Selected Abstracts of Thermal Spray Literature

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Application

Biomedical

Ion Beam Deposited Calcium Phosphate Coatings for Biomedical Applications. Using a plasma-sprayed fluorapatite (FA) target, ion sputter deposition has been successfully employed to deposit thin calcium phosphate coatings onto titanium substrates for biomedical implant applications. As identified by x-ray diffraction (XRD) and laser Raman spectroscopy, the plasma-sprayed target is highly crystalline, nearly pure FA. Typically, the as-deposited calcium phosphate coatings are amorphous and exhibit a very high dissolution rate under physiologic conditions (such as in saline solution). In order to reduce the solubility of the as-deposited coatings, crystallinity must be produced by heat treatment. Both in situ deposition annealing (300, 400, and 500 °C) and post-deposition annealing (500 and 600 °C) in air were performed. According to the results of XRD and transmission electron microscopy (TEM), only post-deposition annealing in air was able to produce the FA phase in the as-deposited amorphous coatings. Other phases in the forms of microcrystallites were also observed in the FA matrix. The higher annealing temperature (600 °C in air) has an effect of increasing the average grain size of the FA matrix and microcrystallites as compared to a lower annealing temperature (500 °C in air). However, the 600 °C post-annealed coating was found to buckle in the cooling process due to a compressive type of thermal stress.

T.-S. Chen. Cited: Dissertation Abstracts Int., Vol 53 (No. 12), June 1993 [in English]. ISSN: 0419-4217. PHOTOCOPY ORDER NUMBER 199405-57-0654.

The Effect of Coating Thickness on the Shear Strength and Failure Mode of Plasma Sprayed Hydroxyapatite Coatings to Bone. The purpose was to evaluate the effect of coating thickness on the shear strength of hydroxyapatite coating (HAC) to bone. Plasma-sprayed HA-coated (50 to 200 μm) and grit-blasted Ti-6Al-V cylinders were transcortically implanted in femora of canines. After 4, 6, 8, and 12 weeks, the implant/bone interfacial shear strength was measured by the push-out test. The results showed that the mean shear strength of 50 μm-HAC implants was higher than that of 200 μm-HAC implants for each time period, with significant difference ($p < 0.05$) found at 4 and 12 weeks. Both the HAC implants revealed significant greater mean shear strength than the uncoated ones. The maximum shear strength was 14.91 ± 4.28 MPa for 50 μm HAC implant at 8 weeks. With bone attached to the surface of HACs under observations of scanning electron microscope (SEM), the failure mode for 50 μm-HACs was in all cases at the HAC/bone interface. However, for 200 μm-HACs, the failure modes occurring at the HAC/bone, inside the coating layer and at the HAC/Ti alloy interface were found.

B.C. Wang, T.M. Lee, E. Chang, and C.Y. Yang. Cited: *Biomed. Eng.—Appl. Basis Commun.*, Vol 4 (No. 6), 25 Dec 1992, p 605-609 [in English]. ISSN: 1016-2356. PHOTOCOPY ORDER NUMBER 199404-57-0456.

Blast Furnace Slag Hole

New Process of Flame Spraying for Ceramic-Based Composite Coating With Heat Resistance. A new process, slope transition and remelting used for spraying Al_2O_3 composite heat-resistant layer on the surface of copper materials with oxyacetylene flames has been introduced. The microstructure of coating layer has been studied by using SEM. Particular attention has been paid to diffusing reaction, liquid sintering, fine grains, and other features. The effects of microstructural features on the bonding strength of coating layer, heat resistance, spalling resistance, and so forth have also been discussed. The service life of the slag hole of blast furnace by using the spraying technology and composition has increased by two times.

J.C. Gao, Y.P. Zhang, S.X. Sheng, L.H. Xie, and X.J. Wang. Cited: *Powder Metall. Technol. (China)*, Vol 11 (No. 1), Feb 1993, p 33-36 [in Chinese]. ISSN: 1001-3784. PHOTOCOPY ORDER NUMBER 199405-57-0603.

