systems showed their high wear resistance.

Keywords: friction, iron compounds, porosity, tribology, wear resistance, x-ray diffraction analysis

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High-stress abrasive wear behavior of some hardfaced surfaces produced by thermal spraying. Steel surfaces were thermally sprayed with nickel chromium boron (NCB) powder (with and without tungsten carbide) using an oxyacetylene torch. The sprayed (hard) surfaces and substrate were characterized for abrasive wear properties. Test parameters such as load and sliding distance were varied. A significant improvement in the abrasive wear resistance (inverse of wear rate) was noted for the thermally sprayed surfaces as compared to that of the substrate. Wear surfaces, subsurface regions, and debris were examined in order to ascertain the operating wear mechanisms. Substrate (mild steel), because of its low hardness, suffered severe wear through the cutting, plowing, and wedging action of the hard abrasive (silicon carbide). Deep cuts on the worn surface, a bulky transfer layer, subsurface cracks, and large-size debris were observed. However, wear was reduced due to high hardness of the layer of NCB powder on the substrate, which resisted the penetration of abrasive into the surface. Presence of tungsten carbide in the layer of NCB powder further reduced the wear of the corresponding specimen because of very high hardness of the tungsten carbide. Shallow wear grooves and finer debris were observed for the NCB coating with and without tungsten carbide. Cutting was the predominating wear mechanism in the case of coatings.

Keywords: abrasion, acetylene, composition, hardness, nickel alloys, powder metals, spraying, substrates, surface treatment, tungsten carbide, wear of materials

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Sliding friction and wear behavior of Al-Ni-Co-Si quasi-crystalline coatings deposited by the high-velocity oxyfuel spraying technique. The sliding friction and wear performance of Al-Ni-Co-Si quasi-crystalline coatings deposited by the high-velocity oxyfuel technique were investigated under dry sliding conditions. This study indicated that changes in the imposed sliding test conditions modified the friction and wear behavior of quasi-crystalline coatings. Qualitative analysis of the contact interface and wear debris were performed with the aim of understanding the role of the third body on the friction and wear processes. The dependence of the coefficient of friction on the sliding velocity and counterpart material was explained by the stick-slip behavior. It was also shown that test conditions favorable for the formation of thick intermediate layers and the densification of the coating subsurface led to low wear rates. Large cylindrical particles, formed by agglomeration of small wear debris, were suggested as a beneficial factor for the reduction of the coefficient of friction.

Keywords: agglomeration, aluminum compounds, densification, deposition, friction, quasi-crystals, spraying, wear resistance

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Friction and wear behavior of flame sprayed polyether etherketone coatings. Polyether etherketone (PEEK) becomes of great interest to applications as bearing and slider materials. In this paper, PEEK coatings with three kinds of crystallinities were deposited using the flame spray process. Employing a uniform design experiment, the friction and wear behavior of the three PEEK coatings were systematically investigated under dry sliding conditions against a 100C6 counterbody on a ball-on-disk arrangement for several loads and sliding velocities. For the three coatings, the friction coefficient significantly

followed the normal distribution. The average friction coefficients appeared to decrease while increasing the sliding velocity, but were insensitive to the applied load in the range of investigation. Among the three coatings, the higher the crystallinity of the coating, the lower its average friction coefficient was. The wear rate of the coating with the lowest crystallinity decreased with an increase in the load and a decrease in the sliding velocity. The wear rate of the coating with the intermediate crystallinity decreased with an increase in the load, but increased with an increase in the sliding velocity at lower loads, and then decreased with an increase in the velocity at higher loads. The wear rate of the coating with the highest crystallinity decreased with the increase of both the load and the sliding velocity. The wear mechanisms of the different coatings are explained in terms of plastic deformation, plow marks, and fatigue tearing.

Keywords: crystallization, fatigue of materials, friction, organic coatings, plastic deformation, wear of materials

J. Li, H. Liao, and C. Coddet, Lab. Etud. Recher. Mat. Plasmas Sur., Univ. Tech. Belfort-Montbeliard, Belfort Cedex 90 010, France. Cited: *Wear, 252*(9-10), May 2002, p 824-831 [in English]. ISSN 0043-1648.

The influence of temperature on the wear mode and deterioration of coatings used for titanium aircraft engine components. The interface between titanium compressor blades and rotors of jet engines was studied to determine the mechanisms responsible for problematic deteriorations of protective Cu-Ni-In coatings. Results indicated that at operational temperatures of 221 °C, titanium from the uncoated disk was transferred to the softer Cu-Ni-In coating on the blade. This in turn created titanium on titanium contact and resulted in fretting wear. At higher temperatures of 454 °C, copper segregation appears to be the dominant deterioration mechanism. In order to simulate these wear modes and evaluate candidate coatings, a unique testing procedure was developed that included a range of gross-slip scale displacements. Cobalt, molybdenum, tungsten carbide, and nickel-base coatings were evaluated by this testing procedure that first involved a low-cycle series of gross-slip displacements (125 μm), followed by a higher cycle series in a reduced (25 μm) gross-slip regime. Results of the study revealed that an unlubricated pure-cobalt coating could protect the blade without damaging the disk at elevated temperatures. While no coatings performed exceptionally at lower temperatures, pure molybdenum exhibited some promise.

Keywords: aircraft engines, cobalt, compressors, indium, jet engines, molybdenum, nickel, protective coatings, rotors, thermal effects, titanium, turbomachine blades, wear of materials

A.J. Freimanis, A.E. Segall, E.J. Whitney, and J. Conway, Jr., Boeing Helicopter Co., Philadelphia, PA 19142. Cited: *Tribol. Trans., 45*(2), 2002, p 193-198 [in English]. ISSN 1040-2004.

Wear resistance of a Cr_3C_2-NiCr detonation spray coating. Coatings can be applied to surfaces to improve the surface characteristics over those of the bulk properties and are widely used in tribological applications either to reduce wear and/or to modify friction during contact. One of the foremost coating methods for combating wear is thermal spraying. To prolong the life of steel slab continuous casting rolls, Cr_3C_2-NiCr detonation spray coating was processed on the roll surface in a steelmaking plant in China. This article studies the mechanical properties and wear resistance of this coating. The abrasive and dry frictional wear testing were performed using a pin-on-disk tester. Experimental results show that the wear resistance of the coated samples—i.e., coating reduces the risk of seizure compared to uncoated samples—is much better than those of the uncoated steel at room and elevated temperatures with any load and sliding velocity. The coating wear mechanisms under different test conditions are discussed.

Keywords: acetylene, chromium compounds, heat treatment, mechanical testing, powder metals, steel, substrates, surface properties, tribology, velocity, wear of materials

J. Wang, B. Sun, Q. Guo, M. Nishio, and H. Ogawa, Venture Business Laboratory, Saga Univ., Saga, Japan. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 261-265 [in English]. ISSN 1059-9630.

The effect of humidity on the sliding wear of plasma transfer wire arc thermal sprayed low-carbon steel coatings. Low-carbon steel coatings were applied on 319 Al alloy substrates using a plasma transfer wire arc (PTWA) type thermal spraying process. A pin-on-disk type wear tester placed in an environmental test chamber was used for the wear tests. Tests were performed in an atmosphere with various humidity levels in the range of 10-99% RH. At low load (≤20 N) and sliding velocity (≤1.0 m/s) tests, an Fe_2O_3-rich compound formed on the worn surfaces as a result of oxidative wear. As the atmospheric humidity increased, a tribopolishing process became active, and the wear rates decreased with increasing humidity. SEM metallography indicated that the microstructures of samples tested at this condition exhibited highly polished metallic contact areas with the compacted hydrated oxide layers entrapped in noncontact areas. By increasing the load in atmospheres with ≤50% RH wear rates increased. The high wear rates were associated with the fracture and fragmentation of the edges of splats. At 50, N 0.5 m/s wear rates started to decrease above 50% RH and also the COF started to decrease. The dominant wear mechanism was a chemical-mechanical polishing process. The decrease in the wear rates started at higher relative humidity levels, e.g. 85% RH at 50 N and 2 m/s as the testing conditions became more severe.

Keywords: aluminum alloys, atmospheric humidity, carbon steel, fracture, metallographic microstructure, polishing, scanning electron microscopy, wear of materials

A. Edrisy, T. Perry, Y.T. Cheng, and A.T. Alpas, Dept. Mechanical, Automotive and Materials Engineering, Univ. Windsor, Windsor, Ontario N9B 3P4, Canada. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 571-577 [in English]. ISSN 0257-8972.

Abrasive wear resistance of plasma sprayed glass-composite coatings. A ball-milled mixture of glass and alumina powders has been plasma sprayed to produce alumina-glass composite coatings. The coatings have the unique advantage of a melted, ceramic secondary phase parallel to the surface in an aligned plateletlike-composite structure. The alumina raises the hardness from 300 HV for pure glass coatings to 900 HV for a 60 wt.% alumina-glass composite coating. The scratch resistance increases by a factor of 3, and the wear resistance increases by a factor of 5. The glass wears by the formation and intersection of cracks, while the alumina wears by fine abrasion and supports most of the sliding load. The wear resistance reaches a maximum at 40 to 50 vol.% alumina, above which there is little further improvement. This critical alumina content corresponds to the changeover from a glass to a ceramic matrix.

Keywords: abrasion, alumina, ball milling, borosilicate glass, ceramic matrix composites, hardness, microstructure, plasma spraying, powder metals, residual stresses, wear resistance

D.T. Gawne, Z. Qiu, Y. Bao, T. Zhang, and K. Zhang, School of Eng. Systems and Design, South Bank Univ., London, SE1 0AA, U.K. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 599-603 [in English]. ISSN: 1059-9630.

Improved wear performance by the incorporation of solid lubricants during thermal spraying. For components that are required to function in sliding or rubbing contact with other parts, degradation often occurs through wear due to friction between the two contacting surfaces. Depending on the nature of the materials being used, the addition of water as a lubricant may introduce corrosion and accelerate the degradation process. To improve the performance and increase the life of these components, coatings may be applied to the regions subject to the greatest wear. These coatings may be engineered to provide internal pockets of solid lubricant in order to improve the tribological performance. In the present study, coatings containing a solid lubricant were produced by thermal spraying feedstock powders consisting of a blend of tungsten carbide-metal and a fluorinated ethylene-propylene (FEP) copolymer-based material. The volume content of this Teflon-based material in the feedstock ranged from 3.5-36%. These feedstocks were deposited using a high-velocity oxyfuel (HVOF) system to produce coatings having a level of porosity below 2%. Sliding wear tests in which coated rotors were tested in contact with stationary carbon-graphite disks identified an optimal level of Teflon-based material in the feedstock formulation required to produce coatings exhibiting minimum wear. This optimal level was in the range of 7-17 vol.% and depended on the composition of the cermet constituent. Reductions in mass loss for the couples on the order of 50% (an improvement in performance by a factor of approximately 2) were obtained for the best performing compositions, as compared to couples in which the coating contained no solid lubricant.

Keywords: cermets, composition, particle size analysis, plasma spraying, porosity, powder metals, protective coatings, solid lubricants, tribology, tungsten carbide, wear of materials

B.R. Marple and J. Voyer, Industrial Materials Inst., National Research Council of Canada, Boucherville, Que., J4B 6Y4, Canada. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 626-636 [in English]. ISSN: 1059-9630.

Hardness and Viscoelastic Properties

Viscoelastic properties of plasma sprayed NiCoCrAlY coatings. A dynamic mechanical analyzer (DMA) was employed to study the damping behavior of plasma sprayed NiCoCrAlY coatings. Results revealed that at low frequencies (0.01-0.1 Hz), the coatings exhibited viscoelastic behavior (enhanced compliant elastic deformation above a certain transition temperature). At higher frequencies (1-100 Hz), anisotropic elastic behavior was observed. This observation confirmed the viscoelastic nature of the coating. A master curve for the storage modulus of NiCoCrAlY coating was successfully constructed using appropriate shift-factors. This master curve can then be used for finite-element or design analyses to provide important data input. Results also indicated that the anisotropic elastic behavior of the NiCoCrAlY coating resulted from nickel diffusion (apparent activation energy of 270 kJ/mol); however, the mechanism for the low frequency viscoelastic behavior was not clearly established.

Keywords: anisotropy, damping, diffusion in solids, dynamic mechanical analysis, elasticity, finite element method, frequencies, nickel compounds, plasma spraying, viscoelasticity

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gapore. Cited: *Thin Solid Films, 405,* 22 Feb 2002, p 146-152 [in English]. ISSN 0040-6090.

Dynamic hardness of detonation sprayed WC-Co coatings. The objective of the present work was to determine the dynamic hardness of WC-Co coatings from the dynamic hardness of the coating substrate system. It was also the purpose of this work to evaluate the influence of coating composition, coating thickness, and substrate materials on the dynamic hardness of the coating. To achieve the above-mentioned objectives, WC-12%Co and WC-17%Co coatings were deposited by detonation spraying on three different substrate materials: mild steel, commercially pure (CP) aluminum, and CP titanium. The dynamic hardness of the coating/substrate composite was evaluated by a drop-weight system. The dynamic hardness of the coating independent of the substrate was determined from the dynamic hardness of the coating/substrate composite.

Keywords: aluminum, carbon steel, composition, deformation, hardness, inorganic coatings, parameter estimation, scanning electron microscopy, strain rate, substrates, thickness measurement, titanium

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High-Velocity/Electric Arc Sprayed Coatings

Characterization of electric arc spray formed nickel superalloy IN718. Nickel superalloy IN718 has been electric arc spray formed under a range of processing conditions as small diameter ring preforms. Top surface deposition temperature has been measured using an infrared thermal imaging video camera. The as-sprayed microstructure has been investigated by a combination of optical microscopy, image analysis, and electron probe microanalysis, and characterized by the through-thickness variation in porosity, grain morphology, and microsegregation behavior. Low top surface temperature preforms had an unfused splat microstructure with intersplat porosity. Intermediate temperature preforms had banded unfused and fused splat microstructures with some cross-splat columnar grains and low levels of porosity. High-temperature preforms had banded unfused/fused splat and equiaxed grains. The extent of microsegregation depended on the manufacturing temperature.

Keywords: deposition, grain size and shape, image analysis, infrared imaging, metallographic microstructure, nickel alloys, optical microscopy, porosity, segregation (metallography), spraying, surface phenomena, thermal effects

A.P. Newberry, P.S. Grant, and M.K. Hedges, Department of Materials, Oxford Centre Advanced Materials/Composites, Oxford Univ., Oxford OX1 3PH, U.K. Cited: *Mater. Sci. Eng. A, 326*(1), 15 March 2002, p 79-91 [in English]. ISSN 0921-5093.

