Selected Abstracts of Thermal Spray Literature

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Applications

Protection of Steel

Guide for the Protection of Steel With Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites.

American Welding Society, Miami, FL, 1993 [in English]. PHOTOCOPY ORDER NUMBER: 199311-72-0528.

Coatings for Belts

The Evolution and Importance of Hazelett Caster Belt Coatings. In the Hazelett continuous casting process, the character and quality of belt surfaces and belt coating plays a very important role in achieving stability of the process and acceptable quality of cast product. This paper reviews the evolution of belt coatings from the early days of the Hazelett continuous twin-belt casting process until today. The paper covers lead, zinc, aluminum, copper and steel casting, with special emphasis on Al. The use of liquid, solid, ceramic and powder coatings and their influence on the liquid metal/belt interface, cast metal quality and casting belt stability, are discussed. Photomicrographs.

W. Szczypiorski. Cited: Conference: Aluminum Cast House Technology: Theory & Practice (Melbourne), 4-8 July 1993, The Minerals, Metals & Materials Society, Warrendale, PA, 1993, p 321-331 [in English]. PHOTOCOPY ORDER NUMBER: 199311-51-1629.

Corrosion

Thermal Sprayed Aluminium Coatings in Seawater With and Without Cathodic Protection. In the last few decades the use of thermal sprayed aluminum and Al alloys for protection of steel in marine atmospheres has been of benefit, although the application of these types of coatings for protection of steel immersed in seawater is not so usual. This paper investigates thermal sprayed Al coatings in seawater. The following coatings have been tested: arc and flame sprayed Al, Al5%Mg and 85%Zn15%Al, both with and without a vinyl sealer. The corrosion of the coatings was measured by the linear polarization technique (LPR). Further, the current demands at the anode potential (−1040 mV SCE) were obtained as a function of time. Polarization to higher potentials was also made to measure the ability of the coatings to supply current to unprotected steel areas. The results indicate low corrosion rates, e.g. <10 μm/year, can be obtained at an average sea temperature of 10-15 °C, and near stagnant seawater flow conditions. The current consumption at the anode potential is much lower than obtained on steel. The measured currents indicate a reduction in anode load to 10% of the load necessary for protection of bare steel. In contrast to the case for immersed painted steel, the damaged part of the total protected area by sprayed Al is supposed to be constant throughout its lifetime. The Al-coatings are also able to act as sacrificial anodes and protect steel in narrow areas where the current from the anode is hindered.

P.O. Gartland and T.G. Eggen. Cited: *Marine Corrosion of Stainless Steels: Chlorination and Microbial Effects*, The Institute of Materials, London, 1993, p 195-211 [in English]. PHOTOCOPY ORDER NUMBER: 199311-35-1898.

Diesel Engine

A Study on the Effect of Ceramic Coating on the Performance in a Diesel Engine. Application of thermal barrier coatings on engine parts is difficult because of high thermal forces. Successful results can be achieved if a combination of proper material with suitable thermal expansion coefficient, optimum coating thickness and appropriate coating methods is chosen. PSZ coating on the cast iron parts seems promising. In terms of diesel engine performance, the specific fuel consumption may decline if the engine is operated at low speed and load. As the coating thickness and area increase, an increase in exhaust gas temperature, decrease in cooling system losses and improvement in engine efficiency are among the expected results.

H.A. Celik. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 217-221 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0156.

Thermal Barrier Coatings

Properties of Plasma Sprayed Thermal Barrier Coatings. Thermal barrier coatings were prepared by plasma spraying method. The effects of varying spray parameter such as H_2 flow rate, plasma current, and spray distance on the coating properties were evaluated. The results showed that bonding strength decreased with lower H_2 flow rate. The coated surface roughness decreased with increasing H_2 flow rate. Besides, H_2 flow rate is the dominant factor on the top coat microstructure. SUS410 and SUS304 stainless steels coated with Metco 202NS (ZrO_2-20% Y_2O_3) and Amdry 962 (NiCrAlY) are discussed.

D.J. Chan, B.C. Wu, J.D. Wu, C.S. Jong, and Y.M. Peng. Cited: *Ch. J. Mater. Sci.*, Vol 25 (No. 3), Sept 1993, p 194-197 [in English]. ISSN: 0379-6906. PHOTOCOPY ORDER NUMBER: 199401-57-0079.

Biomaterials

Radiofrequency Process

A Radio-Frequency Thermal Plasma Spraying for Coating of Hydroxyapatite. The characteristics of novel coating method of hydroxyapatite (HAp) using a radio-frequency thermal plasma were studied. HAp powders (100-200 μm) introduced into the argon plasma (4 MHz, 3-12 kW) were coated on polycrystalline ZrO_2 substrate. High HAp contents in the coated layer were obtained by controlling plasma powers and substrate temperatures. Highly preferred orientation of (00l) planes of HAp crystals in coatings was also observed. The orientation factors were strongly dependent on plasma powers, substrate temperatures, and carrier gas rates. The formation mechanism of the preferred orientation was explained by unidirectional crystallization process. Coatings without contamination with electrode were also obtained by this method. The rf plasma spraying process was thought to be promising for the coating of HAp as a biocompatible material.

T. Kameyama, K. Onuma, M. Ueda, K. Fukuda, A. Hasegawa, K. Akashi, A. Motoe. Cited: 1st Int. Conf. Processing Materials for Properties (Honolulu), 7-10 Nov 1993, The Minerals, Metals & Materials Society (TMS), Warrendale, PA, 1993, p 1097-1100 [in English]. PHOTOCOPY ORDER NUMBER: 199401-E7-C-0004.