Corrosion Resistance

Corrosion Resistance of Newly Developed Inside Coated Materials in Sour Environments. A research program was conducted to evaluate new coating technologies that were applied to oil country tubular goods to improve their corrosion resistance. Six types of coating facilities for 0.5 m long pipes were constructed as candidate process. Chemical vapor deposition (CVD), physical vapor deposition (PVD), plasma transferred arc hardfacing (PTH), polymer coating, low-pressure plasma spraying (LPPS) and laser remelting of LPPS were selected. Titanium nitride was coated mainly by CVD and PVD process. High-nickel alloy was coated by LPPS and PTH process. Tetrafluorethylene-perfluoroalkylether polymer alloy (PFA) was coated by polymer coating process. Corrosion resistance of coated pipes and connections was evaluated under dynamic condition (flow rate was 40 m/s) at 200 to 230 °C in simulated sour environments. Only pipes manufactured by PTH process showed corrosion resistance at 230 °C. According to the above results, a facility manufacturing 5 m long pipe using PTH process was constructed. Tube size is 89.9 mm OD and 76 mm ID for all processes. A high-nickel alloy (15Cr-16Mo-5Fe-2Co-4W) was coated by PTH process, and its thickness was 0.8 to 1.0 mm. A corrosion test was conducted under a dynamic flowing condition. No corrosion attack was observed on the coated surface of long pipe after the corrosion test. The manufacturing procedure of PTH process is established, and its corrosion resistance is excellent.

Cited: K. Masamura, Y. Takeuchi, K. Tamaki, T. Miyagawa, and A. Nakamura. Cited: Paper No. 84, NACE International, Houston, TX, 1994 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0592.

Selection of Metallic and Non-Metallic Materials Suitable for ID Surface Coating of Production Tubings for Sour Service. A research project was conducted for developing highly corrosion-resistant tubulars with thin protective layers on ID surface of high-strength low-alloy steel (N-80) tubings. As a first step of the project, extensive experiments were performed to screen the proper coating materials and coating processes that give sufficient resistance to production environments and thus protect tubing from corrosion and cracking. The surface coatings were prepared on steel coupons and pipes by various processes such as PVD, CVD, plasma spraying, and plasma transferred arc. The tested coatings included metallic, ceramics, and polymeric materials. The screening tests consisted of corrosion tests simulating high-temperature and high-pressure sour environments and mechanical tests that simulated various types of mechanical damages during oil and gas production and workover services. The candidate materials combined with the coating processes that were chosen on the basis of these tests were subjected to trial production of actual size of production tubings and the succeeding performance tests. The compilation of test results also give a database of surface coatings to be applied in oil and gas production.

A. Miyasaka, Y. Yamaguchi, T. Miyagawa, and A. Nakamura. Cited: Paper No. 83, NACE International, Houston, TX, 1994 [in English]. PHOTOCOPY ORDER NUMBER 199405-35-1013.

Erosion/Corrosion

The Erosion-Oxidation Behavior of HVOF Cr_3C_2-NiCr Cermet Coating. DenSys DS-200 coating is a proprietary HVOF Cr_3C_2-NiCr cermet coating used in elevated-temperature service environments including fluidized bed boilers, coal-fired boilers, and municipal waste incinerators. The elevated temperature erosion-corrosion (oxidation) behavior of this HVOF Cr_3C_2-NiCr coating was investigated using a range of test temperatures, impact angles, erodents, and particle velocities. The erosion-corrosion behavior of HVOF Cr_3C_2-NiCr coatings was compared with 1018 steel and other thermal spray coatings including FeCrSiB (Armacor M), nickel-base, Cr_2O_3-$6SiO_2$-$4Al_2O_3$ (Rokide C), Cr_2O_3-$12SiO_2$-$2Al_2O_3$-4MgO (Rokide MBC), and WC-NiCrCo (SMI 712). It was found that the erosion-oxidation resistance of HVOF Cr_3C_2-NiCr coating was higher than 1018 steel and other coatings at both impact angles 30° and 90°. The erosion-oxidation behavior of coatings was well related to their morphology. The high erosion-oxidation resistance of the HVOF Cr_3C_2-NiCr coating was attributed to its low porosity, fine grain structure, and homogeneous distribution of hard carbides/oxides which form a skeletal network within a ductile and corrosion-resistant metal binder.