Study on microstructure and properties of high-velocity arc sprayed Fe_3Al intermetallic coating. Coating structural materials with Fe_3Al based intermetallics may rapidly lead to industrial application of their environment and wear-resistant features. High-velocity arc spraying (HVAS) was used to in situ synthesize Fe_3Al intermetallic coating. The microstructural characterization and properties of the coating have been investigated. The microstructure was found to consist of Fe_3Al-based intermetallic (DO_3 and $B2$) and αFe regions together with fine oxide (αAl_2O_3 layers). Transmission electron microscopy images of coating show that the solidified lamellas are polycrystalline and have a grain size of the order of about 150 nm, and there also exists amorphous state in some areas. It can be concluded that a very high cooling rate has been obtained during HVAS process. Moreover, the coating has relatively higher adhesion strength and microhardness, as well as lower density and porosity.

Keywords: intermetallics, iron alloys, microhardness, microstructure, transmission electron microscopy, wear resistance

Z. Zhu, B. Xu, S. Ma, and Z. Du, School of Materials Science and Engineering, Tianjin Univ., Tianjin 300072, China. Cited: *Chin. Weld. (English Edition), 11*(1), May 2002, p 1-4 [in English]. ISSN 1004-5341.

High-Velocity Oxyfuel and Laser-Glazed Coatings

High-temperature oxidation behavior of HVOF-sprayed unreinforced and reinforced molybdenum disilicide powders. Intermetallics such as silicides are useful for protective coatings against high-temperature corrosion. Especially molybdenum disilicide, which has a great potential as protective coating, e.g., in aircraft engines and gas turbines in the temperature range between 1400 and 1800 °C due to its high melting point and its low brittle-ductile transition temperature of approximately 800-1100 °C. Four types of coatings were produced by high-velocity oxyfuel spraying (HVOF): Unreinforced $MoSi_2$ with low porosity, unreinforced $MoSi_2$ with high porosity, with silicon carbide reinforced $MoSi_2$ and with alumina reinforced $MoSi_2$. The coatings as sprayed were characterized by XRD, SEM and EDX. Microhardness and porosity were measured. The oxidation behavior of the coatings was determined at 500, 1000, and 1500 °C. The influence of the heating rate was investigated during oxidation tests at 1000 °C. The tests at 500 °C showed that the pesting depends on the porosity of the coating. SiC as reinforcing phase seems to accelerate pesting, while alumina reduces this reaction. Unreinforced $MoSi_2$ coatings form a protective SiO_2 layer on the surface with a thickness below 10 µm during oxidation at 1500 °C. The layer seems to be glassy with cristobalite inclusions. The microstructure of the coating changes to a high crystalline two-phase system of $\alpha MoSi_2$ and hexagonal Mo_5Si_3.

Keywords: corrosion, crystal microstructure, energy dispersive spectroscopy, intermetallics, microhardness, phase transitions, porosity, powders, protective coatings, scanning electron microscopy, silicon compounds, spraying, thermooxidation, x-ray diffraction analysis

G. Reisel, B. Wielage, S. Steinhauser, I. Morgenthal, and R. Scholl, Inst. Composite Mat. Surface Tech., Technical Univ. Chemnitz, Chemnitz 09107, Germany. Cited: *Surf. Coat. Technol., 146-147,* Sept/Oct 2001, p 19-26 [in English]. ISSN: 0257-8972.

High-Velocity Oxyfuel Microstructures

Microstructure and stresses in high-velocity oxyfuel sprayed iron aluminide coatings. The microstructure and state of stress present in Fe_3Al coatings produced by high-velocity oxyfuel (HVOF) thermal spraying in air at varying particle velocities were characterized using metallography, curvature measurements, x-ray analysis, and microhardness measurements. Sound coatings were produced for all conditions. The microstructures of coatings prepared at higher velocities showed fewer unmelted particles and a greater extent of deformation. Residual stresses in the coatings were compressive and varied from nearly zero at the lowest velocity to approximately –450 MPa at the highest velocity. X-ray line broadening analyses revealed a corresponding increase in the extent of cold work present in the coating, which was also reflected in increased microhardness. Values of mean coefficient of thermal expansion obtained for as-sprayed coatings using x-ray analysis were significantly lower than those for powder and bulk alloy.

Keywords: characterization, deformation, iron compounds, metallography, microhardness, microstructure, residual stresses, shot peening, stress analysis, thermal expansion, x-ray analysis, x-ray diffraction analysis

T.C. Totemeier, R.N. Wright, and W.D. Swank, Idaho National Engineering and Environmental Lab., Bechtel BWXT Idaho, LLC, Idaho Falls, ID 83415. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 400-408 [in English]. ISSN 1059-9630.

Shock-induced transformations in hexagonal boron nitride by high-velocity thermal spray. Shock synthesis of cubic BN (c-BN) was accomplished using high-velocity thermal spray. Al-8Si-20BN (hexagonal BN, h-BN) composite powders were injected into a high-energy flame where the particles partially melted and accelerated to impact on steel substrates. The shock wave generated by the sudden impact of the droplets propagated through the underlying deposit, which experienced a polymorphic transition to high-pressure forms. Transmission electron microscopy revealed that the deposits contained platelike c-BN embedded in h-BN. The Hugoniot pressure calculation suggested that the impact pressure was sufficient to trigger the nucleation of c-BN.

Keywords: combustion, delamination, grain size and shape, nucleation, phase transitions, substrates, synthesis (chemical), transmission electron microscopy

R. Goswami, H. Herman, S. Sampath, J. Parise, Y. Zhu, and D. Welch, Center for Thermal Spray Research, Dept. Materials Science and Engineering, State Univ. New York, Stony Brook, NY. Cited: *J. Am. Ceram. Soc., 85*(10), Oct 2002, p 2437-2443 [in English]. ISSN 0002-7820.

Dominant effect of carbide rebounding on the carbon loss during high-velocity oxyfuel spraying of Cr_3C_2-NiCr. Cr_3C_2-25% NiCr coatings were deposited by high-velocity oxyfuel (HVOF) spraying process using two commercial powders. The microstructure of the deposited coating was characterized by scanning electron microscopy. The carbon contents in both the deposited coatings and the collected powders were characterized by chemical analysis to clarify the main mechanism controlling the carbon loss during deposition of Cr_3C_2-NiCr coating by HVOF spraying. The results revealed that the carbon loss in the collected powders was much lower than that in the coatings. A model involved in a solid-liquid two-phase particle deposition behavior and rebound-off of large carbide particles during splatting was proposed to explain the effect of droplet conditions including carbide particle size on the carbon loss during deposition of Cr_3C_2-NiCr. It was suggested that the rebound-off of larger carbide particles when the two-phase droplet impacts on the surface is main mechanism responsible for overall high carbon loss during HVOF spraying of Cr_3C_2-NiCr.

Keywords: carbon, decarburization, deposition, microstructure, nickel compounds, particle size analysis, scanning electron microscopy, spraying

C.-J. Li, G.-C. Ji, Y.-Y. Wang, and K. Sonoya, Welding Research Inst., School of Mechanical Engineering, Xi'an Jiaotong Univ., Xi'an, Shaanxi, China. Cited: *Thin Solid Films, 419*(1-2), 1 Nov 2002, p 137-143 [in English]. ISSN 0040-6090.

Experimental study effects of thermal spray procedure and thermal fatigue on microstructure and properties of NiCrAlMoFe coating. This study deals with the behavior of a nickel-base alloy, NiCrMoAlFe, which was thermally sprayed, using flame, plasma, high-velocity oxyfuel (HVOF), and high-

frequency pulse detonation (HFPD) methods, onto a stainless steel substrate. This alloy is used as a coating for heat transfer and structural elements in high-temperature regions of boilers, such as superheater and reheater tubes. The microstructure, porosity, oxide content, and microhardness of the various coatings were determined. Thermal fatigue tests, under an atmosphere similar to that of power-plant service conditions, were conducted in an experimental combustion chamber and, finally, the adhesion between the substrate and the coating layer was evaluated by means of tensile tests. The results obtained are discussed, with special attention being paid to the specific characteristics of the various spraying procedures.

Keywords: adhesion, fatigue of materials, microhardness, microstructure, nickel alloys, plasma spraying, porosity, stainless steel, substrates, tensile testing

V. Higuera Hidalgo, J. Belzunce Varela, A. Carriles Menendez, and S. Poveda Martinez, Energy Dept., Univ. Oviedo, Campus Univ., 33203 Gijon, Asturias, Spain. Cited: *Surf. Eng., 17*(6), 2001, p 512-517 [in English]. ISSN 0267-0844.

Research of coatings properties deposited with HVOF. The properties of WC-Co and NiCrBSi coatings deposited with HVOF, such as adhesion, residual stress, microstructure, porosity, microhardness, and wear resistance, are studied and analyzed. With the modified Almen test, the reliable residual stress in a thermal sprayed coating is obtained, and the relationships between the residual stress and coating thickness or spray techniques are also presented. The single pendulum impact scratch test is used to measure the adhesion of a thermal sprayed coating.

Keywords: adhesion, impact testing, microhardness, microstructure, porosity, residual stresses, wear resistance

Z. Wang, Z. Dong, S. Huo, L. Li, and G. Wang, Harbin Res. Inst. of Welding, Harbin 150080, China. Cited: *Jixie Gongcheng Xuebao/Chin. J. Mech. Eng., 37*(11), Nov 2001, p 96-98 [in Chinese]. ISSN: 0577-6686.

Hydroxyapatite Biomaterial

Acceleration of bonelike crystal growth on polarized plasma sprayed HAp in SBF. Polarizability and bioactivity of the plasma sprayed hydroxyapatite (HAp: $Ca_{10}(PO_4)_6(OH)_2$) coatings were estimated from electromagnetism and material science views in this study. The HAp is well known as a highly bioactive ceramic. HAp coatings prepared by plasma spray method were applied to orthopedic and stomatologic implants. The authors reported that the HAp ceramics were electrically polarizable and that the negatively charged surface enhanced its bioactivity and osteoconductivity. Moreover, it was clarified that the HAp stored electrical charges over six months. However, the polarized HAp bulk ceramics cannot be used as implants owing to their low mechanical strength. Thereupon the authors aimed at the application of the polarization to plasma sprayed HAp. The polarizability of the plasma sprayed HAp was confirmed by thermally stimulated depolarization current measurements. The calculated stored polarization charge was 62.3 $\mu C/cm^2$. The surface morphology of polarized plasma sprayed HAp after immersion in simulated body fluid (SBF) showed that crystals growth on the negatively charged surface was accelerated as well as HAp ceramics.

Keywords: acceleration, body fluids, ceramic materials, electric charge, electromagnetism, hydroxyapatite, morphology, plasma spraying, polarization

R. Kato, S. Nakamura, K. Katayama, and K. Yamashita, Inst. Biomaterials and Bioeng., Tokyo Medical and Dental Univ., Chiyoda, Tokyo 101-0062, Japan. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 145-148 [in English]. ISSN 1013-9826.

Osteoconduction of polarized hydroxyapatite plasma spray coating titanium. Acceleration and deceleration of bonelike crystal growth on electrically polarized HAp ceramics are induced by their surface changes in simulated body fluid, as recently reported by Yamashita et al. In this study, new bone-forming ability of electrically polarized HAp-coated implants was physicochemically characterized and histologically evaluated using femora and tibiae of beagle dogs. Electrical polarizability of the plasma sprayed HAp coatings on titanium was demonstrated by thermally stimulated current (TSC) measurement. The HAp-coated titanium was electrically polarized in a direct current field of 1 kV/cm at 400 °C. The electrical storage of the polarized HAp coatings was clearly detected by TSC measurement. No significant difference between the polarized and nonpolarized hydroxyapatite was recognized by infrared spectroscopy and x-ray diffractometory. The biological reactions of the polarized HAp coatings were histologically investigated. Negatively charged HAp surface exhibited enhanced osteoconduction with direct bone contacting in early stage. The polarized HAp ceramics shortened the period for healing time after operations by ½ compared with nonpolarized HAp.

Keywords: body fluids, ceramic materials, electric charge, implants (surgical), infrared spectroscopy, plasma spraying, polarization, sprayed coatings, titanium, x-ray diffraction analysis

H. Sagawa, T. Kobayashi, R. Kato, S. Nakamura, and K. Yamashita, Tokyo Medical and Dental Univ., Inst. Biomaterials and Bioengineering, Chiyoda, Tokyo 101-0062, Japan. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 199-202 [in English]. ISSN 1013-9826.

Coating of hydroxyapatite films on ceria-stabilized tetragonal zirconia by a spray-pyrolysis technique and its evaluation of biocompatibility by osteoblastic cells. The porous hydroxyapatite (HAp) films were formed on the Ce-TZP/alumina substrate by the spray pyrolysis technique. The biocompatibility of the resulting HAp films were examined using osteoblastic cell. Twenty-five types of the coatings were carried out by changing the combination of solutions for film adhesion (CMP solution) and solution for film formation. The adhesion properties of the resulting calcium-phosphate films were qualitatively examined. The results indicated that the adhesion strength increased the concentration of CMP solution.

Keywords: adhesion, alumina, biocompatibility, cell culture, ceramic materials, elastic moduli, nanostructured materials, polycrystals, porous materials, pyrolysis, scanning electron microscopy, x-ray diffraction analysis, zirconia

W. Nishine, M. Aizawa, M. Nawa, K. Itatani, H. Suemasu, A. Nozue, and I. Okada, Faculty of Science and Engineering, Sophia Univ., Tokyo 102-8554, Japan. Cited: 14th Int. Symposium on Ceramics in Medicine, BIOCERAMICS'01 (ISCM), 14-17 2001 (Palm Springs, CA), S. Brown, L. Clarke, and P. Williams, Ed., International Society for Ceramics in Medicine, *Key Eng. Mater., 218-220,* 2002, p 213-216 [in English]. ISSN 1013-9826.

Properties of heat treated calcium phosphate coatings deposited by high-velocity oxyfuel (HVOF) spray. The influence of crystallization, upon heat treatment, on the properties of high-velocity oxyfuel (HVOF) sprayed hydroxyapatite (HA) coatings was investigated. The characterization of the HA coating was performed by x-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). Differential scanning calorimeter (DSC) was employed to determine the crystallization temperature of the amorphous phase in an as-sprayed HA coating. The study demonstrated the effect of crystallization on the coating properties by considering the changes in materials chemistry, crystallinity level, and mechanical performance. Results showed that complete crystallization of the amorphous phase occurred at approximately 700 °C, and the crystallization temperature was dependent on sample heating rate in the DSC test. The changes of ion groups were detected by FTIR, before and after the phase transformation. The crystallization of the coating after annealing at 750 °C resulted in a significant increase of the coatings' adhesive strength and shear strength, which attained maximum values 34 ± 3 and 14.1 ± 0.8 MPa, respectively. Young's modulus increased from 21 ± 1 to 25 ± 2 GPa. Microhardness measurements confirmed the changes in coating properties. It is also found that the transformation from the amorphous phase has crystalline HA as the only resultant phase detected by XRD.