Biomedical Materials

Ceramic Formation on Metallic Surfaces (Ceramization) for Medical Applications. Surface transformations can be performed on metals in order to combine their load-bearing properties to the inertness and wear resistance of ceramics. In a joint prosthesis, metals are useful for their high fatigue strength and ductility, but they are more sensitive to superficial corrosion and wear than ceramics. Coating a ceramic on a metallic surface will improve the qualities of the metallic component. The various ways of transforming a metallic surface into a ceramic one are described. First, the surface treatments to improve the friction and wear properties are analyzed. Coatings and surface transformations give superficial inert compounds. Many techniques are used to create hard, corrosion resistant layers on the surface. The processes may involve heating of the treated parts. But some metals cannot be heated without an alteration of their mechanical properties. The adhesion strength—and thus, the lifetime—of the ceramic layers depends on the binding forces and on the structure of the interfaces between the bulk metal and the outermost ceramic. Coatings generally have a lower adhesion strength than in situ formed phases and the risk of peeling is higher. Second, the plasma-sprayed coatings performed to improve the bone anchorage are described. This review does not deal with bioactive materials. So, only the alumina coatings and their mechanical compatibility advantage are presented. Titanium alloys as substrates are discussed.

J. Rieu. Cited: *Clin. Mater.*, Vol 12 (No. 4), 1993, p 227-235 [in English]. ISSN: 0267-6605. PHOTOCOPY ORDER NUMBER: 199401-57-0082.

Composites

Synthesis of Discontinuously Reinforced Metal-Ceramic Composites Using Spray Atomization and Deposition Processing. In an attempt to optimize the structure and properties of particulate-reinforced metal-matrix composites (MMCs), a variety of novel synthesis techniques have evolved over the last few years. Among these, the technique of spray processing offers a unique opportunity to synergize the benefits associated with fine particulate technology, namely: microstructural refinement and compositional modifications, coupled with in situ processing, and in some cases, near-net shape manufacturing. Spray technology has resurrected much interest during the last decade and there now exists a variety of spray based methods. These include spray atomization and deposition processing, low pressure plasma deposition, modified gas welding techniques and high velocity oxyfuel thermal spraying. Spray atomization and deposition processing involves the mixing of

reinforcements with the matrix material under nonequilibrium conditions. As a result, there is an opportunity to modify and enhance the properties of existing alloy systems, and also to develop novel alloy compositions. In principle, such an approach will inherently avoid the extreme thermal excursions, and the concomitant macrosegregation associated with conventional casting processes. Furthermore, this technique also eliminates the need to handle fine reactive particulates associated with powder metallurgical processes. The spray atomization and deposition processing of discontinuously reinforced metal-matrix composites (e.g. 6061/SiC, A356/SiC, Ni_3Al/TiB_2) is presented and discussed with particular emphasis on the synergism between processing, microstructure, and mechanical properties.

T.S. Srivatsan and E.J. Lavernia. Cited: Conference: Processing and Fabrication of Advanced Materials for High Temperature Applications. II (Chicago) 1-5 Nov 1992, The Minerals, Metals & Materials Society, Warrendale, PA, 1993, p 141-168 [in English]. PHOTOCOPY ORDER NUMBER: 199311-62-1749.

Performance of a Copper-Based Composite Coating for Steel Casting Applications. Materials in contact with solidifying steel in continuous strip casting operations should have high thermal conductivity, good thermal shock resistance, and high chemical inertness to liquid steel. A good wear resistance could be mandatory particularly during the breaking-in period. A new copper-based composite coating material has been developed in order to fulfill these requirements. This paper presents an evaluation of this coating in comparison with two nickel-based coatings and a ceramic coating. The coating performance was evaluated in a laboratory casting facility and high pressure solidification experiment. This Cu-based coating performed very well on a 4340 steel roll and was found suitable for repeated use in an actual strip casting machine. The good behavior of this coating was related to its particular microstructure and its ability to form a continuous ceramic layer inert to liquid steel.

J.-G. Legoux, S. Dallaire, D. Larouche, and A. Guillet. Cited: Conference: Developments and Applications of Ceramics and New Metal Alloys (Quebec City), 29 Aug.-2 Sept 1993, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, 1993, p 273-282 [in English]. PHOTOCOPY ORDER NUMBER: 199311-51-1690.

Particle Reinforcement

Particle Reinforced Coatings—Processing and Mechanical Properties. Particle reinforced coatings of conventional Ni-base hard alloys have been produced using different thermal spray processes. The improvement of the different particles on the abrasive wear performance could be stated and the influence of the spray processes was described. Nickel-base hard alloys reinforced by hard particles can be used in abrasive wear conditions. The processing of the coatings as it affects metal/hard phase interactions and hard phase compositions has to be taken into account and adopted to the application.

E. Lugscheider and P. Jokiel. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 159-164 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0155.