B.Q. Wang and K. Luer. Cited: Paper No. 539, NACE International, Houston, TX, 1994 [in English]. PHOTOCOPY ORDER NUMBER 199405-35-1074.

Permeation Barrier

Reduction of Deuterium Permeation Through DIN 1.4914 Stainless Steel (MANET) by Plasma-Spray Deposited Aluminium. The formation of a permeation barrier on DIN 1.4914 (MANET) martensitic stainless steel by plasma spraying aluminum on the surface of the steel, followed by heat treatment of the sample to form Al_3Fe and Al_5Fe_2 is described. Vacuum plasma spraying was chosen because it ensures that the sample will be exposed to low temperatures during the aluminum layer deposition and will not interfere with the heat treatment that MANET has to undergo in order to produce a homogeneous, fully martensitic structure. Measurements of the permeation rate of deuterium in the bare and aluminum-deposited MANET were performed by a gas permeation technique over the temperature range 573 to 743 K and for driving deuterium pressures in the range 3 to 50 kPa. Such measurements showed a reduction of the permeation rate between two and three orders of magnitude and there was evidence that surface reactions were the rate-governing process.

A. Perujo, K.S. Forcey, and T Sample. Cited: *J. Nucl. Mater.*, Vol 207, Dec 1993, p 86-91 [in English]. ISSN: 0022-3115. PHOTOCOPY ORDER NUMBER 199404-13-0201.

Tribological Performance

The Tribological Performance Investigation of Steels After Various Surface Treatments, Solid Lubricants Deposition, and Ceramic Coatings. The objective is to investigate the tribological performance of hard coating, soft film, and surface-treated parts (e.g., SCM415, SACM645, SCM440). The hard coatings, deposited on SDM440, include WC + 12%Co by continuous detonation spraying, ZrO_2 + 8%Y_2O_3, Cr_2O_3 + 20%ZrO_2, Cr_2O_3 + 50%ZrO_2, and Cr_2O_3 ceramic coatings by plasma spraying. The soft films are MoS_2, teflon, and MoS_2 blended with teflon, while the surface treatments include carburization, salt bath soft nitriding (TF-1), and induction. The wear testing is performed on the SRV wear machine under dry and lubricated conditions, respectively, and 100Cr6 steel ball is used. Scanning electron microscopy was used for wear mechanism observation and x-ray diffraction identified the phase transformation during coating process. The experiment concluded that: (1) of all the ceramic coatings investigated under dry wear, WC-Co possesses the lowest coefficient of friction, and the coefficient of friction plotted against time can be classified into four different types. (2) The WC-Co possesses the highest wear resistance. Among the solid lubricants, the teflon coating coupled with tufftrided pretreatment, under dry wear, and phosphating pretreatment under lubricated wear, possesses the best wear resistance. Carburization is the most wear-resistant treatment of the surface treatments. (3) The worn surface of Cr_2O_3 under dry wear depicted the wear mechanisms of microcracking, while the dominant wear mechanism of steel/ceramic coating pair is material transfer of steel to the ceramic surface, the adhesion is very severe. The metal transfer, identified from ceramic surface, is much reduced under lubricated wear. (4) The solid lubricant coated specimens that possess the lower coefficient of friction, and ceramic coatings and surface treatments that possess lower surface roughness, will induce better wear resistance.

Y.L. Su, J.S. Lin, J.L. Hunge. Cited: *Chinese J. Mater. Sci.*, Vol 25 (No. 4), Dec 1993, p 283-294 [in Chinese]. ISSN: 0379-6906. PHOTOCOPY ORDER NUMBER 199404-57-0535.

Characterization

Experimental Design

Evaluation of High Energy Plasma Sprayed WC-Co Coatings Using Experimental Design. Experimental design is an effective means of producing optimum spraying parameters to enhance thermal sprayed coatings. A range of WC-Co coatings is widely used in the aircraft industry to resist severe wear environments. The Box, Bisgaard, and Fung experimental design method was employed to study the relationship between plasma spraying parameters and coating properties for WC-12Co coatings. The coating properties examined were hardness, bond strength, porosity, and microstructural evaluation.