Keywords: adhesion, annealing, calcium compounds, crystallization, differential scanning calorimetry, hydroxyapatite, infrared spectroscopy, microhardness, phase transitions, shear strength, x-ray diffraction analysis

H. Li, K.A. Khor, and P. Cheang, School of Mechanical/Production Engineering, School of Materials Engineering, Nanyang Technological Univ., Singapore 639798, Singapore. Cited: *Biomaterials, 23*(10), 2002, p 2105-2112 [in English]. ISSN 0142-9612.

A functionally graded titanium/hydroxyapatite film obtained by sputtering. A functionally graded film of titanium/hydroxyapatite (HA) was prepared on a titanium substrate using a radiofrequency magnetron sputtering. The ratio of titanium to HA was controlled by moving the target shutter. The film was composed of five layers, with overall film thickness of 1 μm. The HA was concentrated close to the surface, while the titanium concentration increased with proximity to the substrate. The bonding strength between the film and the substrate was 15.2 MPa in a pullout test and the critical load from a scratch test was 58.85 mN. The corresponding values of a pure HA sputtered film were 8.0 MPa and 38.47 mN, respectively. The bonding strength of a pure HA plasma spray coating was 10.4 MPa in the pullout test. The graded film and the pure HA film were sputter-coated to a thickness of 1 μm on titanium columns (10 mm in length and 4 mm in diameter). These columns were implanted in diaphyses of the femora of six adult dogs and a pushout test was carried out after 2, 4, and 12 weeks. After 12 weeks, the pushout strengths of the graded film, the pure HA film and the noncoated columns were 3.7, 3.5, and 1.0 MPa.

Keywords: bond strength (materials), functionally graded materials, hydroxyapatite, magnetron sputtering, plasma spraying, sputter deposition, substrates, titanium

K. Ozeki, T. Yuhta, Y. Fukui, H. Aoki, and I. Nishimura, Applied Systems Engineering, Graduate School of Science and Engineering, Tokyo Denki Univ., Hiki, Saitama 350-0394, Japan. Cited: *J. Mater. Sci.: Mater. Med., 13*(3), 2002, p 253-258 [in English]. ISSN 0957-4530.

Hydroxyapatite-coated Ti-6Al-4V: part 2: The effects of postdeposition heat treatment at low temperatures. The present investigation explores the effects of a 90 h postdeposition annealing treatment at 400 °C in air on the crystallographic and chemical properties of a plasma sprayed hydroxyapatite (HA) coating, the thickness and composition of the interfacial oxide layer, and the fatigue behavior of the underlying Ti-6Al-4V substrate. X-ray diffraction analysis revealed that significant recovery of the crystalline HA structure oc-

curred as a result of the treatment; however, as compared with results obtained through treatment at higher temperatures, recovery obtained through use of the present treatment was incomplete. X-ray photoelectron spectroscopy analysis showed no changes in the constituents of the oxide layer, with the oxide species TiO_2, Al_2O_3, V_2O_5, V_2O_3, and VO_2 present on both the as-sprayed and the heat treated substrates. A change in film thickness was observed, however, as evidenced by a change in color from opaque bronze to dark purple. The fatigue resistance of the substrate was found to be significantly reduced by the heat treatment, with the lives of heat treated coupons with coatings of all thicknesses closely resembling those of as-sprayed coupons with thick HA coatings and uncoated stress-relieved coupons presented in part 1 of this study. Stress relief was identified as the most likely cause of these reductions.

Keywords: annealing, crystal structure, crystallography, deposition, fatigue of materials, heat treatment, organic coatings, plasma spraying, sprayed coatings, stresses, substrates, titanium compounds, x-ray diffraction analysis, x-ray photoelectron spectroscopy

A.K. Lynn and D.L. DuQuesnay, Dept. Mechanical Engineering, Royal Military College of Canada, Kingston, Ont. K7K 7B4, Canada. Cited: *Biomaterials, 23*(9), 2002, p 1947-1953 [in English]. ISSN 0142-9612.

Hydroxyapatite-coated Ti-6Al-4V: part 1: The effect of coating thickness on mechanical fatigue behavior. The present investigation examines the effect of coating thickness on the fatigue behavior of hydroxyapatite (HA)-coated Ti-6Al-4V. Uniaxial fatigue tests were conducted on grit-blasted Ti-6Al-4V coupons with HA coatings deposited by atmospheric plasma spray at thicknesses of 0, 25, 50, 75, 100, and 150 μm, as well as on grit-blasted specimens that had received a stress-relieving heat treatment. Coupons with 150 μm HA coatings were shown to have significantly decreased fatigue resistances, with lives similar to those of the stress-relieved specimens, while coatings of thickness 25-100 μm were found to have no affect on fatigue resistance. Residual stresses generated during deposition, cracks propagating toward the substrate from within the coating, and stress relief due to heat inputs from the spraying process were all considered with respect to their potential effects on fatigue behavior. Stress relief in the substrate due to enhanced heat-transfer mechanisms was identified as the most likely source of the observed reductions in substrate fatigue life in the 150 μm coupons.

Keywords: coating techniques, crack propagation, deposition, fatigue of materials, heat transfer, heat treatment, hydroxyapatite, plasma spraying, residual stresses, substrates

A.K. Lynn and D.L. DuQuesnay, Dept. Mechanical Engineering, Royal Military College of Canada, Kingston, Ont. K7K 7B4, Canada. Cited: *Biomaterials,* 23(9), 2002, p 1937-1946 [in English]. ISSN 0142-9612.

The contribution of coating microstructure to degradation and particle release in hydroxyapatite coated prostheses. Plasma sprayed coatings of hydroxyapatite powder are widely used on hip replacements. Commercially, they are supplied by a large number of companies and thus offer different coating design philosophies. This study focuses on a retrieved prosthetic stem that exhibited coating loss on the femoral stem occurring concurrently with third-body wear. The purpose of the research was to establish possible links between the coating microstructure and the clinical findings. A coated stem and cup were sectioned and the cross section was prepared to reveal the coating microstructure. Characterization included x-ray diffraction, FTIR spectroscopy, and crystalline particle quantification within the coating. It was found that the coating has a high amorphous content that provides fast resorption. The amount of crystalline particles increased on the distal location of the stem and the threads of the acetabular shell and was generally higher on the cup. Accelerated degradation illustrated how the coating may be a particle-generating source by preferential dissolution of the amorphous phase, possibly allowing liberation of crystalline areas and other particulates at the substrate-coating interface. Such particles mainly include the less-soluble hydroxyapatite formed from unmelted particles in the plasma or recrystallization in the coating, but may also include entrapped grit lodged in the substrate during the roughening process. This study accents the importance of coating microstructure in understanding coating resorption.

Keywords: crystal microstructure, crystallization, degradation, dissolution, Fourier transform infrared spectroscopy, plasma spraying, sprayed coatings, x-ray diffraction analysis

K.A. Gross, N. Ray, and M. Rokkum, School of Physics and Materials Engineering, Monash Univ., Clayton, Vic. 3800, Australia. Cited: *J. Biomed. Mater. Res., 63*(2), 2002, p 106-114 [in English]. ISSN 0021-9304.

The cell attachment and morphology of neonatal rat calvarial osteoblasts on the surface of Ti-6Al-4V and plasma sprayed HA coating: effect of surface roughness and serum contents. The biocompatibility of material plays an important role in the bone-implant interface for the prosthetic implant fixation. The biocompatibility of implants is associated with the chemical composition, surface topography, surface energy, and surface roughness of biomaterials. The effects of two factors, surface roughness and serum contents, on osteoblast behavior at the surface of Ti-6Al-4V and plasma sprayed HA coating were investigated in the experiment. The osteoblasts derived from neonatal rat calvarial were cultured in Dulbecco's modified Eagle medium (DMEM) with fetal bovine serum (FBS) on the surface of polished Ti-6Al-4V (Ti-p), grit-blasted Ti-6Al-4V (Ti-b), polished HA coating (HAC-p), and as-sprayed HA coating (HAC). Under culture medium containing 4% FBS, the level of cell attachment to the polished surface is significantly higher than the rough surface of the same experimental materials during all culture periods. Increasing the contents of FBS up to 10%, the difference of osteoblast attachment is not found between Ti-p and Ti-b. Under 4% serum condition, the cell morphology attached to smooth surfaces (Ti-p and HAC-p) is spread faster and are more flattened than the one to rough surface of the same experimental materials by SEM. After 24 h culture, the corroded cracks are easily observed at the surface of polished HA coatings, and the cell morphology on HAC-p coatings are elongated and less flattened compared with Ti-p. The result is consistent with statistical difference of cell attachment between Ti-p and HAC-p under 4% serum condition.

Keywords: biocompatibility, composition, implants (surgical), morphology, plasma spraying, prosthetics, statistical methods, surface roughness

T.M. Lee, R.S. Tsai, E. Chang, C.Y. Yang, and M.R. Yang, Dept. Orthopedics, National Cheng Kung Univ. Medical Center, Tainan, Taiwan. Cited: *J. Mater. Sci.: Mater. Med., 13*(4), 2002, p 341-350 [in English]. ISSN 0957-4530.

Plasma sprayed hydroxyapatite coating on titanium alloy with ZrO_2 second phase and ZrO_2 intermediate layer. The cohesive and adhesive strengths of plasma sprayed hydroxyapatite (HA) coatings were strengthened by, respectively, adding ZrO_2 particles as a reinforcing second-phase (HA+ZrO_2 composite coating), and using an intermediate ZrO_2 layer between the HA coating and the titanium alloy substrate as a bond coat (two-layer HA/ZrO_2 coating). The phase contents and microstructure of the plasma sprayed coatings were investigated by x-ray diffractometry, scanning electron microscopy, and transmission electron microscopy. The surface roughness of the grit-blasted titanium alloy and the ZrO_2 bond coat was measured by a surface recorder. Results indicate that the bond strength of the HA coatings increases from 28.6 ± 3.2 MPa for HA coating to 32.5 ± 4.2 MPa and 36.2 ± 3.0 MPa for HA+ZrO_2 and two-layer HA/ZrO_2 coatings, respectively. It was found that the interface between the HA coating and the titanium alloy is a site of critical weakness when compared to the cohesive strength of the interlamellar and intralamellar structure of the HA coating. The strengthening mechanisms of the two systems are discussed.

Keywords: composite materials, hydroxyapatite, microstructure, plasma spraying ,scanning electron microscopy, substrates, surface roughness, titanium alloys, transmission electron microscopy, x-ray diffraction analysis, zirconia

B.-Y. Chou and E. Chang, Dept. Mater. Sci. Eng., National Cheng Kung Univ., Tainan 701, Taiwan. Cited: *Surf. Coat. Technol., 153*(1), 1 April 2002, p 84-92 [in English]. ISSN 0257-8972.

In vitro behavior of albumin-loaded carbonate hydroxyapatite gel. Hydroxyapatite (HA) powder, porous HA, plasma sprayed HA, apatite cements, and sintered HA have all been investigated as delivery systems for compounds such as human growth hormone and vancomycin. However, many previous studies showed that the period of release was limited to 2-3 weeks. The concept of using a nanoporous matrix as a means of immobilizing proteins is well known, but has largely been confined to silica-based systems. Carbonate hydroxyapatite (CHA) is more soluble in vivo than HA, and when formed as an aqueous precipitate it is often formed as nanocrystals. This study investigated the release profiles of ovine albumin (OVA) from CHA gel stored in phosphate-buffered saline (PBS) and double distilled water (DDW) for times of up to 1 year. It was found that 7.9% OVA could be loaded onto apatitic gels by means of a purely aqueous process. This process provided a simple low-temperature method of protein adsorption on a high surface area apatitic matrix at physiological pH. The rate of short-term release of OVA was lower from CHA gels than from microcrystalline HA powder. However, the period of release from the CHA gel was short term and may have been associated with recrystallization of the gel. OVA loaded into CHA gel was found to remain undegraded in vitro at 37 °C for periods of up to 1 year.

Keywords: adsorption, carbonates, gels, hormones, low temperature phenomena, pH effects, plasma spraying, proteins

J.E. Barralet, S. Aldred, A.J. Wright, and A.G.A. Coombe, Biomaterials Unit, School of Dentistry, Univ. Birmingham, Birmingham B4 6NN, U.K. Cited: *J. Biomed. Mater. Res., 60*(3), 5 June 2002, p 360-367 [in English]. ISSN 0021-9304.

Novel double layer hydroxyapatite (HA)/Ti coating for biocompatibility improvement of metallic implants. A novel double-layer composite coating composed of a hydroxyapatite (HA) top layer and a single titanium (Ti) underlayer on 316L stainless steel was formed using plasma spraying and physical vapor deposition processes, respectively. Structural characterization techniques, including XRD, SEM, and EDX, were used to investigate the microstructure, morphology, and crystallinity of the coating. Corrosion behavior of the coated specimens, as an indication of biocompatibility, was also evaluated. Electrochemical potentiodynamic tests were performed in physiological solutions. The results indicate that the double-layer HA/Ti coating on 316L stainless steel has a positive effect on the corrosion resistance. The decrease in

corrosion current density was significant for these coated specimens and was much lower than the values obtained for uncoated and single HA coated specimens. These results have been compared with the results of the corrosion behavior of HA coated and uncoated commercially pure titanium and cobalt-chromium alloys.

Keywords: biocompatibility, corrosion resistance, current density, energy dispersive spectroscopy, implants (surgical), microstructure, morphology, physical vapor deposition, plasma spraying, scanning electron microscopy, sprayed coatings, stainless steel, x-ray diffraction analysis

M.H. Fathi, M. Salehi, A. Saatchi, V. Mortazavi, and S.B. Moosavi, Materials Engineering Dept., Isfahan Univ. Technology, Isfahan 84154, Iran. Cited: *Surf. Eng., 17*(6), 2001, p 459-464 [in English]. ISSN 0267-0844.

Maxillofacial implants of polarized hydroxyapatite plasma spray-coating titanium. Electrical polarizability of plasma sprayed hydroxyapatite (HAp) coatings on titanium was demonstrated by thermally stimulated current (TSC) measurement. The biological reactions of the polarized HAp coatings were histologically investigated. The HAp coated titanium was electrically polarized in a direct-current field of 1 kV/cm at 400 °C. The electrical storage of the polarized HAp coatings was clearly detected by TSC measurement. Negatively charged HAp surface exhibited enhanced osteogenesis with direct bone contacting in early stage. The polarized HAp ceramics shortened the period for healing time after operations by ½ compared with nonpolarized HAp.