Residual Stress

Residual Stress Characteristics of Gradation Coating Components. The residual stresses of gradation coating components induced by a fabrication process were analyzed by comparison with two-layer composites prepared by a direct bonding. First, the gradation coating components of stabilized zirconia/nickel based alloy composites were chosen for a finite element method analysis of residual stress distributions. It was verified that the residual stresses at the interface produced by a uniform heating process decreased by use of the gradation techniques. Especially, stress singularities at the edge of the interface of the direct bonding composites disappeared in case of the gradation coating components. However, the residual stresses at the surface of the gradation coating could not be decreased using the gradation techniques. Second, the effects of the gradation geometry and material constants, such as Young's modulus and thermal expansion coefficients on the residual stresses of the gradation coating components were investigated by the thermoelastic analysis using a finite element method. As a result, it was found that the residual stresses could be effectively analyzed by application of the dimensionless parameter, which is $\sigma\ (1 \times \mu_2)/[E_2(\alpha_1 - \alpha_2)\Delta T]$ (σ; residual stress, $\mu_1 = \mu_2$; Poisson's ratio, E_2; Young's modulus of coating film 2, $(\alpha_1 - \alpha_2)$; difference of thermal expansion coefficients between substrate one and coating film two, ΔT; temperature difference) in case of the gradation coating components. The analytical results indicated that the dimensionless residual stresses decreased with increasing the coating thickness ratio, t/T (t: coating thickness, T: substrate thickness) and Young's modulus ratio, E_2/E_1.

Y. Itoh, M. Takahashi, M. Miyazaki, and H. Kashiwaya. Cited: *J. Soc. Mater. Sci. Jpn.*, Vol 41 (No. 469), Oct 1992, p 1575-1580 [in Japanese]. ISSN: 0514-5163. PHOTOCOPY ORDER NUMBER: 199311-62-1576.

Diagnostics of Particles

Behavior of Ni-Al Particles in Argon: Helium Plasma Jets. To better understand the plasma spray coating process, an experimental study of the interaction between a subsonic thermal plasma jet and injected Ni-Al particles was performed. The velocity, temperature, and composition of the Ar/He gas flow field were mapped using an enthalpy probe/mass spectrometer system. The sprayed particle flow field was examined by simultaneously measuring the size, velocity, and temperature of individual particles. Particle and gas temperatures were compared at the nominal substrate stand-off distance and axially along the median particle trajectory. Temperature and velocity differences between the particle and the gas surrounding it are shown to vary substantially depending on the trajectory of the particles. On the median trajectory, the average particle is transferring heat and momentum back to the plasma by the time it reaches the substrate. Because the exchange of heat and momentum is highly dependent on the particle residence time in the core of the plasma, the condition of particles at the substrate can be optimized by controlling the particle trajectory through the plasma.

W.D. Swank, J.R. Fincke, and D.C. Haggard. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 243-250 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-58-1269.

Experimental Design

A Design of Experiment Study of Plasma-Sprayed Alumina-Titania Coatings. An experimental study is presented of the plasma spraying of alumina-titania powder. This powder system is being used to fabricate heater tubes that emulate nuclear fuel tubes for use in thermal-hydraulic testing. Coating experiments were conducted using a Taguchi fractional-factorial design parametric study. Operating parameters were varied around the typical spray parameters in a systematic design of experiments to display the range of plasma processing conditions and their effect on the resultant coating. The coatings were characterized by hardness and electrical tests, image analysis, and optical metallography. Coating qualities are discussed with respect to dielectric strength, hardness, porosity, surface roughness, deposition efficiency, and microstructure. The attributes of the coatings are correlated with the changes in operating parameters.

T.J. Steeper, D.J. Varacalle, Jr, G.C. Wilson, W.L. Riggs II, A.J. Rotolico, and J. Nerz. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 251-256 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-61-1435.

Experimental Design

Characterization of Vacuum Plasma Sprayed Mechanofused NiAl. Vacuum plasma spray is a melt spray process capable of producing coatings or near-net shaped deposits with ultra-fine grained structures. Mechanofusion is a novel technique for processing powdered materials. In this study, mixtures of elemental nickel and aluminum powders either blended or mechanofused, were vacuum plasma sprayed, yielding a series of Ni-Al intermetallic phases. Mechanofusion resulted in significant effects on the phase distribution in subsequently as-sprayed deposits. After heat treatment at 1100 °C, single phase NiAl was obtained for both the mechanofused and blended samples. The microhardness of the NiAl is comparable to that produced by other methods. These preliminary experiments indicate that mechanofusion and vacuum plasma spraying can be employed to produce various compounds using mixed elemental powders.

Z.J. Chen, H. Herman, C.C. Huang, and R. Cohen. Cited: Conference: High-Temperature Ordered Intermetallic Alloys V (Boston), 30 Nov-3 Dec 1992, Materials Research Society, Pittsburgh, PA, 1993, p 835-840 [in English]. PHOTOCOPY ORDER NUMBER: 199311-12-1563.

Feedstock

Nd-Fe-B Materials

Thermal Spray of Nd-Fe-B. Among the materials consisting of rare earth metals, transition metals and boron, Nd-Fe-Co-B based materials are used for plasma spray coating at low pressure. Plasma spraying was conducted using argon or N_2 gas for plasma forming gas, and using the same gas as plasma forming gas for atmosphere gas. The sprayed films on mild steel on aluminum substrates are estimated by means of EPMA and x-ray diffraction. Results indicated that it is possible to obtain films which show approximately the same components and crystal structures as the raw powders with small amounts of pores, using powders of which powder particle size is <100 μm.

N. Asahi, K. Asaka, K. Ueda, and M. Sasaki. Cited: Conference: 1st Int. Conf. Processing Materials for Properties (Honolulu), 7-10 Nov 1993, The Minerals, Metals & Materials Society (TMS), Warrendale, PA, 1993, p 1197-1200 [in English]. PHOTOCOPY ORDER NUMBER: 199401-58-0023.