T.C. Nerz, J.E. Nerz, B.A. Kushner, and W.L. Riggs. Cited: *Surf. Eng.*, Vol 9 (No. 3), 1993, p 213-220 [in English]. ISSN: 0267-0844. PHOTOCOPY ORDER NUMBER 199404-57-0439.

Thermal Barrier Coatings

Microstructural Characterization of Plasma-Sprayed Zirconia Thermal Barrier Coatings by X-Ray Diffraction Full Pattern Analysis. Thick two-layered thermal barrier coatings made of Ni-Co-Cr-Al-Y and yttria-partially stabilized zirconia were plasma sprayed at controlled deposition temperature onto stainless steel substrates. During the spraying of the top coat, the deposition temperature was kept as constant as possible using a front air or liquid-argon-cooling system. The correlation between process parameters and microstructure was investigated by scanning electron microscopy and x-ray diffraction (XRD) analysis. The application of a new procedure for XRD data processing, based on the Rietveld method, made it possible to obtain good accuracy in the phase determination and quantitative evaluation of zirconia polymorphs. Moreover, the crystallite size and microstrain were refined simultaneously to phase percentages. Also the preferred orientation in the coating could be taken into account, adding useful information and increasing the reliability of all the other results. The influence on the coating microstructure of changing the deposition temperature and environment is also discussed.

P. Scardi, L. Lutterotti, and E. Galvanetto. Cited: Conf.: 20th Int. Conf. Metallurgical Coatings and Thin Films. I (San Diego, CA), 19-23 April 1993, *Surf. Coat. Technol.*, Vol 61 (No. 1-3), 3 Dec 1993, p 52-59 [in English]. ISSN: 0257-8972. PHOTOCOPY ORDER NUMBER 199404-57-0468.

Composites

Fiber Reinforcement

Development of Thermally Sprayed Metal-Matrix Composites With Optimized Mechanical Behavior. Improvement of strength and toughness defines the main goals by processing fiber-reinforced metal-matrix composites (MMCs) for structural applications by thermal spraying. To achieve these goals the role of fiber-matrix interface, for example, the influence of mechanical interface properties on composite load-bearing behavior and fracture mechanisms must be understood. Investigation has been made on austenitic stainless steel (e.g., X12CrNi17.7) (continuous) fiber-reinforced NiCr alloy (NiCr18Al6Si) with 15% fiber volume content. Two series of samples with different interface properties were evaluated. The composite mechanical behavior was determined in tensile test, the interface properties were estimated in a push-out test. The experimental results are discussed with relation to theoretical predictions.

H. Kern and J. Janczak. Cited: Conf.: Advanced Composites '93: International Conference on Advanced Composite Materials (Wollongong, Australia), 15-19 Feb 1993, Minerals, Metals & Materials Society, Warrendale, PA, 1993, p 1157-1159 [in English]. PHOTOCOPY ORDER NUMBER 199404-62-0694.

Feedstock

General Review

Flame Spraying: Quality Powder Is Stipulated for Result [Original Title: Vlamspuiten: Kwaliteit Poeder is Bepalend Voor Resultaat]. The powder manufacturing process and powder characteristics influence the thermal spraying process and the properties of the coating produced. As well as chemical composition, powders are characterized by grain shape, grain size, and grain size distribution. The influence of the production process on these factors is discussed. The most common powder manufacture processes, spray drying, coating, vaporization, arc smelting, sintering and plasma smelting, are described, noting their advantages, disadvantages, and particular uses. A significant new development is the production of hollow spray powders. The importance of powder quality is stressed, and aspects covered by quality control are outlined.

T.G. Kraak. Cited: *Met. Kunstst.*, Vol 31 (No. 11), 1 June 1993, p 20-23 [in Dutch]. PHOTOCOPY ORDER NUMBER 199404-58-0396.