Keywords: bone, coatings, electric fields, histology, hydroxyapatite, titanium

H. Sagawa, T. Kobayashi, T. Sakai, M. Ueshima, S. Nakamura, and K. Yamashita, Inst. Biomaterials Bioengineering, Tokyo Medical and Dental Univ., Chiyoda, Tokyo, 101-0062, Japan. Cited: *Biomaterials for Drug Delivery and Tissue Engineering* (Conf. Proc.), 27-29 Nov 2000 (Boston, MA), Vol 662, S. Mallapragada, M. Tracy, B. Narasimhan, E. Mathiowitz, and R. Korsmeyer, Ed., Materials Research Society, 2001, p LL2.9.1-LL2.9.5 [in English]. ISSN: 0272-9172.

Influence of Spray Parameters

The role of starting powder size on the compressive response of standalone plasma sprayed alumina coatings. Cylindrical standalone tubes of plasma sprayed alumina were tested in uniaxial compression at room temperature, using strain gages to monitor axial strains. The effect of lamella size on the mechanical response was investigated by employing different starting powders to fabricate samples. The average powder sizes investigated included 9, 19, and 32 μm alumina; the resulting effective lamella diameters were 10, 28, and 55 μm, respectively. Similar stress-strain hysteresis was observed on unloading in all tubes, independent of lamella size. A strong correlation between the failure stress and the cumulative strain at failure was also observed for tubes fabricated from the three powders. For samples with approximately constant densities, tubes plasma sprayed with the 9 μm powder exhibited greater moduli than tubes sprayed from either 19 or 32 μm powders. This difference was attributed to the greater percentage of unmelted αAl_2O_3 in the coating.

Keywords: compaction, failure (mechanical), plasma spraying, powders, strain, strain gages, stresses, temperature

R.W. Trice, C. Batson, C. Scharff, and K.T. Faber, Purdue Univ., School of Materials Engineering, West Lafayette, IN 47907. Cited: *J. Mater. Sci., 37*(3), 1 Feb 2002, p 629-636 [in English]. ISSN 0022-2461.

Influence of the thermal spray procedure on the properties of a nickel-chromium coating. A modified NiCr coating was thermal spray projected using different procedures (flame, plasma, HVOF, and HFPD) onto stainless steel specimens. This type of coating is normally used as protection against heat, corrosion, and erosion actions encountered in superheater and reheater tubes in power-plant boilers. The microstructures, porosities, oxide contents, and microhardnesses of the coatings were determined. Thermal fatigue tests under an atmosphere similar to power-plant service conditions were conducted in an experimental combustion chamber and, finally, the adhesion between the substrate and the coating layer was evaluated by means of tensile tests. The results obtained are discussed, with special attention being paid to the specific characteristics of the different spraying procedures.

Keywords: chemical modification, chromium, composition, microhardness, microstructure, nickel, oxides, porosity, protective coatings, stainless steel, tensile testing

V. Higuera, F.J. Belzunce, A. Carriles, and S. Poveda, Univ. Oviedo, Campus Univ., 33203 Gijon, Spain. Cited: *J. Mater. Sci., 37*(3), 1 Feb 2002, p 649-654 [in English]. ISSN 0022-2461.

Influence of solidification and wetting on flattening behavior of plasma sprayed ceramic particles. In this study, the influence of both solidification and wetting at the splat/substrate interface on the flattening behavior of the plasma sprayed ceramic panicles was investigated. Commercially available ceramic powders were sprayed and collected onto a substrate, which was mirror polished, plasma vapor deposition coated and preheated before spraying. Transition temperature, T_t, was decided from the observation of the splat morphology. While the bottom part of the splat solidified at the substrate temperature nearby T_t, the solidification on the bottom surface of the splat was not always the necessary condition for the splashing. The wetting at splat/substrate interface seems to be the most dominant factor on the flattening of the thermal sprayed ceramic particles.

Keywords: interfaces (materials), morphology, physical vapor deposition, plasma spraying, rapid solidification, substrates, thermal effects, wetting

Y. Tanaka and M. Fukumoto, Ariake Natl. College of Technology, Omuta, Fukuoka 836-8585, Japan. Cited: *Int. J. Mater. Prod. Technol., 2* (special issue), 2001, p 518-523 [in English]. ISSN 0268-1900.

Effect of wetting at splat/substrate interface on the flattening behavior of a freely fallen droplet. A free-falling experiment of a copper metal droplet was conducted as a simulation to a thermal spray. Previous results showed that a bottom surface microstructure of the splat strongly corresponds to the resultant splat morphology. In order to understand the effect of a wetting at the splat/substrate interface on the flattening behavior of the freely fallen metal droplet, the bottom surface microstructure and a grain size in a cross section of the splats obtained on the substrate of various temperatures were investigated.

Keywords: computer simulation, grain size and shape, interfaces (materials), metallographic microstructure, morphology, spraying, substrates, thermal effects, wetting

E. Nishioka, T. Matsubara, and M. Fukumoto, Toyohashi Univ. Technology, Toyohashi, Aichi 441-8580, Japan. Cited: *Int. J. Mater. Prod. Technol., 2* (special issue), 2001, p 700-705 [in English]. ISSN 0268-1900.

Atomization and particle-jet interactions in the wire arc spraying process. The wire arc spraying process, one of several thermal spray processes, has gained a sizable part of the thermal spray market. However, better control is needed for this process to be used for applications of high-precision coatings. This study is aimed at investigating the liquid-metal droplet formation process in order to identify methods for droplet trajectory control. A high speed Kodak imaging system has been used to observe the droplet formation for different operating conditions. Decreasing the upstream pressure and the current levels leads to a reduction in the asymmetric melting of both the anode and cathode. By decreasing the interactions of the large eddy structures with the formed metal agglomerates, one can achieve better control of the particle trajectories and jet divergence. Thus, coatings can be obtained with higher definition and improved reliability.

Keywords: anodes, cathodes, liquid metals, melting, nozzles, particle size analysis, plasma jets, plasma spraying, plasma torches, sprayed coatings

N.A. Hussary and J.V.R. Heberlein, Dept. Mechanical Engineering, Univ. Minnesota, Minneapolis, MN 55455. Cited: *J. Therm. Spray Technol., 10*(4), Dec 2001, p 604-610 [in English]. ISSN: 1059-9630.

The influence of plasma composition on the properties of plasma treated biomaterials. Metals and polymers of biological interests were subjected to different plasmas and characterization techniques. The properties of treated materials were found to be very dependent on plasma conditions. The results indicate that CH_4 plasmas are very suitable for the treatment of both kinds of biomaterials. Under ion bombardment in plasma immersion ion implantation (PIII) experiments, they provided hard protective coatings for metals. In addition, stable low contact angles were obtained.

Keywords: biocompatibility, biomedical equipment, corrosion resistance, hydrophobicity, nylon polymers, plasmas, polytetrafluoroethylenes, polyurethanes, silicones

N.C. Cruz, E.C. Rangel, G.Z. Gadioli, R.P. Mota, R.Y. Honda, M.A. Algatti, and W.H. Schreiner, Lab. de Interfaces e Filmes Finos, Dept. Fisica, UFPR, 81531-990. Curitiba, PR, Brazil. Cited: *Mechanisms of Surface and Microstructure Evolution in Deposited Films and Structures* (Conf. Proc.), 17-20 April 2001 (San Francisco, CA), Vol 672, J. Amar, G. Gilmer, M.V. Ramana Murty, and J. Sanchez, Jr., Ed., Materials Research Society, p O3.35.1-O3.35.6 [in English]. ISSN: 0272-9172.

Nanostructured Coatings

Determination of the mechanical properties of nanocrystalline iron-chromium-base thermal spray coatings. Thermal spraying has been developed as an advanced coating process, which allows the generation of non-equilibrium microstructures due to its high cooling rates. Recently, this process has become of growing interest in industrial applications. The microstructure of three iron-chromium-base coatings deposited by twin wire arc spraying (TWAS) and high-velocity oxyfuel (HVOF) process has been investigated by x-ray diffraction (XRD), transmission electron microscopy (TEM), and scanning electron microscopy (SEM) and has been found to contain nanocrystals of about 20 nm in diameter. Characteristic differences in microstructure can be found in porosity and oxide content due to different particle velocities in both coating processes. The application of these coatings is dependent on the knowledge of the mechanical design parameters such as Young's modulus, yield stress, ultimate tensile strength (UTS), and fatigue behavior. These values have been investigated in a static and a dynamic three-point bending test. It has been found that the porous TWAS sprayed FeCr13 coating has an effective elastic modulus in the range of bulk aluminum alloys, whereas dense HVOF coatings show nearly the expected value of cast iron alloys.

Keywords: elastic moduli, fatigue of materials, iron alloys, microstructure, nanostructured materials, porosity, scanning electron microscopy, tensile strength, transmission electron microscopy, x-ray diffraction analysis, yield stress

G. Burkle, F. Banhart, A. Sagel, C. Wanke, G. Croopnick, and H.-J. Fecht, Center for Micro- and Nanomaterials, Univ. Ulm, DE-89081 Ulm, Germany. Cited: Proc. Int. Symposium on Metastable, Mechanically Alloyed and Noncrystalline Materials (ISMANAM), 24-29 June 2001 (Ann Arbor, MI), *Mater. Sci. Forum, 386-388,* 2002, p 571-576 [in English]. ISSN 0255-5476.

Near-nanostructured WC-18 pct Co coatings with low amounts of non-WC carbide phase: part II. Hardness and resistance to sliding and abrasive wear. The authors investigated the mechanical properties, microstructure, and tribological performance of high-velocity oxyfuel (HVOF) deposited WC-18%Co coatings. The results show that the hardness of the coatings increases with the temperature of the particle at deposition. Coatings deposited with propylene fuel gas have higher hardness (1100-1300 kgf/mm^2) than coatings produced with hydrogen (735-1000 kgf/mm^2). Generally, the sliding-wear resistance increases linearly with the hardness but is decreased by the presence of cracks at splat interfaces. On any given coating, the hardness varies by as much as 400 kg/mm^2, which results in corresponding local variations in sliding-wear resistance. Abrasion wear shows the same dependence on hardness and fracture as sliding wear.

Keywords: abrasion, coatings, cobalt, crystal microstructure, fracture, hardness, mechanical properties, nanostructured materials, synthesis (chemical), thermal effects, tribology, wear resistance

Y. Liu, Y. Qiao, J. He, E.J. Lavernia, and T.E. Fischer, Dept. of Materials Science and Engineering, Stevens Inst. Technology, Hoboken, NJ 07030. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci., 33*(1), Jan 2002, p 159-164 [in English]. ISSN 1073-5623.

Bimodal distribution of mechanical properties on plasma sprayed nanostructured partially stabilized zirconia. The mechanical behavior of nanostructured partially stabilized zirconia (PSZ) coatings was evaluated via Knoop microhardness. The distribution of the microhardness values of the feedstock particles and coatings under a 10 g load were analyzed via Weibull statistics. The percentage of nonmolten material was determined using scanning electron microcopy and image analysis. It was observed that the nanostructured coatings present a bimodal distribution in their Weibull plots, indicating the presence of two phases that are described as molten and nonmolten. The presence of the bimodal distribution in the mechanical properties allows the prediction of microhardness values of these nanostructured coatings.

Keywords: image analysis, microhardness, nanostructured materials, plasma spraying, raw materials, scanning electron microscopy, sprayed coatings, statistical methods, Weibull distribution

R.S. Lima, A. Kucuk, and C.C. Berndt, Dept. of Materials Science and Engineering, State Univ. New York, Stony Brook, NY 11794-2275. Cited: *Mater. Sci. Eng. A, 327*(2), 30 April 2002, p 224-232 [in English]. ISSN 0921-5093.

Microstructure and mechanical properties of WC-10Co cemented carbides sintered from nanocrystalline spray conversion processed powders. Mechanical properties and microstructure of nanocrystalline WC-10Co cemented carbides were investigated. The nanocrystalline WC-10Co cemented carbide powders were manufactured by reduction and carbonization of the nanocrystalline precursor powders that were prepared by the spray drying process the of solution containing ammonia meta-tungstate (AMT) and cobalt nitrate. The WC powders (diameter of which were about 100 nm) mixed homogeneously with cobalt binder phase and were sintered at 1375 °C under the pressure of 1 mtorr. In order to compare the microstructure and mechanical properties with the nanocrystalline WC-10Co, commercial WC powders with diameters of 0.57-4 μm were mixed with cobalt powders and were sintered at the same condition with that of nanocrystalline powders. TaC, Cr_3C_2, and VC of varying amounts were added into nanocrystalline WC-10Co cemented carbides as grain-growth inhibitors. To investigate the microstructure of cobalt binder phase in the WC-10Co cemented carbides, a Co-W-C alloy was fabricated at the temperature of sintering process for the WC-10Co cemented carbides. The hardness of WC-10Co cemented carbides increased with decreasing the WC grain size following the Hall-Petch type relationship. The fracture toughness of WC-10Co cemented carbides increases with increasing the hexagonal close-packed/face-centered cubic (hcp/fcc) ratio of cobalt binder phase by hcp/fcc phase transformation.

Keywords: cobalt, crystal microstructure, grain growth, mechanical properties, nanostructured materials, sprayed coatings

S.I. Cha, B.K. Kim, and S.H. Hong, Dept. Materials Science and Engineering, Korea Advanced Inst. Science and Technology Yusung-gu, Taejon 305-701, South Korea. Cited: *Rare Met., 21*(suppl.), July 2002, p 130-135 [in English]. ISSN 1001-0521.

Plasma sprayed nanocrystalline Ti-Ru-Fe-O coatings for the electrocatalysis of hydrogen evolution reaction. Nanocrystalline Ti-Ru-Fe-O (2-1-1-2) was prepared by mechanical alloying in a ZOZ attritor. Vacuum plasma spray (VPS) was then used to deposit coatings of this material on a substrate. Energy-dispersive x-ray fluorescence and x-ray diffraction analysis was used to follow the change in the chemical composition and crystalline structure of the powder upon deposition by VPS. Nanocrystalline Ti-Ru-Fe-O (2-1-1-2) prepared by the ZOZ attritor contains more than 50 wt.% of hexagonal Fe_2Ti and a smaller amount ($\leq$10 wt.%) of a cubic phase. Iron contamination coming from the attrition of the milling tools yields [Fe] $\approx$ 38 wt.%, almost twice as much as the nominal composition of the powder. When it is used for VPS, reaction between Fe_2Ti and Ru results in the formation of several cubic phases with lattice parameters ranging from 2.96 to 3.02 A. This reflects a change in the Ru content on the 1a (12, 12, 12) site of the cubic lattice. The deposition process also results in the formation of Ti_2O_3. This phase is present in excess at the surface of the coating, but can be efficiently dissolved through etching in an acid solution. The cathodic overpotential for hydrogen evolution of such activated coatings in typical chlorate electrolysis conditions is $\eta_{i250} = -550$ mV.