Stainless Steel/Copper

Research on the Material—the Copper-Sprayed Stainless Steel. This material is made up of stainless steel, on the matrix of which a copper coating is sprayed by means of plasma. It greatly improves its heat conductivity, the heat shock resistance, and the capacity of the creep resistance under high temperature. With homogeneous heat transfer, the blackening on the heated section is greatly reduced. This material is constituted by spraying a Cu coating on the matrix of stainless steel by means of plasma.

Y.F. Xie. Cited: *Mater. Mech. Eng. (China)*, Vol 16 (No. 6), 15 Dec 1992, p 48-49 [in Chinese]. ISSN: 1000-3738. PHOTOCOPY ORDER NUMBER: 199311-58-1299.

Materials

AlN Coating

Synthesis of Al_2O_3-AlN Coatings by Low Pressure Plasma Spraying and Nitriding. AlN has some attractive properties for many applications including high thermal conductivity and a lower thermal expansion. The formation of AlN coating was not seen through the reaction of aluminum powder with N_2 atmosphere by LPPS in N_2 atmosphere. In order to form Al_2O_3-AlN composite coatings, Al_2O_3-Al and Al_2O_3-C composite coatings obtained by low pressure plasma spraying were heated at high temperature in a N_2 atmosphere. For the direct nitridation of Al in Al_2O_3-Al coatings, AlN contents in coatings increased with the increase of heating temperature and time. When the carbothermal reduction of Al_2O_3-C composite coatings was carried out in N_2 atmosphere, the formation of AlN in Al_2O_3-C coatings depended greatly on the existence of carbon powders on the surface of Al_2O_3-C coatings during heat-treatment.

A. Ohmori, M. Wakamatsu, and K. Kamada. Cited: 1st Int. Conf. Processing Materials for Properties (Honolulu), 7-10 Nov 1993, The Minerals, Metals & Materials Society (TMS), Warrendale, PA, 1993, p 1077-1080 [in English]. PHOTOCOPY ORDER NUMBER: 199401-E7-C-0003.

Copper-Titanium Diboride

Copper-Titanium Diboride Coatings Obtained by Plasma Spraying Reactive Micropellets. Electrotribological applications require materials with both high electrical conductivity and wear resistance. For this purpose, a copper-base plasma sprayed coating containing titanium diboride particles was developed. The process for fabricating this Cu-TiB_2 coating consists of plasma spraying reactive powders that contain a Cu-Ti alloy and boron. The reaction between the Cu alloy and B proceeds in different steps going from solid-state diffusion of Ti and Cu to the synthesis of TiB_2 in a liquid <1083 °C. Plasma sprayed Cu coatings contain finer TiB_2 crystals than Cu-TiB_2 materials synthesized in a furnace at 1200 °C. Coatings with 25 vol% TiB_2 have hardnesses that are comparable to Cu-Co-Be and Cu-Ni-Be alloys and to Cu-W and Cu-Mo alloys used in spot welding. Their low electrical resistivity of 52 $\mu\Omega \cdot$ cm could be increased by lowering the oxygen content with coatings and controlling the formation of TiB_2 clusters, the Ti content in solution in Cu remaining low after the synthesis reaction.

J.G. Legoux, and S. Dallaire. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 283-286 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-58-1271.

HfC on C/C Composites

HfC Plasma Coating of C/C Composites. The surface properties of C/C composites such as hardness and corrosion or erosion resistance can be modified by a ceramic coating applied by plasma torch. The technique of plasma spraying in controlled temperature and atmosphere, that was developed and patented by the CEA, makes it possible to apply coatings to the majority of metals and ceramics without affecting the characteristics of the composite. An example of hard deposit of HfC on a C/C composite (A223P3) is described. The characteristics of the deposit and of the bonding with the C/C composite were studied before and after a heat treatment under vacuum for 2 h at 1000 °C.

M. Boncoeur, G. Schnedecker, and J.D. Lulewicz. Cited: 16th Annual Conference on Composites and Advanced Ceramic Materials. I (Cocoa Beach, FL), 7-10 Jan 1992, *Ceram. Eng. Sci. Proc.*, Vol 13 (No. 7-8), July-Aug 1992, p 348-355 [in English]. ISSN: 0196-6219. PHOTOCOPY ORDER NUMBER: 199401-E7-D-0008.

Intermetallics

Oxidation and Protection of Ti_3Al-Based Intermetallic Alloys. Titanium aluminides containing 20-30 at.% aluminum can suffer from severe subsurface embrittlement (alpha case) when exposed to air at elevated temperatures for extended periods. For example, the alloys Ti-24Al-12.5Nb-1.5Mo and Ti-24Al-8Nb-2Mo-2Ta (based on the Ti_3Al α-2 intermetallic compound) embrittle to a depth of approx 80 μm during 1000 h exposure to air at 815 °C, resulting in major reductions in tensile properties. Plasma sprayed coatings of the MCrAlY and MCr types deposited over a thin diffusion barrier of chromium or tungsten, have been found effective in protecting these alloys against oxidation and embrittlement at this temperature.

D.W. McKee. Cited: Conference: High-Temperature Ordered Intermetallic Alloys V (Boston), 30 Nov-3 Dec 1992, Materials Research Society, Pittsburgh, PA, 1993, p 953-958 [in English]. PHOTOCOPY ORDER NUMBER: 199311-35-1923.