Spraying of Zirconia

Energy Problems and Thermal Spraying. Plasma spraying is important surface modification technology. The need for a coating system in the field of energy production such as fusion reactor, MHD, coal conversion, terrestrial heat high efficiency engine, space and ocean developments, biomedical use, fuel cell, and superconductor film, and so forth, is now widely spreading. The comparison of various spraying means such as LPS, HVOF, and APS is made from the viewpoint of getting a good quality coating. How to obtain perfectly molten ZrO_2 by the use of hybrid and multi-arc coating means is discussed. B-1900 nickel base superalloy is also discussed.

N. Iwamoto. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Thermal Spray. Soc.)*, Vol 30 (No. 4), Dec 1993, p 34-41 [in Japanese]. ISSN: 0916-6076. PHOTOCOPY ORDER NUMBER 199404-57-0438.

Ti-Ni-Cu-P

Spraying of Composite Powder TiC-Ni-Cu-P in Plasma of Combustion Products. Peculiarities of spraying and properties of coatings of composite TiC-Ni-Cu-P powder are studied. It is shown that spraying with supersonic plasma jet of combustion products provides high quality products: adhesion, 40 to 60 MPa; porosity, 3 to 5%. Such coatings are characterized by high wear resistance and recommended to be used in friction units.

S.V. Petrov and S.A. Sin'kovskii. Cited: *Poroshk. Metall.*, (No. 9-10), Sept-Oct 1993, p 43-47 [in Russian]. ISSN: 0032-4795. PHOTOCOPY ORDER NUMBER 199405-57-0628.

Materials

MoSi

Protecting Properties of Oxidation Resistant Plasma Sprayed $MoSi_2$ Coating. $MoSi_2$ behaves in a ductile manner in the temperature range >1273 K. Moreover, this material has so-called self-repairing property due to its capability to form protective SiO_2 layer on the surface until silicon would be consumed. $MoSi_2$ coating on SUS 304 steel or Ti-6Al-4V alloy was made by plasma spraying, and to examine the oxidation resistance property of the coating itself, weight gain after oxidation was measured. For the evaluation of the oxidation-protecting property, both ferroxyl test and gas permeability test were carried out on the oxidized coatings. Weight gain was observed in the LPPS coating after the various oxidation tests. This is attributed to the formation of SiO_2 layer on $MoSi_2$ surface. In both ferroxyl test and gas permeability test, the drastic decrease of the through porosity in the coating was recognized. Moreover, SiO_2 oxide was observed in the pre-crack tip region after the oxidation test. Consequently, $MoSi_2$ coating seems to have the possibility of void sealing effect by the formation of SiO_2 layer while the coating material is exposed to the oxidation atmosphere.

M. Fukumoto, T. Ueda, and I. Okane. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Thermal Spray. Soc.)*, Vol 30 (No. 4), Dec 1993, p 20-25 [in Japanese]. ISSN: 0916-6076. PHOTOCOPY ORDER NUMBER 199404-57-0436.

Modeling

Plasma Spray Process

Computer Modelling of the Manufacturing Process of Ceramic Thermal Barrier Coatings. Some recent results of a computer model of the deposition process for plasma spraying ceramic coating are presented. The developed model contains three parts: first, it simulates the construction of the coating by projecting particles of known radius and velocity onto a substrate. These splash to form thin disks and interact to form the coating. The results of the calculation are the variations of temperature, porosity, and shape of the pores in the coating as a function of process parameters. Porosity distributions are then transformed by micromechanical theories into the actual macroscopic mechanical properties of the coating needed by any continuum model. The computed thermal and mechanical properties are used in finite element simulation of the coating to calculate the stresses induced by the spraying process in a yttria-stabilized zirconia coating on a flat nickel-base superalloy plate. The residual stresses are assumed to be due to the subsequent cooling.

G. Jacucci, S. Dirolini, M. Marchese, and J.H. Harding. Cited: Conf.: *Computational Plasticity: Fundamentals and Applications*, Part II (Barcelona, Spain), 6-10 April 1992, Pineridge Press Limited, Swansea U.K., 1992, p 1683-1695 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0578.