Keywords: catalysis, contamination, crystalline materials, electrodes, etching, fluorescence, hydrogen, lattice constants, mechanical alloying, nanostructured materials, plasma spraying, powders, protective coatings, ruthenium, surface properties, x-ray diffraction analysis

E. Irissou, M. Blouin, L. Roue, J. Huot, R. Schulz, and D. Guay, INRS-Energie et Materiaux, Varennes, Quebec, J3X 1S2, Canada. Cited: *J. Alloy. Compd., 345*(1-2), 28 Oct 2002, p 228-237 [in English]. ISSN 0925-8388.

Microstructural characteristics of cold sprayed nanostructured WC-Co coatings. The cold spray process was used to prepare nanostructured WC-Co coatings. The coating microstructural characteristics and phase composition were analyzed via optical microscopy, scanning electron microscopy (SEM), and x-ray diffraction (XRD). The morphology and microstructure of the nanostructured WC-Co powder were also analyzed by SEM and XRD. A 10 μm thick coating was achieved. The powder particles and coating microhardness were also evaluated and compared. The results show that there is no degradation of the WC-Co powder during the cold spray process and well-bonded and phase pure WC coating can be produced by the cold spray process.

Keywords: crystal microstructure, microhardness, morphology, nanostructured materials, phase composition, scanning electron microscopy, tungsten compounds, x-ray diffraction analysis

R.S. Lima, J. Karthikeyan, C.M. Kay, J. Lindemann, and C.C. Berndt, Dept. Materials Science and Engineering, State Univ. New York at Stony Brook, 306 Old Engineering Building, Stony Brook, NY 11794-2275. Cited: *Thin Solid Films, 416*(1-2), 2 Sept 2002, p 129-135 [in English]. ISSN 0040-6090.

A new way to prepare nanostructured materials: flame spraying of microemulsions. In this report the authors describe a new method to obtain nanostructured coatings or powders based on the flame decomposition of microcompartmentalized solutions. Metal nanoclusters of well-defined size are obtained by reduction of a metal salt inside the water compartment of water in oil (w/o) microemulsions, formed by water in hexane and stabilized by an appropriate surfactant. Metal nanoclusters can be separated from the mother solution by spraying the microemulsion solution into an air/acetylene flame. In this way, nanostructured coating or powder, almost preserving the original structure of the nanoparticles synthesized in the microemulsion system, can be obtained in quantities sufficient for industrial applications. As an example we report the flame spraying of gold microemulsions to produce gold coating onto silicon wafers. This study reports a new method allowing the use of a microemulsion synthetic pathway for the production of consistent amount of nanoparticles. This method could be of great utility in many applications involving nanoparticles in the fields of physics, chemistry, biotechnology, and biology.

Keywords: biotechnology, crystal atomic structure, decomposition, flame spraying, industrial applications, microemulsions, nanostructured materials, nanotechnology, salts, silicon wafers, solutions, sprayed coatings

M. Bonini, U. Bardi, D. Berti, C. Neto, and P. Baglioni, Dept. Chemistry, CSGI, Univ. Florence, 50019 Florence, Italy. Cited: *J. Phys. Chem. B, 106*(24), 20 June 2002, p 6178-6183 [in English]. ISSN 1089-5647.

Plasma spray coatings in different nanosize alumina. Three kinds of nanostructured alumina coatings were prepared by air plasma spraying (APS). The microstructure of these coatings was characterized by SEM and x-ray diffraction (XRD). The surface roughness, porosity, and microhardness of as-sprayed coatings were measured. The results indicated that the smaller the size of starting powder was, the better properties the coating possessed. The differences among phase analysis of these as-sprayed coatings could explain it.

Keywords: alumina, microhardness, microstructure, nanostructured materials, plasma spraying, porosity, scanning electron microscopy, sprayed coatings, surface roughness, x-ray diffraction analysis

Y. Zeng, S.W. Lee, and C.X. Ding, Shanghai Inst. Ceramics, Chinese Academy of Science, Shanghai, China. Cited: *Mater. Lett., 57*(2), Dec 2002, p 495-501 [in English]. ISSN 0167-577X.

Plasma Sprayed Microstructures

Aluminum phosphate sealed alumina coating: characterization of microstructure. The microstructure of aluminum phosphate sealed plasma sprayed alumina coating was characterized by x-ray diffractometry, scanning electron microscopy, and analytical transmission electron microscopy. Microstructural

characterization was carried out to identify the phases of the coating and to understand better the strengthening effect of aluminum phosphate sealant in the coating. The main phases in the coating are metastable γAl_2O_3 and stable αAl_2O_3. The overall structure of the coating is lamellar with columnar γAl_2O_3 grains. The aluminum phosphate sealant shows good penetration into the coating to the depth of about 300 μm filling the structural defects such as pores, cracks, and gaps between the lamellae. The sealant in the coating has the relative composition of 26 at.% aluminum and 74 at.% phosphorus giving the molar ratio P:Al of 3, which refers to the metaphosphates $Al(PO_3)_3$. There is also some crystalline aluminum phosphate in the coating, in the form of berlinite-type orthophosphate $AlPO_4$, owing to the reaction between the sealant and the alumina coating. Thus, the phosphate bonding in the alumina coating is based both on chemical bonding resulting from the chemical reaction with the alumina coating and on adhesive binding resulting from the formation of the condensed phosphates in the structural defects of the coating.

Keywords: adhesives, alumina, characterization, crystalline materials, grain size and shape, metallographic microstructure, scanning electron microscopy, sealants, transmission electron microscopy, x-ray diffraction analysis

M. Vippola, S. Ahmaniemi, J. Keranen, P. Vuoristo, T. Lepisto, T. Mantyla, and E. Olsson, Tampere Univ. Technology, Inst. Materials Science, Tampere 33101, Finland. Cited: *Mater. Sci. Eng. A, 323*(1-2), 31 Jan 2002, p 1-8 [in English]. ISSN 0921-5093.

Microstructural study of aluminum phosphate-sealed, plasma sprayed chromium oxide coating. Microstructural characterization of aluminum phosphate-sealed, plasma sprayed chromium oxide coating was carried out in order to study the strengthening mechanisms of the aluminum phosphate sealant in the coating. Characterization was performed using x-ray diffractometry, scanning electron microscopy, and analytical transmission electron microscopy. The structure of the sealed coating was lamellar with columnar αCr_2O_3 grains extending through the lamella thickness. Amorphous aluminum phosphate sealant had penetrated into the structural defects on the coating such as cracks, gaps, and pores between the lamellae. The relative composition was 25 at.% Al and 75 at.% P for the sealant in the coating, giving the molar ratio P/Al to 3, which corresponds to that of metaphosphates $Al(PO_3)_3$. There is no indication of reaction products from the chemical reactions between the sealant and the coating. Thus, the aluminum phosphate sealing in the chromium oxide coatings can be explained mainly by adhesive binding resulting from the formation of the condensed phosphates with the appropriate adhesive properties to the coating, and not by chemical bonding resulting from the chemical reactions between the sealant and the coating.

Keywords: adhesives, aluminum compounds, amorphous materials, chromium compounds, microstructure, plasma spraying, scanning electron microscopy, sealants, transmission electron microscopy, x-ray diffraction analysis

M. Vippola, S. Ahmaniemi, P. Vuoristo, T. Lepisto, T. Mantyla, and E. Olsson, Tampere Univ. Technology, Inst. Materials Science, Tampere 33101, Finland. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 253-260 [in English]. ISSN 1059-9630.

Relationships between the microstructure and properties of thermally sprayed deposits. Thermally sprayed deposits have layered structure composed of individual splats. The individual splats have quenching microstructure of quasi-stable preferred fine grains. However, this fine-grained microstructure of the deposits is usually not reflected by improved performance of the deposits because a layered structure with two-dimensional voids occurs between lamellar interfaces. The microstructure of the thermal spray deposits with the emphasis on the layer structural parameters is reviewed. Conventionally, one of the most common quantitative parameters used to characterize the microstructure of the thermally sprayed deposits is the porosity, measured by different methods. However, it is illustrated that the relationships between properties and porosity for bulk porous materials processed by conventional processes cannot be applied to thermally sprayed deposits owing to the two-dimensional characteristics of voids. The total porosity in the deposits is not meaningful from the viewpoint of prediction of the deposit properties. An idealized structural model and related parameters, instead of porosity, are proposed to characterize quantitatively the microstructure of the thermally sprayed deposit. The relationships between the properties and the structural parameters are presented for the plasma sprayed ceramic deposits based on the proposed microstructure model. The properties include the Young's modulus, fracture toughness, erosion resistance, and thermal conductivity of the plasma sprayed ceramic deposits. The correlations of theoretical relationships with reported experimental data are discussed. An agreement of theoretical with observed values suggests that the lamellar structure of the deposit with limited interface bonding is the dominant factor controlling the performance of the deposit.

Keywords: elastic moduli, erosion, fracture toughness, image analysis, interfaces (materials), microcracks, microstructure, optical microscopy, porosity, quenching, thermal conductivity, volume fraction

C.-J. Li and A. Ohmori, Welding Research Inst., School of Mechanical Engineering, Xi'an Jiaotong Univ., Xi'an, Shaanxi, 710049, China. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 365-374 [in English]. ISSN 1059-9630.

Thermal properties and microstructure of a plasma sprayed wollastonite coating. Wollastonite coatings were deposited using an atmospheric plasma spraying technique. The microstructure and phase compositions of the coating before and after heat treatment were investigated using scanning electron microscopy (SEM), x-ray diffraction (XRD), and differential thermal analysis (DTA) technologies, respectively. In addition, the coefficient of thermal expansion and thermal diffusivity of the coating were also investigated. Crystalline wollastonite, glassy phase, and tridymite (SiO_2) were observed in the coating. Tridymite (SiO_2) likely reacted with other composites such as CaO and glassy phase to form crystalline wollastonite when the coating was heated at about 882 °C. During the first thermal cycle, the coefficient of thermal expansion of the coating decreased dramatically between 700 and 850 °C, and the thermal diffusivity of the coating was 2.7 to 3.1×10^{-3} cm^2/s between 20 and 1000 °C. During the second thermal cycle, the coefficient of thermal expansion of the coating increased slightly between room temperature and 1000 °C, and the thermal diffusivity of the coating increased by about 20% compared with that of the first thermal cycle. The atmospheric plasma sprayed wollastonite coating may be used as thermal barrier coating.

Keywords: bond strength (materials), differential thermal analysis, heat treatment, metallographic microstructure, phase composition, plasma spraying, residual stresses, scanning electron microscopy, thermal barrier coatings, thermal diffusion, thermal expansion, x-ray diffraction analysis

X. Liu and C. Ding, Plasma Spray Laboratory, Shanghai Inst. Ceramics, Chinese Academy of Sciences, Shanghai 200050, China. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 375-379 [in English]. ISSN 1059-9630.

Porosity of Coatings

Structural characterization of laser-treated Cr_3C_2-NiCr coatings. The interconnected porosity of the Cr_3C_2-NiCr coatings obtained by high-velocity oxyfuel spraying is detrimental in corrosion- and wear-resistance applications. Laser treatments allow sealing of their surfaces through melting and resolidification of a thin superficial layer. A Nd:YAG laser beam was used to irradiate Cr_3C_2-NiCr coatings either in the continuous wave mode or at different repetition rates in the pulsed one. Results indicated that high peak and low mean laser irradiances are not good, since samples presented deep grooves and an extensive crack network. At low peak and higher mean laser irradiances the surface was molten, and only a few shallow cracks were observed. The interconnected porosity was completely eliminated in a layer up to 80 μm thick, formed by large Cr_7C_3 grains imbedded in a NiCr matrix.

Keywords: characterization, corrosion resistance, crack initiation, crystal structure, grain size and shape, inorganic coatings, laser beam effects, melting, metallic matrix composites, neodymium lasers, porosity, sealing (closing), solidification, surface structure, wear resistance

P. Serra, J.M. Miguel, J.L. Morenza, and J.M. Guilemany, Univ. Barcelona, Dept. Fisica Apl. i Optica, E-08028 Barcelona, Spain. Cited: *J. Mater. Res., 16*(12), Dec 2001, p 3416-3422 [in English]. ISSN: 0884-2914.

Pulse Plasma Sprayed Coatings

Deposition of silicon carbide coatings by spraying a powder accelerated electrodynamically in a coaxial pulse plasma generator. This paper presents the results of examinations of silicon carbide (SiC) coatings formed on a silicon single crystal by deposition of a SiC powder accelerated electrodynamically under conditions of pulse plasma. The coatings thus obtained appeared to be solid SiC layers with a hexagonal 2H structure. The microstructure and the thermal conductivity of the coatings were examined. The measured effective thermal conductivity of thin (10 μm) polycrystalline SiC coatings deposited on silicon was about 51-75 W/m · K, which is one order of magnitude lower than that of monocrystalline SiC (270 W/m · K).

Keywords: ceramic coatings, deposition, electrodynamics, microstructure, plasma spraying, polycrystalline materials, powders, thermal conductivity

A.R. Olszyna, Fac. of Materials Science and Engineering, Warsaw Univ. Technology, 02-507 Warsaw, Poland. Cited: *Mater. Manuf. Process., 17*(3), May 2002, p 379-385 [in English]. ISSN 1042-6914.

Quasi-Crystalline Coating

Mechanical spectroscopy of icosahedral Al-Cu-Fe quasi-crystal metal-based composites. Since the bulk AlCuFe quasi-crystals are extremely brittle and therefore not suitable for mechanical spectroscopy, two different types of AlCuFe quasi-crystal metal-based composites have been studied. One is AlMg3% based metal-matrix composite reinforced with quasi-crystalline particles and the second is a quasi-crystalline coating deposited on a steel substrate using thermal spraying. The internal friction of these composites was measured in a forced-torsion pendulum and in a free-free bar apparatus. The obtained results are discussed.

Keywords: aluminum alloys, brittleness, deposition, internal friction, particles (particulate matter), quasi-crystals, reinforcement, spectroscopy, sprayed coatings, spraying, steel, substrates

J. Fikar, R. Schaller, N. Guilbaud, and N. Baluc, Ecole Polytech. Federale de Lausanne, IGA, DP, CH-1015 Lausanne, Switzerland. Cited: *Diffusion and Defect Data. Pt A Defect and Diffusion Forum,* Vol 203-205, Scitec Publications Ltd., 2002, p 289-292 [in English]. ISSN 1012-0386.