Tungsten

Taguchi Analysis of the Influence of Plasma Spray Parameters on the Microstructure of Tungsten Coatings. Tungsten and W alloys are candidate coating materials for divertor plates in future tokamak fusion reactors. The physical properties of these coatings deposited by plasma spraying are related to their microstructure. In the present work, the influence of five selected spray factors on the microstructure of plasma-sprayed W coatings was investigated according to a Taguchi design of experiment approach. The coating evaluation was performed by optical and electron microscopy on copper-infiltrated coatings in order to minimize pullout during metallographic preparation of the samples. This analysis permitted to obtain information about the lamella thickness and interlamellar contact. Measurements of the oxygen content, density, and specific surface were also performed on the sprayed coatings. The Taguchi statistical analysis showed that the spray atmosphere (air or controlled atmosphere) is the single most influent factor affecting the coating microstructure.

S. Boire-Lavigne, R.G. Saint-Jacques, and C. Moreau. Cited: Conference: Developments and Applications of Ceramics and New Metal Alloys (Quebec City) 29 Aug-2 Sept 1993, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, 1993, p 473-485 [in English]. PHOTOCOPY ORDER NUMBER: 199311-58-1273.

WC=C

Prevention of Erosion and Corrosion in Slurries Using Various Inorganic Coatings. Erosion and corrosion experiments on 14 different coatings on one duplex stainless steel (e.g. SAF 2205) are reported. Wing shaped specimens fixed to a rotating disk were exposed to a mixture of synthetic sea water and 0.025-2.5% of silica sand. The total material loss and the corrosion rate were measured. For some of the coatings pure erosion rates only were also determined. The effects of velocity and sand concentration are noted. The lowest material losses were obtained with two diffusion coatings and four sintered thermal spray coatings. Sprayed WC-Co coatings showed relatively high corrosion rates and material losses due to the low corrosion resistance of cobalt.

E. Bardal, M. Bjordal, T.G. Eggen, T. Rogne, and T. Solem. Cited: Conference: Progress in the Understanding and Prevention of Corrosion, Vol I (Barcelona, Spain), July 1993, The Institute of Materials, p158-164 [in English]. PHOTOCOPY ORDER NUMBER: 199401-35-0297.

Mechanical Properties

ASTM C 633

Application of Fracture Mechanics to the Interpretation of Bond Strength Data From ASTM Standard C633-79. The debonding specimen used in ASTM Standard C633-79 has a nonuniform stress distribution at the interface between the coating and the substrate. This means that bond strengths determined according to the standard could be significantly lower than actual strengths. A new specimen, 50% longer than the standard specimen, was developed to alleviate this problem. The elongated specimen has a uniform stress distribution that is equal to the uniform stress assumed by ASTM Standard C633-79. Thus, bond strengths obtained using the elongated specimens are higher and more representative of the actual bond strength than estimates obtained from the standard specimen. A procedure is developed to transform the existing bond strength values obtained using the C633-79 Standard specimens to the more representative bond strength values that would be obtained if the tests were repeated using the elongated specimens. A combination of finite-element analyses and laboratory test data is used to identify the relation between the bond strength values of standard specimens and those of elongated specimens. Examples are presented and the procedure is verified by comparisons with bond strength data for Colmonoy No. 6 and aluminum oxide coatings.

W. Han, E.F. Rybicki, and J.R. Shadley. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 235-241 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-58-1268.

Surface Preparation

The Influence of Substrate Surface Roughness on the Adhesive Strength of Zinc-Sprayed and Aluminium-Sprayed Coatings for Instance. Corrosion protection coatings have three important properties: adhesive strength, thickness and chemical resistance. The adhesive strength, which is one of the prerequisites, is highly dependent on surface pretreatment, for which it is well known that the adhesion conditions for protective coatings are better on blast-cleaned than on pickled surfaces. This is especially true for metal-

sprayed coatings and quality blasting with suitable abrasive material is a basic prerequisite for a good protective coating adhesion. Despite the fundamental importance of surface pre-treatment there are few scientifically based references in the literature to the relationships between abrasive material, blasting conditions, sprayed metal, steel surface roughness and the sprayed coatings adhesion. A literature search on this subject covering the last ten years produced hardly any significant papers. Based on this fact, different open blasting materials—preponderant slags—were tested, especially with regard to the adhesive strength of the metal to the sprayed coatings.

W.D. Schulz. Cited: Conference: Progress in the Understanding and Prevention of Corrosion, Vol I (Barcelona, Spain), July 1993, The Institute of Materials, London, 1993, p 330-336 [in English]. PHOTOCOPY ORDER NUMBER: 199401-58-0063.

Metallography

A Comparison of Techniques for the Metallographic Preparation of Thermal Sprayed Samples. Metallographic preparation of thermal spray coated samples is often difficult because hard and soft materials, which normally require different polishing techniques, are commonly present in a single spray-coated sample. In addition, the microstructures of many spray-deposited materials make them prone to pull-out damage during cutting, grinding, and polishing operations. Alternative metallographic techniques to prepare three common types of thermal sprayed coatings are compared: (1) a plasma sprayed alumina—titania wear coating, (2) a plasma sprayed zirconia thermal barrier coating, and (3) a high-velocity oxyfuel (HVOF) sprayed tungsten carbide/cobalt (WC/Co) hard coating. Each coating was deposited onto a steel substrate and was prepared with metallographic protocols based on silicon carbide (SiC) papers, bonded diamond platens, and diamond slurries. Polishing with SiC papers generally produced edge rounding and significant pull-out, which increased the apparent porosity of the coatings. Polishing with bonded diamond platens produced less edge rounding, but some pull-out was still observed. Preparation by diamond slurry lapping consistently produced the best overall results. Porosity artifacts produced by polishing with SiC papers and bonded diamond platens also resulted in spuriously low hardness values for the WC/Co samples; however, hardness results for the two ceramic coatings were not affected by the polishing method.