Temperature during Spraying

Analysis of Temperature Conditions in the System "Coating-Sublayer-Basis" under Gas-Thermal Spray-Coating of Composite Powders. Peculiar features of a state of the laminar heterogeneous systems, multilayer coating-sublayer-base (copper-graphite-steel), have been studied under conditions of plasma spraying of clad composite powders. Typical results of the quasi-stationary heat-transfer process mathematical simulation have been presented for the above system.

V.G. Prokopov, N.M. Fialko, Yu.V. Sherenkovskii, G.P. Sherenkovskaya, Yu.S. Borisov, V.N. Korzhik, and A.P. Murashov. Cited: *Elektron. Obrab. Mater.*, (No. 2), Feb 1992, p 12-15 [in Russian]. ISSN: 0013-5739. PHOTOCOPY ORDER NUMBER 199405-58-0543.

Patent

Automotive Disk Brake

Composite Disk Brake Rotor With Self-Lubricating Coating and Method of Making Thereof. A method of making a disk brake rotor with a self-lubricating, thermally conductive coating thereon that enhances the friction wear life of a disk brake assembly within which it is used comprises: (a) controllably roughening at least the outside braking surfaces of a lightweight metal disk brake rotor, the roughening being carried out to promote mechanical adhesion of coatings applied thereover; (b) thermal spraying one or more coatings onto the roughened outside braking surface, the exposed coating being electric arc sprayed using a codeposit of iron-base material and powdered graphite to form an iron matrix composite coating; and (c) surface heat treating essentially said exposed coating to dissolve and precipitate graphite and to form a simulated cast iron and also to densify the coating and remove residual stresses resulting from deposition. The rotor may be made of aluminum, magnesium, or alloys or metal-matrix composites of such metals. An intermediate layer of a nickel-base alloy containing graphite may be applied to form a thermal barrier. An intermediate adhesion layer of an aluminum-cast iron composite, a nickel/aluminum composite, or a nickel-base alloy may be applied as an adhesion enhancing intermediate layer. The surface heat treating may be carried out by use of a laser, or by pulsed arc lamp heating or induction heating.

G.S. Cole and R.C. McCune, Jr. Cited: Patent: GB2268511, United Kingdom, 7 July 1993, 12 Jan 1994 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0641.

Corrosion-Resistant Coating

A Corrosion Coating and Process for Producing It. Disclosed is an impervious corrosion-resistant Ni-Cr coating on a metallic substrate that protects the substrate from a corrosive medium and a process for producing the coating on the substrates by thermal spraying. The substrate may be, for example, of steel or an aluminum, nickel, or cobalt alloy.

A.A. Ashary and R.C. Tucker. Cited: European Patent EP0560544A2, 5 March 1993, 15 Sept 1993 [in English]. PHOTOCOPY ORDER NUMBER 199405-58-0500.

Feedstock

Molten Zinc Resistant Alloy. Disclosed is an alloy of 3 to 9 wt% B with the balance Mo, which may be used as a thermal spray coating for articles intended to be exposed to molten zinc (e.g., stainless steel pot rolls in hot dip zinc plating lines).

J.C. Wood, S. Katoh, and H. Nitta. Cited: Patent: European Patent EP0570219A2, 13 May 1993, 18 Nov 1993 [in English]. PHOTOCOPY ORDER NUMBER 199405-58-0501.

Feedstock for Arc Spraying

Flux Cored Wire. A specific flux cored wire for application to essentially bare metal (e.g., steel) surfaces or for thermally spraying (e.g., arc spraying) base metal surfaces having imperfections (e.g., voids) therein is characterized in that the wire is constructed of a copper-base alloy consisting essentially of 5.5% Sn, 2.0% Si, and the balance Cu.

D.D. Kiilunen and D.A. Sart. Cited: Patent: GB2268432, United Kingdom, 2 Jan 1991 [in English]. PHOTOCOPY ORDER NUMBER 199405-58-0564.