Comparative study of the tribological behavior of thermal sprayed quasi-crystalline coating layers. To investigate the role of tribological reactions on the friction and wear of quasi-crystalline materials, coatings with two alloy compositions have been prepared by plasma and high-velocity oxyfuel (HVOF) spraying techniques. The tribolayers were characterized by the formation of a transfer film on the counterface and densification of the coating subsurfaces. It was observed that the thickness of the transfer film and pore-free region were dependent on the composition and process used for the deposition of the coatings as well as the sliding velocity. As the sliding velocity increased, the growth rate of the transfer film decreased, resulting in a decrease of the coefficient of friction. On the other hand, the wear rate appeared to be controlled by the thickness of the pore-free region formed within the coating surface zone.

Keywords: densification, friction, plasma spraying, sprayed coatings, tribology, wear of materials

E. Fleury, Y.-C. Kim, J.-S. Kim, D.-H. Kim, W.T. Kim, H.-S. Ahn, and S.-M. Lee, Center for Noncrystalline Materials, Dept. of Metallurgical Engineering, Yonsei Univ., Seoul 120-749, South Korea. Cited: *J. Alloy. Compd., 342*(1-2), 14 Aug 2002, p 321-325 [in English]. ISSN 0925-8388.

Potential industrial applications of Aluminum-base quasi-crystals: plasma sprayed vs. HVOF sprayed coatings. Quasi-crystalline coatings with various aluminum-base systems were deposited onto 304 stainless steel substrates using two thermal spraying techniques: plasma spraying and high-velocity oxyfuel spraying. The friction and wear performances of the coatings were evaluated using two different testing devices, varying testing conditions, and counterpart materials. Values of the friction coefficient were found to be strongly dependent on the testing devices and the counterpart materials, with values ranging from 0.15-0.4. In testing conditions corresponding to high sliding velocity, this study showed that the contact problem was posed over a third-body system due to the formation of an intermediate layer. Values of the coefficient of friction were found to be approximately the same for all coating layers regardless of the thermal spraying techniques used; however, larger differences were obtained in the wear performance. The tribological properties were also evaluated at high temperature. It is noted that quasi-crystal coating layers exhibit better friction and wear performances at 450 °C than at room temperature. In comparison to potential coating candidate such as Cr_2O_3 for piston rings in automotive engines, tribological property of quasi-crystalline coating layers seems to be promising one; however, wear performance need to be improved.

Keywords: aluminum alloys, fracture toughness, high-temperature effects, industrial applications, plasma spraying, sprayed coatings, stainless steel, substrates, thermal conductivity, tribology

S.M. Lee, E. Fleury, J.S. Kim, Y.C. Kim, D.H. Kim, W.T. Kim, and H.S. Ahn, Korea Inst. of Industrial Technology, Inchon, South Korea. Cited: *Quasicrystals—Preparations, Properties and Applications* (Conf. Proc.), 27-30 Nov 2000 (Boston, MA), Vol 643, E. Belin-Fere, P. Thiel, A.P. Tsai, and K. Urbana, Ed., Materials Research Society, 2001, p K1521-K15212 [in English]. ISSN: 0272-9172.

Roughness Effects

Effect of substrate surface roughness on the adherence of NiCrAlY thermal spray coatings. The adherence of plasma sprayed NiCrAlY bond coats can be improved by an appropriate substrate surface finish. The interface fracture energy for crack propagation along the coating/substrate interface has been measured for different surface roughness by means of a specially designed four-point bending test. An increase of the interface fracture energy of about 15% was observed for a three times higher surface roughness. In addition, four-point bending tests with the coating on the side face of bending specimens were performed to analyze the fracture and spalling behavior of the coatings both under large tensile and compressive substrate deformations.

Keywords: bending (deformation), compression testing, crack propagation, elastic moduli, fracture toughness, interfaces (materials), plasma spraying, Poisson's ratio, spalling, substrates, surface roughness, tensile testing

I. Hofinger, K. Raab, J. Moller, and M. Bobeth, Caterpillar Inc., Peoria, IL 61656-1875. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 387-392 [in English]. ISSN 1059-9630.

The influence of surface roughness of sprayed zirconia coatings on laser treatment. The influence of surface roughness of plasma sprayed zirconia coatings on postlaser treatment was investigated. To minimize the influence from the nonuniform laser beams obtained through the usual optics on the laser treatment of coatings, a conventional YAG laser gun was modified, and laser beams with a uniform intensity were obtained by installing the kaleidoscope. The melted depth of the polished coatings was approximately half that of as-received coatings even when treated at the same power density (38.4 W/mm^2) and this difference of melted depth between the as-received coatings and polished coatings increased with the power density (47.9 W/mm^2). In the case of as-sprayed coatings with a rough surface, uneven and roughly treated areas were sharply increased in accordance with the power density. As-received coatings with surface roughness (R_a, 4.7 μm) showed an increased diffuse reflectance compared with polished coatings (R_a, 0.27 μm), and the difference in reflectance between the as-sprayed and polished coatings was approximately 10% near the wavelength of the Nd/YAG laser (1016 nm). In this experiment, the appearance of the monoclinic phase, one of the important indicators determining the stability of TBC coating, was not observed and nontransformable t^1 phase was still predominant after laser treatment.

Keywords: laser beams, laser optics, neodymium lasers, surface roughness, zirconia

S.O. Chwa and A. Ohmori, Joining/Welding Research Inst., Osaka Univ., Osaka 567-0047, Japan. Cited: *Surf. Coat. Technol., 148*(1), 1 Nov 2001, p 88-95 [in English]. ISSN: 0257-8972.

Si_3N_4 Coatings

Microstructure and properties of thermally sprayed silicon nitride-based coatings. The preparation of thermally sprayed, dense, Si_3N_4-based coatings can be accomplished using composite spray powders with Si_3N_4 embedded in a complex oxide binder matrix. Powders with excellent processibility were developed and produced by agglomeration (spray drying) and sintering. Optimization of the heat transfer into the powder particles was found to be the most decisive factor necessary for the production of dense and well-adhering coatings. In the present work, different thermal spray processes such as detonation gun spraying (DGS), atmospheric plasma spraying (APS) with axial powder injection, and high-velocity oxyfuel (HVOF) spraying were used. The coatings were characterized using optical and scanning electron microscopy (SEM), x-ray diffraction (XRD), and microhardness testing. The wear resistance was tested using a rubber-wheel abrasion wear test (ASTM G 65). In addition, thermoshock and corrosion resistances were determined. The microstructure and the performance of the best coatings were found to be sufficient, suggesting the technical applicability of this new type of coating.

Keywords: agglomeration, corrosion resistance, drying, hardness testing, optical microscopy, plasma spraying, powders, scanning electron microscopy, silicon nitride, sintering, wear resistance, x-ray diffraction analysis

S. Thiele, R.B. Heimann, L.-M. Berger, M. Herrmann, M. Nebelung, T. Schnick, B. Wielage, and P. Vuoristo, Fraunhofer Inst. Ceramics Technology, D-01277 Dresden, Germany. Cited: *J. Therm. Spray Technol., 11*(2), June 2002, p 218-225 [in English]. ISSN 1059-9630.

Solution-Precursor Thermal Spray

Mechanisms of ceramic coating deposition in solution-precursor plasma spray. The solution-precursor plasma spray (SPPS) method is a new process for depositing thick ceramic coatings, where solution feedstock (liquid) is injected into a plasma. This versatile method has several advantages over the conventional plasma spray method, and it can be used to deposit nanostructured, porous coatings of a wide variety of oxide and nonoxide ceramics for many possible applications. In an effort to understand the SPPS deposition process, key diagnostic and characterization experiments were performed on SPPS coatings in the Y_2O_3-stabilized ZrO_2 (YSZ) system. The results from these experiments show that there are multiple pathways to SPPS coating formation. The atomized precursor droplets undergo rapid evaporation and breakup in the plasma. This is followed by precipitation, gelation, pyrolysis, and sintering. The different types of particles reach the substrate and are bonded to the substrate or the coating by sintering in the heat of the plasma. The precursor also reaches the substrate or the coating. This precursor pyrolyzes in situ on the substrate, either after it reaches a "cold" substrate or upon contact on a "hot" substrate and helps bond the particles. The coating microstructure evolves during SPPS deposition as the coating temperature reaches approximately 770 °C.

Keywords: atomization, deposition, feedstocks, microstructure, plasma diagnostics, plasma spraying, porous materials, precipitation (chemical), pyrolysis, sintering, yttrium compounds, zirconia

T. Bhatia, A. Ozturk, L. Xie, E.H. Jordan, B.M. Cetegen, M. Gell, X. Ma, and N.P. Padture, Dept. Metallurgy and Materials Engineering, Inst. Materials Science, Univ. Connecticut, Storrs, CT 06269-3136. Cited: *J. Mater. Res., 17*(9), Sept 2002, p 2363-2372 [in English]. ISSN 0884-2914.

Substrate Temperature During Thermal Spray Process

Estimating the surface temperature profile from a sequence of partial thermal images. This paper considers the processing of thermal images taken during an arc spraying process. It describes a filtering method for reconstructing an estimate of the required surface temperature from a sequence of images that contain unpredictable amounts of blurring and obscuration. A practical use of the filtering to control average surface temperature during metal arc spraying is also described.

Keywords: image reconstruction, industrial robots, spraying, spray guns, temperature control

P.D.A Jones and S. Duncan, Dept. Engineering Science, Oxford Univ., Oxford OX1 3PJ, U.K. Cited: *Sensor Fusion and Decentralized Control in Robotic Systems IV* (Conf. Proc.), 28-29 Oct 2001 (Newton, MA), Vol 4571, G.T. McKee and P.S. Schenker, Ed., SPIE—The International Society for Optical Engineering, 2001, p 199-207 [in English]. ISSN: 0277-786X.

Superhard Steel Coatings

Superhard steel coatings. Superhard steel coatings can be applied using conventional thermal spray technology onto a wide variety of conventional metal surfaces on existing industrial parts, devices, and machines. Since the bulk of wear and corrosion phenomenon occurs at the surface, this approach results in the development of revolutionary low-cost material systems that exhibit unique combinations of properties (wear and corrosion resistance, toughness, friction). Incorporation of this technology into existing material systems is expected to vastly extend lifetimes, reduce total ownership costs, and spawn entirely new material technologies that are able to perform in new and demanding environments and in ways previously not possible.

Keywords: corrosion resistance, friction, spraying, steel, surface treatment, toughness, wear of materials

D.J. Branagan and T. Harrison. Cited: *Mater Technol., 16*(4), Dec 2001, p 233-235 [in English]. ISSN 1066-7857.

Thermal and Phase Stability of Coatings

Phase stability of $La_2Ce_2O_7$ solid solution. The phase stability of $La_2Ce_2O_7$ solid solution was studied in this paper due to its promising application in thermal barrier coatings. This material has higher phase stability than yttria-stabilized zirconia (YSZ, Y_2O_3-ZrO_2). After long-term annealing at 1400 °C, the crystal structure of $La_2Ce_2O_7$ was still stable without phase-transformation. Due to the contraction of the crystal lattice, it shows a low thermal expansion coefficient below 300 °C. High-temperature x-ray diffraction was employed for the structure study of $La_2Ce_2O_7$.

Keywords: cerium compounds, phase transitions, solid solutions

X.Q. Cao and J. Meng, Changchun Inst. Applied Chemistry, Chinese Academy of Science, Changchun 130022, China. Cited: *Rare Met., 21*(suppl.), July 2002, p 110-113 [in English]. ISSN 1001-0521.

High-temperature damping behavior of plasma sprayed NiCoCrAlY coatings. There is a trend to design the turbine coating and the substrate as in integral, layered, engineering assembly. Under the harsh environment of the turbine engine, a failure in one component can quickly lead to failure in other components. Materials that are used in structural applications are prone to mechanical vibration, which, when not attenuated, will lead to fatigue of components and shortening of life cycle. Therefore, it is necessary to examine the thermal stability and dynamic mechanical properties of coatings under dynamic conditions. In addition to these noise reduction and vibration amplitude control motivated objectives, however, mechanical energy dissipation processes also find intrinsic applications in cases for which a thorough understanding of the mechanisms responsible for the damping response of the material is required. This article describes the damping behavior and mechanisms that exist in plasma sprayed NiCoCrAlY coatings.

Keywords: creep, damping, dislocations (crystals), dynamic mechanical analysis, energy dispersive spectroscopy, fatigue of materials, noise abatement, optical microscopy, plasma spraying, scanning electron microscopy, thermodynamic stability, x-ray diffraction analysis

K.A. Khor, C.T. Chia, Y.W. Gu, and F.Y.C. Boey, School of Mechanical Production Engineering, Nanyang Technological Univ., Singapore 639798, Singapore. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 359-364 [in English]. ISSN 1059-9630.

Thermal Cycling

The effect of the type of thermal exposure on the durability of thermal barrier coatings. The effect of cycle frequency on the spallation failure of thermal barrier coatings has been investigated. The exposure conditions affect the lifetimes of the coatings and can even change the relative performance of different bond coats. The very strong effect of exposure temperature is consistent with thermally grown oxide growth being a first-order variable in scale failure.

Keywords: fracture toughness, oxidation, sintering, thermal cycling

G.M. Kim, N.M. Yanar, E.N. Hewitt, F.S. Pettit, and G.H. Meier, Dept. of Materials Science/Engineering, 848 Benedum Hall, Univ. Pittsburgh, Pittsburgh, PA 15261. Cited: *Scr. Mater., 46*(7), April 2002, p 489-495 [in English]. ISSN 1359-6462.

Degradation of thermal barrier coatings due to thermal cycling up to 1150 °C. The degradation of thermal barrier coatings (TBCs) due to thermal cycling up to 1150 °C has been studied. During thermal cycling, the bond coat in the TBCs was oxidized to form an alumina and a mixed oxide layer between the top coat of yttria-stabilized zirconia (YSZ) and the bond coat of *M*CrAlY alloy. The mixed-oxide layer mainly consists of αCr_2O_3 and $(Ni,Co)(Cr,Al)_2O_4$ spinel phases, which are formed above the α-alumina layer. Interestingly, the alumina layer gradually disappeared during the oxidation, while the content of chromium in the mixed oxide increased with increasing oxidation time. As the oxidation accelerated after the disappearance of the alumina layer, cracks initiated and propagated in the mixed oxide layer near the YSZ. Eventually, the crack propagation induced the spallation of some YSZ top coatings after the 2000 h oxidation.

Keywords: alumina, crack propagation, degradation, oxidation, thermal cycling, zirconia

M.S. Ali, S. Song, and P. Xiao, Materials Group, Dept. Mechanical Engineering, Brunel Univ., Uxbridge, Middlesex, UB8 3PH, U.K. Cited: *J. Mater. Sci., 37*(10), 15 May 2002, p 2097-2102 [in English]. ISSN 0022-2461.