M.F. Smith, D.T. McGuffin, J.A. Henfling, and W.J. Lenling. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 287-294 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-62-1624.

Preparation and Evaluation of Thermal Sprayed Coatings. In the evaluation of thermal sprayed coatings the examination of prepared cross sections is still one of the most important ways of assessing the required quality characteristics of the coating. In contrast to compact materials, numerous defects can occur as a result of the method of preparation of the sample due to the inhomogeneous nature of thermal sprayed coatings. Experience is also required in the microscopic evaluation of such samples if incorrect interpretation is to be avoided.

E. Leistner. Cited: *Prakt. Metallogr.*, Vol 30 (No. 9), Sept 1993, p 428-440 [in English and German]. ISSN: 0032-678X. PHOTOCOPY ORDER NUMBER: 199311-21-0290.

Microstructure

Ceramic Coatings

Microstructural Design of Ceramic Plasma Sprayed Coatings. The influence of powder characteristics, like grain size and morphology, on the microstructure and properties of ceramic plasma spray coatings was investigated. It could be shown that by varying the powder features, it is possible to produce coatings with very different microstructures. For example, porosities between 3.5-18% can be achieved for ZrO_2-coatings by using agglomerated or spheroidized powders. The homogeneity of an agglomerate is also found to cause a homogeneous microstructure of the coating. Spherical powder particles lead to denser coatings, because the heat transfer is nearly equal from every point on the particle surface to the center and therefore those particles will melt faster and more homogeneously. Powder morphology and state of agglomeration influence significantly the properties of resultant coatings. The present data indicate the influence of powder characteristics on the resultant coating quality. To achieve the postulated properties of a ceramic coating for a certain application, microstructural design becomes necessary. As shown, one of the most important factors, influencing the microstructure is the powder quality. Therefore microstructural design also means powder design.

W. Kollenberg and J. Decker. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 229-234 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0040.

Interface Characteristics

Structure of Plasma-Sprayed ZrO_2 /(Ni/Al) Interface. The structures of plasma-sprayed ZrO_2 /(Ni/Al) interfaces before and after hot isostatic pressing (HIP) treatment were studied by TEM, ED and x-ray diffraction analysis. The plasma-sprayed ZrO_2 /(Ni/Al) interfacial region is of definite thickness and consists of multi-phase structures. An amorphous ZrO_2 sublayer, an amorphous plus microcrystalline ZrO_2 sublayer and NiO were found in the interface. NiO phase formed by the reaction between the ceramic coating and Fe-0.45C substrate in local regions. However, the thickness and amount of NiO tended to increase and the NiO particles tended to distribute continuously when the coating was subjected to HIP treatment. HIP treatment can accelerate the diffusion of atoms in the interfacial region.

Z. Liu, H. Chen, and Y. Chuang. Cited: J. Mater. Sci. Technol., Vol 9 (No. 5), Oct 1993, p 350-354 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0164.

Microstructure of Zirconia

A Study on the Microstructures and Martensitic Transformation in Plasma-Sprayed ZrO_2 (8 wt.% Y_2O_3) Coatings. The microstructures and effect of the residual stresses on the stress induced martensitic transformation in plasma-sprayed ZrO_2 (8 wt.%.Y_2O_3) coatings on iron were discussed. Acoustic counts and hardness decreased with an increase of compressive axial (or radial) residual stress, since martensitic transformation was repressed. The critical stress for inducing phase transformation increased and was influenced greatly by the residual stress as the deposition rate decreased. This is because stress intensification decreases with decreasing the deposition rate. Transformable equilibrium tetragonal phase precipitated only at boundaries, which are believed to have small cooling rates due to a collision between solid/liquid interfaces, and was transformed readily by applied stress. It was revealed that the critical stress depended not on the effective stress of Von Mises' criterion but on the residual stress (σ_y, σ_y or σ_z). This implies that martensitic transformation occurs predominantly at these boundaries.

J.D. Lee, J.Y. Ra, K.T. Hong, and S.K. Hur. Cited: *J. Korean Inst. Met. Mater.*, Vol 30 (No. 12), Dec 1992, p 1458-1466 [in Korean]. PHOTOCOPY ORDER NUMBER: 199312-57-1476.

Modelling

Plasma Process

Mathematical Modelling in Thermal Plasma Spraying. Two different flow models, elliptic and parabolic, for prediction of flow in an atmospheric dc plasma jet are described and tested for flow regimes characteristic of the plasma spraying process. Particle dynamics and heat transfer within the jet are also included. Results were obtained for zirconia powder using the two models and compared, with the emphasis on particle heating and melting. The influence of the substrate on the flow field and on the behavior of the particles is analyzed numerically. Experiments, still in progress, are briefly discussed. They are designed to collect data on plasma flow parameters for comparison with model predicted data.

M. Jankovic, J. Mostaghimi, and J.O. Noga. Cited: Conference: Developments and Applications of Ceramics and New Metal Alloys (Quebec), 29 Aug-2 Sept 1993, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, 1993, p 487-501 [in English]. PHOTOCOPY ORDER NUMBER: 199311-57-1401.