Net Shape Manufacturing Process

High-Velocity Flame Spray Apparatus and Method of Forming Materials. A thermal spray apparatus for producing very dense material such as coatings and free-standing near-net shapes comprises a thermal spray gun including a body portion receiving feedstock, means for heating the feedstock and accelerating the heated feedstock, and a barrel portion having an inlet receiving the heated accelerated feedstock and an outlet directing the heated accelerated feedstock towards a target. Also there are liquid feed means for feeding a molten metal feedstock into the heated accelerated feedstock adjacent to the barrel portion outlet, the accelerated feedstock atomizing the molten metal feedstock and projecting the atomized molten metal feedstock substantially uniformly distributed in the heated feedstock at the target.

D.R. Marantz. Cited: European Patent EP0570084A2, 7 Sept 1989, 18 Nov 1993 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0560.

Solid Lubricant Composites

Thermally Spraying Metal/Solid Lubricant Composites Using Wire Feedstock. A method of thermal spraying a solid lubricant (e.g., graphite or BN) impregnated metal matrix onto a metal target, comprises the steps of: (a) creating a flame or arc into which a consumable strand is fed, the strand being constituted as a hollow sheath of metal and a core therein comprising essentially solid lubricant powder particles, the flame or arc melting the metal of such strand; (b) applying a pressurized jet of atomizing gas to the melt and lubricant particles to project a spray of molten heavy metal and lubricant particles generally homogeneously distributed throughout such spray, the graphite being protected against ablation during transit from the flame or arc to the target; and (c) surface heat treating essentially only the deposit to precipitate additional graphite while densifying the metal and controlling microstructure. The metal may be iron, aluminum, nickel, copper, molybdenum, or alloys thereof. When graphite is used it may be encapsulated in a protecting material, for example, nickel, silicon carbide, or boron trioxide. The target may be aluminum, magnesium, or alloys thereof. The method finds particular application in the production of engine blocks for an internal combustion engine.

M.J. Zaluzec, R.C. McCune, Jr, and L. Van Reatherford. Cited: Patent: GB2268510, United Kingdom, 7 July 1993, 12 Jan 1994 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0639.

Tungsten Carbide Composites

Process for Producing Immersion Member of Molten Metal Bath. The process comprises forming on the surface of the base for the immersion member of flame spray coating comprising 1 to 50 wt% of tungsten boride, 3 to 25 wt% of at least one metal selected among nickel, cobalt, chromium, and molybdenum, and the balance of tungsten carbide and inevitable impurities, impregnating the formed coating with a liquid treatment mainly comprising chromic acid (H_2CrO_4 and $H_2Cr_2O_7$), and burning the resulting coating. This process provides an excellent immersion member which has a dense and firm surface coating layer which has not been available heretofore, is excellent in the resistance to erosion, erosive peeling and abrasion, and scarcely undergoes adhesion of metal.

Cited: M. Mizunuma, T. Uchiyama, and K. Tarumi. Cited: European Patent EP569585A1, 29 Nov 1991, 18 Nov 1993 [in English]. PHOTOCOPY ORDER NUMBER 199405-57-0559.

Properties

Stresses

Residual Micro- and Macrostresses in the Plasma-Sprayed Zirconia-Based TBCs. Micro- and macrostresses and the size of coherently diffracting domains were studied with the aid of x-ray diffraction in plasma-sprayed ZrO_2-$7Y_2O_3$ thermal barrier coatings (TBCs) as functions of substrate (a nickel-base superalloy) temperature. The macrostresses were measured by the $\sin^2 \psi$-technique, the microstresses and the domain size were evaluated from x-ray line broadening. The changes in the macrostresses were explained by differences in the thermal contractions of the ceramic layer and the metallic substrate, while the variations in the microstresses were attributed to the growth of the m-ZrO_2 phase with the increase of the substrate temperature during deposition. The increase in dislocation density associated with the formation of the m-ZrO_2 phase was revealed by XRD and was also confirmed by transmission electron microscopy.

M. Levit, I. Grimberg, and B.-Z. Weiss. Cited: *Mater. Lett.*, Vol 19 (No. 1-2), March 1994, p 48-52 [in English]. ISSN: 0167-577X. PHOTOCOPY ORDER NUMBER 199405-57-0566.