Thick Thermal Barrier Coating

Improved sealing treatments for thick thermal barrier coatings. Zirconia-based $8Y_2O_3$-ZrO_2, $22MgO$-ZrO_2, and $25CeO_2$-$2.5Y_2O_3$-ZrO_2 thick thermal barrier coatings (1000 µm) were studied with different sealing methods for diesel engine and gas turbine applications. The aim of the sealing procedure was to improve the hot corrosion-resistance and mechanical properties of porous, thick thermal barrier coatings (TTBC). The surface of the coatings was sealed with three different methods: (1) laser glazing, (2) an aluminum phosphate sealing treatment, and (3) detonation gun spraying of a dense top coating on the TTBC. Sealant penetration into the coating microstructure were determined by scanning electron microscopy/energy-dispersive spectrometry (SEM/EDS) and optical microscopy. Coatings were characterized by x-ray diffraction (XRD), microhardness, and porosity measurements. The thickness of the densified top layers in all cases was 50-400 µm. X-ray diffraction analysis showed some minor phase changes and reaction products caused by the phosphate-based sealing treatment and some crystal orientation and phase changes in laser-glazed coatings. The porosity of the outer layer of the sealed coating decreased in all cases, which led to increased microhardness values.

Keywords: corrosion resistance, crystal microstructure, crystal orientation, detonation, diesel engines, energy dispersive spectroscopy, gas turbines, glazes, microhardness, porosity, scanning electron microscopy, sealing (finishing), spray guns, thickness measurement, zirconia

S. Ahmaniemi, P. Vuoristo, and T. Mantyla, Inst. Materials Science, Tampere Univ. Technology, Tampere 33101, Finland. Cited: *Surf. Coat. Technol., 151-152,* 1 March 2002, p 412-417 [in English]. ISSN 0257-8972.

Wear and Corrosion

Failure of gas turbine blades. The first-stage blades of a gas turbine had suffered a severe deterioration after around 10,500 h service. The expected service life was 40,000 h. Failure analysis (visual observations, studies by optical microscopy, scanning electron microscopy [SEM], SEM backscattered electron [SEM-BSE], EDX, x-ray diffraction [XRD], and dimensional metrology) has been carried out. Blades, manufactured in the nickel superalloy CMSX-4, lost the protective coatings from their tips due to wear. Unprotected surfaces suffered high-temperature hot corrosion (type I corrosion). It is concluded that failure was mainly caused by an uneven clearance (out-of-line) between rotor and lining.

Keywords: corrosion, energy dispersive spectroscopy, failure analysis, gas turbines, optical microscopy, protective coatings, rotors, scanning electron microscopy, superalloys, surfaces, x-ray diffraction analysis

J.M. Gallardo, J.A. Rodriguez, and E.J. Herrera, Grupo de Metal. e Ing. de los Mat., Es. de Ingenieros de la Univ. de Sev, Sevilla 41092, Spain. Cited: *Wear, 252*(3-4), Feb 2002, p 264-268 [in English]. ISSN 0043-1648.

A comparison of boundary wear film formation on steel and a thermal sprayed Co/Cr/Mo coating under sliding conditions. In this paper, the action of the zinc dialkyl dithiophosphate (ZDDP) antiwear additive has been examined on two different materials (AISI 52100 steel and a Co/Cr/Mo thermal spray coating) sliding against cast iron in reciprocating mode. Tests have been conducted under lubricated wear conditions at relatively low (20, 50 °C) and elevated (up to 100 °C) bulk oil temperatures. A comparison is made among the friction, wear, and chemical natures of the wear film formed under varying temperatures, on two materials, in two lubricants (one free from and one containing ZDDP), and after different test durations. The wear film has been examined by energy-dispersive x-ray analysis (EDAX) and x-ray photoelectron spectroscopy (XPS). In this work, it has been shown in this work that the friction coefficient is dependent on the temperature, the lubricant and the nature of the contacting surfaces. In the presence of ZDDP, a wear film, comprising zinc, sulfur, and phosphorus, forms even at the lowest bulk oil temperature of 20 °C. The nature of the film is dependent on the substrate material and the steel and Co/Cr/Mo coating showed contrasting film characteristics. In this paper, the wear and friction results for each couple in oil containing and free from additives is discussed with reference to the nature of the wear film. A correlation has been made among the wear, friction, and chemical analysis measurements.

Keywords: cast iron, friction, lubrication, sprayed coatings, steel, x-ray analysis, x-ray photoelectron spectroscopy, zinc compounds

A. Neville and V. Kollia-Rafailidi, Dept. Mechanical/Chemical Engineering, Heriot-Watt Univ., Edinburgh EH14 4AS, U.K., *Wear, 252*(3-4), Feb 2002, p 227-239 [in English]. ISSN 0043-1648.

Residual stresses in aluminum phosphate sealed plasma sprayed oxide coatings and their effect on abrasive wear. Effect of residual stresses on plasma sprayed alumina and chromia coatings sealed with aluminum phosphate were studied as a function of the temperature of the sealing treatment. Stresses were measured by x-ray stress analysis and high-speed circular microhole drilling method. Residual stress states were correlated with other coating properties such as microhardness, porosity, microstructure, and dry abrasion wear resistance. Correlations were found between sealing treatment temperature, residual stress state, and wear resistance. Wear resistance of the oxide coatings was increased at all sealing temperatures. Sealing treatment affected coatings by two mechanisms. Aluminum phosphate sealing induced compressive stresses to coatings and simultaneously bonded coating lamellar structure.

Keywords: alumina, chromium compounds, compressive stress, microhardness, microstructure, plasma spraying, porosity, residual stresses, sealing (closing), stress analysis, thermal effects, wear resistance

S. Ahmaniemi, M. Vippola, P. Vuoristo, T. Mantyla, M. Buchmann, and R. Gadow, Inst. Materials Science, Tampere Univ. Technology, Tampere 33101, Finland. Cited: *Wear, 252*(7-8), April 2002, p 614-623 [in English]. ISSN 0043-1648.

Correlation of microstructure and wear resistance of ferrous coatings fabricated by atmospheric plasma spraying. The correlation of microstructure and wear resistance in ferrous coatings applicable to diesel engine cylinder bores was investigated in this study. Seven kinds of ferrous spray powders, two of which were stainless steel powders and the others blend powders of ferrous powders mixed with Al_2O_3-ZrO_2 powders, were sprayed on a low-carbon steel substrate by atmospheric plasma spraying. Microstructural analysis of the ferrous coatings showed that various iron oxides such as FeO, Fe_2O_3, and γFe_2O_3 were formed in the martensitic (or austenitic) matrix as a result of the reaction with oxygen in air. The blend coatings containing γAl_2O_3 and *t*-ZrO_2 oxides, which were formed as Al_2O_3-ZrO_2 powders, were rapidly solidified during plasma spraying. The wear test results revealed that the blend coatings showed better wear resistance than the ferrous coatings because they contained a number of hard Al_2O_3-ZrO_2 oxides. However, delamination occurred when cracks initiated at matrix/oxide interfaces and propagated parallel to the worn surface in the case of the large hardness difference between the matrix and oxide. The wear rate of the coating fabricated with STS316 powders was slightly higher than other coatings, but the wear rate of the counterpart material was very low because of the smaller matrix/oxide hardness difference due to the presence of many iron oxides. In order to reduce the wear of both the coating and its counterpart material, the matrix/oxide hardness difference should be minimized, and the hardness of the coating should be increased over a certain level by forming an appropriate amount of oxides.

Keywords: alumina, delamination, diesel engines, hardness, interfaces (materials), iron compounds, metallographic microstructure, plasma spraying, powder metals, solidification, wear resistance, zirconia

B. Hwang, J. Ahn, and S. Lee, Center for Advanced Aerospace Mat., Pohang Univ. Science and Technology, Pohang, 790-784, South Korea. Cited: *Metall. Mater. Trans. A: Phys. Metall. Mater. Sci., 33*(9), Sept 2002, p 2933-2945 [in English]. ISSN 1073-5623.

Wollastonite Coatings

Study on structure and properties of plasma sprayed wollastonite coatings. Wollastonite coating deposited on Ti-6Al-4V substrate was prepared using plasma spraying technology. The tensile bonding strength of the coating was measured with ASTM C 633 methods. Simulated body-fluid (SBF) tests were carried out to evaluate the bioactivity of the coating. Scanning electron microscopy (SEM), x-ray diffraction (XRD), and infrared (IR) spectroscopy were used to investigate the surface morphology, microstructure, and phase compositions of the coating before and after it was soaked in SBF for various times. The results indicate that the plasma sprayed wollastonite coating has a rough surface and a lamellar structure including some pores and microcracks. The primary crystalline phase of the as-sprayed coating is triclinic wollastonite. The abundant glassy phase is also discovered in the coating. The bonding strength of the wollastonite coating amounts to about 39 MPa, which is thought to result from the fact that the thermal expansion coefficient of wollastonite coating comes close to that of the Ti-6Al-4V substrate. In SBF test, the surface of the coating is covered by carbonate-containing hydroxyapatite, which indicates that wollastonite coatings could have good bioactivity.

Keywords: coatings, morphology, plasma spraying, strength of materials, titanium alloys

X. Liu and C. Ding, Shanghai Inst. Ceramics, Chinese Academy of Science, Shanghai 200050, China. Cited: *Kuei Suan Jen Hsueh Pao/J. Chin. Ceram. Soc., 30*(1), Feb 2002, p 20-25 [in Chinese]. ISSN 0454-5648.

Review

Advantages of Thermal Spray

Thermal spray basics. Thermal spray is an established industrial method for the surfacing and resurfacing of metal parts. The benefits are typically lower cost, improved engineering performance, and/or increased component life. With the emergence of new designs in equipment and materials, attractive coating solutions are now available in the aerospace, industrial gas turbine, petrochemical and gas, and automotive industries.

Keywords: bond strength (materials), bonding, combustion, cost effectiveness, laser applications, melting, microstructure, porosity, spraying, substrates, surface roughness, surface treatment

M.R. Dorfman, Product Maintenance Materials, Sulzer Metco (US) Inc., Westbury, NY 11590. Cited: *Adv. Mater. Process., 160*(7), July 2002, p 47-50 [in English]. ISSN 0882-7958.

Thermal spray materials. The final properties of a thermal spray coating are based on its microstructure properties, and these depend on both the material and the deposition method. This paper covers thermal spray materials, including those for clearance control, thermal barrier coatings, wear resistance, and salvage and repair. It includes discussions of their properties, compositions, and application methods.

Keywords: bonding, composition effects, melting, microstructure, thermal barrier coatings, thermal conductivity, thermodynamic properties, wear resistance

M.R. Dorfman, Sulzer Metco (US) Inc., Westbury, NY 11590. Cited: *Adv. Mater. Process., 160*(9), Sept 2002, p 49-51 [in English]. ISSN 0882-7958.

Thermal spray applications, Part IV. Thermal spray processes are applied in a wide range of industries. This article provides examples of thermal spray coatings in the aerospace, industrial gas turbines, automotive, and industrial market segments. It briefly describes specific applications and customer benefits in these market segments and forecasts the future of thermal spray technology.

Keywords: aerospace applications, automobile engines, closed-loop control systems, coatings, engine cylinders, gas turbines, jet engines, petrochemical plants, plasma guns, process control, sensors, tungsten compounds

M.R. Dorfman, Sulzer Metco (US) Inc., Westbury, NY. Cited: *Adv. Mater. Process., 160*(10), Oct 2002, p 66-68 [in English]. ISSN 0882-7958.

Thermal Spray Coating Process

Plasma physics and technology; industrial applications. Plasma technologies offer a wide spectrum of possible treatments of materials. In particular, in function of the peculiar physical characteristics of the plasma, produced by different ionization systems, three types of processes on the materials can be activated: (1) destruction of toxic/harmful materials, (2) superficial modification of existing materials, (3) creation of new materials. Thermal plasma can be used to destroy the solid, liquid, and gaseous toxic halogenated and hazardous substances or to generate anticorrosion, thermal barriers, antiwear coatings, etc. Cold plasmas can be used for surface modifications of materials, ranging from the simple topographical changes to the creation of surface chemistries and coatings that are radically different with respect to the bulk material. Each of the three lines has a different weight with respect to an immediate industrial transferring. While the first two are ready for an immediate industrial utilization of the processes, the third one is still under investigation. Some industrial processes are described and, in the case of some treatments of toxic substances, a comparative cost analysis is presented.

Keywords: industrial applications, ionization, surface treatment, thermal barrier coatings, toxic materials

G. Bonizzoni and E. Vassallo, Istituto di Fisica del Plasma, Consiglio Nazionale delle Ricerche, Milano 20125, Italy. Cited: *Vacuum, 64*(3-4), Jan 2002, p 327-336 [in English]. ISSN 0042-207X.

Surface engineering technologies. The deposition methods and characteristics of coatings and thin films, like enhanced wear resistance, corrosion resistance, abrasion, adhesion, and erosion were discussed. The surface treatments applicable to the coatings were classified on the basis of service requirements, design constraints, and economic concerns. Thermal sprays, chemical and physical deposition, diffusion, and electroplating were the major coating microstructures. Analysis of their characteristics was done and revealed that thermal sprayed coatings had excellent erosion resistance as compared to plasma sprayed coatings.

Keywords: abrasion, adhesion, chemical vapor deposition, cladding (coating), compressive stress, corrosion resistance, diffusion, erosion, fracture toughness, laser beam effects, physical vapor deposition, sprayed coatings, thin films

R.C Tucker Jr., Tucker Group LLC, Wesley Chapel, FL 33543. Cited: *Adv. Mater. Process., 160*(4), April 2002, p 36-38 [in English]. ISSN 0882-7958.

Sealing the gap. AB Sulzer Metco developed a plasma gun used for spraying abradable coatings. Plasma spray applied abradables are superior to other processes because of lower blade wear, lower operating cost, extended tem-

perature operating capability, greater spray process control and more process reliability. The ability to produce coated components with reliable and consistent microstructure begins with the thermal spray powder. End-user reproducibility of clearance control coatings can be guaranteed by spray testing production lots of material and using statistical process control (SPC).

Keywords: abrasion, corrosion resistance, gas turbines, heat treatment, machining, plasma guns, plasma spraying, polyesters, porosity, solid lubricants, spray guns

R. Thomason. Cited: *Prod. Finish. (London), 54*(10), Dec 2001, DMG World Media (UK) Ltd., p 10-12 [in English]. ISSN: 0032-9762.