Nondestructive Testing

Photothermal Inspection

Fast Photothermal Inspection of Plasma-Sprayed Coatings of Primary Circulation Seal Rings of a Nuclear Reactor. II. After the Trial Run. In the 1991 QNDE conference a photothermal inspection of the plasma-sprayed coatings of two seal rings used in the main pump of the primary circulation in the PWR-type nuclear reactor was described. The measurements concentrated on detecting the most critical flaw type, adhesion defects at the interface between the coating and the substrate. The samples were tested immediately after they were coated and lapped, and already then two thermal anomalies could be found. Afterwards, the samples were subjected to a 1600 h trial run and inspected again with the same method. The results of this second inspection round are presented. The sample is a pair (a rotor and a stator) of seal rings made of stainless steel and coated with 300 μ m thick plasma-sprayed chromium oxide layer to increase the resistance to mechanical strain. It was found that the appearance of the numerous delamination defects during the trial run simulating the real environment of use emphasizes the importance of the reliable NDE method for this purpose. The effectiveness of the photothermal method applied to this practical problem of major importance has been quite clearly demonstrated in this study, which has already lead to practical applications.

R. Lehtiniemi, J. Hartikainen, J. Rantala, J. Varis, and M. Luukkala. Cited: Conference: Review of Progress in Quantitative Nondestructive Evaluation (La Jolla, CA), 19-24 July 1992, Plenum Press, New York, 1993, p 1931-1937 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0141.

Thermography

Use of Thermography in Arc and Plasma Spraying. Original Title: Anwendung der Thermografie Beim Lichtbogen- und Plasmaspritzen. Initially, the arc spraying and atmospheric plasma spraying processes are described. In thermal spraying, determination of the particle and substrate temperatures is essential for understanding the formation of the coating and its quality. The physical fundamentals of contactless radiation thermometry, based on Planck's radiation formula and Wien's displacement law, are discussed. Tests have shown that thermographic measurement of absolute temperature is not always possible, since the emission coefficient is influenced by various factors, e.g. surface condition and structure, and spray gun temperature. Alternatively, ratio pyrometry is limited to determination of temperature at one given point. The evolution of a thermographic system is described, which uses a Hg-Cd-Te detector to measure the temperature distribution—thereby the relative temperatures—upon the impingement of particles on a substrate surface. The detector operates in the short-wave sector of the infrared spectrum and enables determination of temperatures of 0-2000 °C.

J. Drozak and R. Lauterbach. Cited: *Dunne Schichten*, Vol 2 (No. 3), Sept 1991, p 30-33 [in German]. PHOTOCOPY ORDER NUMBER: 199312-22-1083.

Ultrasonic Inspection

Ultrasonic Attenuation of Water-Infiltrated Thermal Barrier Coatings. Plasma sprayed Y_2O_3-stabilized ZrO_2 thermal barrier coatings show a characteristic time dependence of the ultrasonic attenuation when immersed in water. This effect can be used for the identification of differently prepared coatings and to look for changes in the plasma spray process.

J. Bamberg and H. Schmitt. Cited: Conference: Review of Progress in Quantitative Nondestructive Evaluation (La Jolla, CA), 19-24 July 1992, Plenum Press, New York, 1993, p 1915-1921 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0140.

Particle Temperature

In-Flight Particle Surface Temperature Measurement: Influence of the Plasma Light Scattered by the Particles. The application of optical pyrometry to low-melting-point plasma-sprayed particles can be limited by the plasma light scattered by the particles themselves. From spectroscopic measurements of the plasma between 650-1050 nm and using the Mie scattering theory, the intensity of scattered light has been determined in the case of nickel particles sprayed using an Ar/He plasma. The results show that, even in spectral regions between the atomic lines of the plasma gas, the scattered light can be important compared to the thermal emission of the particles. This scattered light leads to values of measured temperatures, which are all the more overestimated because the particle temperature is low and the particle/torch distance short. For a 50 μm Ni particle at 1550 °C, located 10 cm from the torch, the measurement error made with a double wavelength pyrometer is estimated at 100 °C.

P. Gougeon and C. Moreau. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 229-234 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-58-1267.

Patent

Arc Spraying Method

Depositing Metal Onto a Surface. In order to deposit metal onto a surface such as a cylindrical surface, an arc spraying method is used with a consumable electrode, a non-consumable electrode and a jet of atomizing gas blown through the arc in a radial direction to propel the molten metal of the consumable electrode from the arc to the cylinder wall. The non-consumable electrode and the atomizing gas jet both rotate about the cylinder axis so that the entire surface can be covered. The supply for the consumable electrode will normally come from a reel which can be stationary such that the consumable electrode does not rotate about its own axis.

A.R.E. Singer, G.I. Davies, and A.D. Roche. Patent: EP0459995, European Patent 12 Jan 1990, *Auszuge aus den Europaischen Patentanmeldungen*, Teil I, Vol 7 (No. 50), 11 Dec 1991, p 4639 [in English]. PHOTOCOPY ORDER NUMBER: 199311-58-1316.

Composites

Arc Sprayed Continuously Reinforced Aluminum Base Composites. A metal matrix composite is produced by forming a rapidly solidified aluminum base alloy into wire. The wire is arc sprayed onto at least one substrate having thereon a fiber reinforcing material to form a plurality of preforms. Each of the preforms has a layer of the alloy deposited thereon, and the fiber reinforcing material is present in an amount ranging from approx 0.1-75 vol% thereof. The preforms are bonded together to form an engineering shape.