Surface Modification

Laser Glazing

Characterization of Laser Produced High Molybdenum Surface Alloys on Stainless Steel Substrates. High molybdenum surface alloys on stainless steels 304L and 316L were produced by laser surface alloying. For this, a layer of 60 μm thickness was overlaid on the substrates by plasma spraying of molybdenum powders. These were further treated by a Nd:YAG pulsed laser for alloying. Depths of alloying in the range of 440 to 1110 μm were achieved. Concentration in the range of 5.2 to 15.0 wt% Mo within the laser-alloyed zone was, in general, uniform throughout. During alloying, in situ heating at 700 °C was required to prevent cracking in samples with 5.2 to 6.0 wt% Mo. Higher molybdenum content enhanced the cracking tendency and made it difficult to prevent cracking completely even at this temperature. Fully austenitic microstructure of the substrate metals transformed to austenitic-ferritic duplex for 5.2 to 9.0 wt% Mo and to fully ferritic for 15.0 wt% Mo. Primary solidification mode also changed to FA, FA + F, and finally to F depending upon molybdenum content in the alloyed zone. Ferrite content in the alloyed zone was in the range of 31 to 79% depending upon the amount of molybdenum. Microhardness was increased from 173 VHN for 316L to 198 to 790 VHN depending upon wt% molybdenum in the alloyed zone. Preliminary studies indicated that pitting potential in 3.5% NaCl aqueous solution improved substantially from 132 mV for 304L and 240 mV for 316L to 480 mV and 500 mV, respectively, for 5.5 to 6.0 wt% Mo in the alloyed zone.

D. Kumar, A.R. Biswas, G.L. Goswami, K. Sridhar, and M.B. Deshmukh. Cited: *J. Laser Appl.*, Vol 5 (No. 2-3), Fall 1993, p 23-32 [in English]. ISSN: 1042-346X. PHOTOCOPY ORDER NUMBER 199404-58-0456.

Testing

Adhesion

Evaluation of Adhesive Strength of Thermal Sprayed Coatings and Its Modelling. A relation between the adhesive strength and surface characteristics of substrates is presented. The topography of the substrate surfaces is evaluated by average surface roughness and fractal dimension established by Mandelbrot. The adhesive strength is proportional to both average surface roughness and fractal dimension. The shear adhesive strength increases with average surface roughness and its fracture mode consists of three different types. Finally, the substrate surfaces are modeled by series of circular arcs and the microscopic adhesive strength is discussed based on a proposed model.

S. Amada and H. Yamada. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Thermal Spray. Soc.)*, Vol 30 (No. 4), Dec 1993, p 26-33 [in Japanese]. ISSN: 0916-6076. PHOTOCOPY ORDER NUMBER 199404-57-0435.

Thermal Shock

Thermal Shock Characteristics of Thermally Sprayed ZrO_2 Coatings with Overlay Coated Aluminum. The thermal sprayed ZrO_2 coating has been used for the improvement of thermal resistance. The coatings, however are often subjected to cracks and exfoliations. The effect of aluminum overlay coating of the thermal shock characteristics of specimen with ZrO_2 coating was investigated. The test specimen was a round bar of SUS 304 stainless steel and SS400 steel, thermal spray coated with ZrO_2 to a thickness of 0.1 mm on the 80Ni20Cr (0.1 mm in thickness). The thermal shock test was conducted by the repetition of heating at 1273K for 300 s and subsequent quenching into water. The results obtained are as follows: (1) The initiation of cracks or exfoliations of ZrO_2 coating is delayed by the overlay coating of aluminum, in the course of the repetition of thermal shock. (2) Aluminum overlay coating also brings about a sealing effect to the pores remaining in the ZrO_2 coating and makes a contribution to a rise in the degree of cohesion between particles. (3) Residual stress of thermal sprayed ZrO_2 coating is small, for reasons of occurrence of microcracks and decrease of thermal strain, due to the overlay coating of aluminum onto the sprayed ZrO_2 layer at high temperature. This residual stress in compression is accumulated in the coating with the increase of the number of heat shock cycles.

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