Safety

Noise Measurements

Noise emissions in thermal spray operations. Acoustic noise generation is an accompanying effect produced during thermal spraying. This type of noise is found both during the preparatory stages, such as grit blasting and compressed air cleaning, and during thermal spraying. A real-time noise meter was used to measure the noise level at frequencies between 63 and 8000 Hz during the operation of powder flame, wire flame, wire arc, air plasma, and high-velocity oxyfuel (HVOF) spraying processes. Noise was reported as either an A-weighted noise spectrum or an equivalent sound pressure level. The effect of different parameters, such as secondary plasma gas type, modes of wire flame torch operation, and use of compressed air cooling were investigated. The results indicated that the turbulence of the gas departing from the torch gives rise to jet noise. High gas flows mainly contributed to the lower frequencies, whereas combustion and plasma generation contributed to the higher frequencies. Noise level was the highest (123 dB(A)) with HVOF spraying and air plasma spraying with the use of a small-diameter nozzle and hydrogen as a secondary plasma gas. All manual operators of thermal spray equipment require hearing protection. The use of different hearing protection devices is discussed, and the attenuation provided by each device is reported.

Keywords: acoustic noise, acoustic waves, crack initiation, crack propagation, plasma spraying, porosity, thermal barrier coatings, turbulence

K.A. Gross, School of Physics and Materials Engineering, Monash Univ., Monash, Vic. 3800, Australia. Cited: *J. Therm. Spray Technol., 11*(3), Sept 2002, p 350-358 [in English]. ISSN 1059-9630.

Testing

Nondestructive Testing

Application of nondestructive evaluation in aerospace coatings. Wear-resistant cermet coatings are used in aircraft landing gears and thermal barrier coatings (TBC) are applied to hot-section components of turbine engines. A series of experiments have been conducted to characterize cermet and TBC coatings using nondestructive evaluation (NDE) techniques. A cermet coating is tested using conventional ultrasonic and eddy-current methods as well as an ultrasonic leaky surface wave technique. The results demonstrate the ability of these techniques to detect the presence of defects on the surface or beneath the surface of the coating and at the coating-substrate interface. Ultrasonic time-of-flight and eddy-current quadrature measurements also show the ability to detect minute changes in the thickness of cermet coatings. Knowing the coating thickness, the density of the coating is estimated by comparison of the theoretical and the experimental transfer functions of the ultrasonic signals. Nondestructive evaluation techniques were also used to inspect thermal barrier coatings. In particular, eddy-current technique was used to measure the thickness of plasma sprayed TBC specimens, and, knowing the thickness, ultrasonic techniques were applied to obtain an estimate of the porosity content.

Keywords: aircraft parts and equipment, cermets, eddy currents, interfaces (materials), nondestructive examination, plasma spraying, porosity, surface waves, transfer functions, turbines, ultrasonic testing, wear resistance

J.S.R. Giguere, B. Roge, K.I. McRae, and A. Fahr, National Research Council of Canada, Building M-14, IAR-SMPL, Ottawa, Ont., K1A0R6, Canada. Cited: *Smart Nondestructive Evaluation for Health Monitoring of Structural and Biological Systems,* Proc. SPIE, Vol 4702, T. Kundu, Ed., 18-19 March 2002 (San Diego, CA), SPIE, The International Society for Optical Engineering, 2002, p 83-92 [in English]. ISSN 0277-786X.

Residual Stress Determination

Development of the high-precision incremental-step hole-drilling method for the study of residual stress in multilayer materials: Influence of temperature and substrate on ZrO_2-Y_2O_3 8wt.% coatings. The aim of this study was to determine internal stress locked in a zirconia ZrO_2-Y_2O_3 8 wt.% coating and substrate produced by plasma spray. Zirconia layers are suitable for thermal barrier coatings due to their high thermal isolation. The authors varied the spraying temperature and the type of substrate in order to show the technological conditions that play an important role in determining coating quality. The deposit studied consisted of partially stabilized zirconia used in the aircraft industry as a thermal barrier in combustion chambers. The high-precision incremental-step hole-drilling method was used to determine the residual stress introduced into nine samples. The authors obtained the residual stress gradient in the test specimen. Compressive residual stress has a beneficial effect on fatigue life, crack propagation, material lifetime, and coating adhesion. The stress was measured in zirconia coatings deposited on stainless steel, aluminum, and cast iron substrates at spraying temperatures of 85, 150, and 210 °C.

Keywords: crack propagation, drilling, plasma spraying, residual stresses, stainless steel, thermal barrier coatings, zirconia

G. Montay, A. Cherouat, J. Lu, N. Baradel, and L. Bianchi, GSM/LASMIS, Univ. technologie de Troyes, Troyes Cedex 10010, France. Cited: *Surf. Coat. Technol., 155*(2-3), 17 June 2002, p 152-160 [in English]. ISSN 0257-8972.

Residual stress measurement of thermal barrier coatings using laser fluorescence technique and their life prediction. Nondestructive determination of the remaining life of coatings of gas turbine parts is highly desirable. The present paper describes early attempts to prove the feasibility of doing this based on the optical measurement of the stress in the oxide that attaches the coating to the metal component. Both standard regression methods and neural network methods are compared, and it was found that the neural network approach was superior for the case where multiple signal features were present. All methods provide useful predictions for the idealized case considered.

Keywords: fluorescence, mechanical variables measurement, metals, neural networks, optical variables, measurement, oxides, regression analysis, reliability, residual stresses

E.H. Jordan, Y.H. Sohn, W. Xie, M. Gell, L. Xie, F. Tu, K.R. Pattipati, and P. Willett, Dept. Mechanical Engineering, School of Engineering, Univ. Connecticut, Storrs, CT 06269-3139. Cited: *AUTOTESTCON* (Conf. Proc.), 20-23 Aug 2001 (Valley Forge, PA), IEEE, Inst. Electrical and Electronics Engineers Inc., p 593-603 [in English]. ISSN: 0734-7510.

Scratch or Impact Loading Testing

Response of plasma sprayed alumina-titania ceramic composite to high-frequency impact loading. The life of mechanical components used for tribological and other applications, where surfaces are exposed to different types of loading, can be significantly enhanced through deposition of ceramic/ceramic composite on the surfaces. Among various spray deposition techniques, plasma spraying is most widely used. However, coatings developed through this technique need to be evaluated for performances under different conditions. The main aim of the present investigation is to study the response of the plasma sprayed alumina-titania (AT-13) ceramic composites subjected to high-frequency impact loading, in both as-sprayed and microwave-treated (post-processed) conditions in terms of indentation scar dimension and acoustic emission (AE) signals emitted by the impulsed material. The significance of AE monitoring for evaluation of critical load and duration for the onset of cracking of spray deposits is illustrated. Results show critical load and duration for the onset of cracking as 10 N and 3 min, respectively, in both cases. Results are discussed with illustrations.

Keywords: acoustic emissions, ceramic materials, crack initiation, impact resistance, microhardness, tribology

K. Vijayakumar, M.M. Mayuram, R. Krishnamurthy, and A.K. Sharma, Mechanical Engineering Dept., Indian Inst. Technology, Madras, Chennai 600 036, India. Cited: *Mater. Lett., 56*(3), Oct 2002, p 252-262 [in English]. ISSN 0167-577X.

Repeated impact test on plasma sprayed alumina insulation film for fusion reactor. The adhesive strength of insulation films for fusion reactor is important from the viewpoint in which the durability is improved. In the present study, the adhesive strength of a plasma sprayed alumina insulation film coated on the stainless steel substrate was investigated by using a repeated impact test. The impact tests were performed at three kinds of mean impact pressure, three, five, and twelve times as large as the yield strength of the substrate, about 200 MPa, in two surface materials combinations of alumina/alumina and alumina/stainless steel. In the alumina/alumina combination, the durability of the alumina films were over 30,000 cycles at the mean impact pressures of three and five times, and the authors confirmed sufficiently high adhesive strength of the alumina film. Also, the alumina/stainless combination improved the durability of the alumina film by a factor of 2.7. While at the mean impact pressure of 12 times, because the stainless steel substrate gave rise to a plastic strain that was two orders higher than the allowable strain of the alumina films, the alumina film was fractured by the propagation of cracks.

Keywords: adhesion, alumina, cracks, durability, electric breakdown, electromagnetic fields, fusion reactions, metallic films, plasma spraying, stainless steel, substrates

M. Kanari, T. Abe, Y. Kosaku, and S. Tanzawa, Hiroki, Seiji, Naka Res. Establishment, Japan Atomic Energy Research Inst., Takasaki-shi, Japan. Cited: *Nippon Genshiryoku Gakkaishi/J. At. Energy Soc. Jpn., 43*(12), Dec 2001, p 58-64 [in Japanese]. ISSN: 0004-7120.

Stiffness

Laser-induced surface acoustic waves for evaluation of elastic stiffness of plasma sprayed materials. The elastic properties of plasma sprayed deposits have been evaluated using a laser-excited surface acoustic wave (SAW) technique and an inversion processing analysis. The SAWs including Lamb and Rayleigh waves were generated in plasma sprayed NiCoCrAlY and ZrO_2, respectively, and their group velocity dispersions were used to determine the elastic properties (i.e., Young's modulus, Poisson's ratio and density) of the deposits. Estimated elastic moduli from the velocity dispersions of A_0-mode Lamb waves are in the range of 40-140 GPa for the deposits, which are much lower than the values 220-240 GPa of the comparable dense materials. The dramatic reductions in modulus and density of ZrO_2 deposit have been attributed to the presence of high porosity and particularly microcracks. Moreover, this study has emphasis on exploiting the applicability of each kind of the SAWs for the elastic property evaluation of different sprayed materials. Both Lamb and Rayleigh wave dispersions are useful for the estimation of APS and VPS-deposited NiCrAlY, but S_0-Lamb and Rayleigh waves are exceptional for that of sprayed ZrO_2, because of its characterization of high acoustic attenuation and inconsequent displacement across the weak bonded interface of ZrO_2 and substrate.

Keywords: acoustic waves, elastic moduli, interfaces (materials), laser applications, microcracks, porosity, stiffness

X.Q. Ma, Y. Mizutani, and M. Takemoto, Centre des Materiaux P.M. Fourt, 91003 Evry Cedex, France. Cited: *J. Mater. Sci., 36*(23), 1 Dec 2001, p 5633-5641 [in English]. ISSN: 0022-2461.

Thermal Properties

Thermal properties of the plasma sprayed $MgTiO_3$-$CaTiO_3$ and $CaTiO_3$. The thermal diffusivity and thermal conductivity of plasma sprayed materials $MgTiO_3$-$CaTiO_3$ and $CaTiO_3$ were investigated over the range of 20-500 °C using the flash method. The thermal diffusivity of both materials decreases with increasing temperature. The thermal conductivity of both materials is nearly the same; with increasing temperature it first decreases and then it increases. The thermal diffusivity was measured at room temperature after annealing up to 800 °C. This value increased after annealing above 600 °C.

Keywords: annealing, plasma spraying, thermal conductivity of solids, thermal diffusion

K. Neufuss and A. Rudajevova, Inst. Plasma Physics, 182 21 Praha 8, Czech Republic. Cited: *Ceram. Int., 28*(1), 2002, p 93-97 [in English]. ISSN 0272-8842.

Nucleate pool boiling on porous metallic coatings. The results of systematic experimental investigations of the heat transfer to distilled water in saturated pool boiling at atmospheric pressure are reported. The tests were conducted using stainless steel tubes of various diameters heated electrically and flat horizontal plates. Surface finishes ranged from smooth lapped finish through emery-board-finished and sandblasted surfaces to surfaces with porous coatings. Various methods of deposition: electrolytic treatment, plasma spraying, gas-flame spraying, and modified gas-flame spraying were employed to form metal coatings on flat horizontal surfaces and on the external surface of stainless steel tubes. The main goal of this investigation was to obtain information about the parameters of the porous coatings that influence the heat-transfer rate. The nucleate boiling burnout heat fluxes measured were essentially independent of surface finishes under study. Based on the obtained experimental data published until now, mathematical models of nucleate pool boiling on porous surfaces are verified with emphasis on the prediction of the heat-transfer coefficient.

Keywords: atmospheric pressure, coating techniques, heat transfer, mathematical models, plasma spraying, porous materials, stainless steel, tubes (components)

J.T. Cieslinski, Technical Univ. Gdansk, Gdansk 80952, Poland. Cited: *Exp. Therm. Fluid Sci., 25*(7), Jan 2002, p 557-564 [in English]. ISSN 0894-1777.

The effects of sample surface treatments on laser flash thermal diffusivity measurements. The effects of sample surface treatments on laser flash thermal diffusivity measurements were studied. A prediction of the relative error in the thermal diffusivity evaluation was obtained by modeling the thermal properties of the blackening layers. Results showed good agreement between the results obtained and the experimental results.

Keywords: ceramic coatings, error analysis, laser applications, light absorption, mathematical models, plasma spraying, porous materials, sprayed coatings, surface treatment, thermal diffusion

F. Cernuschi, L. Lorenzoni, P. Bianchi, and A. Figari, CESI, 20090 Segrate (MI), Italy. Cited: *Infrared Phys. Technol., 43*(3-5), June 2002, p 133-138 [in English]. ISSN 1350-4495.

Thermal properties measurements using laser flash technique at cryogenic temperature. In the frame of the Italian TRASCO program, the authors have studied the possibility to stiff SC cavities by deposition of thermal sprayed copper on thin niobium. They have investigated the use of the laser flash technique to test the thermal conductivity in the normal direction of deposited copper with the pure coat technique. The use of Au-Fe/Cromel P thermocouples as temperature sensors, motivated by the need to adapt the classical technology from room temperature to the cryogenic environment, allowed the thermal transient study. A great effort has been spent to develop data analysis procedures in order to reduce noise and heat dissipation effects. The measurements have demonstrated the reliability of the apparatus, and the results confirm the interest in the copper spraying stiffening for the SC cavities.

Keywords: data reduction, heat losses, laser applications, thermal conductivity, thermocouples, transients

G. Penco, D. Barni, P. Michelato, and C. Pagani, INFN Milano, LASA, Segrate (MI), Italy. Cited: Proc. IEEE Particle Accelerator Conf., June 18-22, 2001 (Chicago, IL), Vol 2, P. Lucas and S. Webber, Ed., U.S. Dept. Office of Naval Research, Inst. Electrical and Electronics Engineers Inc., p 1231-1233 [in English].

Wear

Use of scanning white light interferometry in the characterization of wear mechanisms in thermal sprayed coatings. Thermal spray coatings are widely used to reduce wear damage in certain engineering applications. There are several methods of measuring coating wear resistance. Among these, one of the easiest is the combination of the ball-on-disk test with interferometric measurements (noncontact profilometer). The main purpose of this article is to analyze the major wear mechanisms that occur in thermal sprayed coatings tested under sliding conditions. This work shows how scanning white light interferometry can be easily used to study the wear mechanisms of some coatings, and allows abrasive, adhesive, and fatigue wear mechanisms to be distinguished. The main features of each of these mechanisms observed through the images of the interferometric microscope are reported.

Keywords: fatigue of materials, interferometry, microscopes, tribology, wear resistance

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