S.K. Das, M.S. Zedalis, and P.S. Gilman. Patent: US5217815, USA, 6 Dec 1990, 8 June 1993 [in English]. PHOTOCOPY ORDER NUMBER: 199311-62-1712.

Spray Process

Spraying Onto Rotating Substrates; Coating Internal Tubular Surfaces Using Exothermic Mixture; Centrifugal Force. A method of providing a coating on a substrate comprises spraying particulate material via spraying means onto the substrate while rotating the substrate at a sufficiently high speed that the particulate material is initially held on the substrate by centrifugal force. The substrate may be planar but is preferably tubular. Thermal spray nozzles along a support deposit metal and ceramic powder onto the internal surface of the rotating tube. In a modification, a planar substrate and spray nozzles are rotated at substantially the same angular velocity. The coating material may be an exothermic reaction mixture which is subsequently ignited. Holes may be provided in the substrate so that portions of the sprayed material extend therein to provide a mechanical lock with the substrate. A number of individual planar substrates may be mounted about the circumference of a support with a nozzle fixed at the center. Centrifugal force is also used: (i) to coat internal surfaces by packing an exothermic medium mixture in a tube, rotating and subsequently igniting; (ii) to weld components together using a ceramic/metal powder deposited in a V-shaped joint; and (iii) to form a molded product by rotating a mold containing a thermally softened material. In addition centrifugal force is used in a number of different applications using a variety of materials including: forming glass articles; manufacturing bread; removing fat from meat products; impregnating wood products; and forcing lubricants into bearings.

W.M. Thomas, G. Thomas, R.E. Thomas, and M.D.F. Harvey, Patent: GB2264719, United Kingdom, 29 Jan 1993, 8 Sept 1993 [in English]. PHOTOCOPY ORDER NUMBER: 199401-58-0031.

Post Processing

Heat Treatment

The Heat Treatment Characteristics of Plasma Sprayed ZrO_2-MgO Coatings. The plasma spray process was used to deposit coatings of ZrO_2-MgO powders onto SM45C substrate, and the characteristics of as-deposited and heat treated coatings have been investigated. Particularly, the variations of microstructure, porosity, wear resistance, thermal shock resistance, and thermal barrier in ZrO_2-MgO coatings after heat treatment under lower pressure have been investigated. It was found that coatings of ZrO_2-MgO consist of layered structure with thickness 2-3 μm, and with grain size of 0.06 μm. The amount of porosity was increased with increased spray distance, and the lowest amount of porosity was obtained at the arc current of 450 A, and at the spray distance of 50 mm. After heat treatment, the amount of porosity was found to be decreased, and wear resistance, microhardness, and thermal shock resistance were improved. However, the thermal barrier was decreased.

S.-S. Kim, H.-S. Kim, and B.-K. Jeong. Cited: *J. Korean Inst. Met. Mater.*, Vol 31 (No. 6), June 1993, p 698-704 [in Korean]. PHOTOCOPY ORDER NUMBER: 199311-57-1394.

Densification

Thermal, Mechanical and Thermo-Mechanical Post-Treatment of Thermally Sprayed Coatings. Increasing demands in corrosion and wear protection require the development of new materials as well as the improvement of already existing materials or compounds. Especially from the economic point of view, it seems to be most practical to coat components with high-quality layers. Therefore, the use of composites gets increasing importance. Besides other depositing techniques, the thermal spraying exhibits several advantages. On the one hand there are practically no restrictions concerning the substrate's geometry; on the other hand, the processing of metallic as well as nonmetallic materials is possible. For several applications the benefit of coatings in the state as sprayed is satisfactory. However, more aggressive environments demand thermally sprayed coatings with a low porosity, a smooth surface and favorable residual stresses. This can be obtained by suitable post-treatments of the depositions. Depending on the desired materials properties, a remelting can be done by means of laser or electron beams, or the densification by hot-isostatic pressing or by shot peening. Examples of these post-treatments are presented.

H.D. Steffens, W. Brandl, Ch. Buchmann, J. Lebkuchner-Neugebauer, and R. Podleschny. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 365-370 [in English]. PHOTOCOPY ORDER NUMBER: 199401-58-0112.

Laser

Plasma-Sprayed Coatings Treated With Lasers: Tribological Behavior of Cr_2O_3. The effects of laser treatment on thin plasma-sprayed Cr_2O_3 ceramic coatings are studied by comparing the wear values of the plasma-sprayed coatings before and after Nd-YAG laser treatment. Block-on-ring type tests were carried out using a ceramic-steel SAE 4620 pair in linear contact. The wear mechanism and the changes that laser treatment produce on the coatings with regard to porosity, microstructure, and adherence are also considered.

J.M. Cuetos, E. Fernandez, R. Vijande, A. Rincon, and M.C. Perez. Cited: *Wear*, Vol 169 (No. 2), 15 Oct 1993, p 173-179 [in English]. ISSN: 0043-1648. PHOTOCOPY ORDER NUMBER: 199401-57-0125.

Structural Change of Plasma Sprayed ZrO_2 Coating After Laser Remelting. An improvement on the properties of plasma sprayed ZrO_2 ceramic coating on 45 steel by laser remelting treatment has been observed by TEM, SEM, EPMA, and x-ray diffraction analysis. After laser remelting, the ZrO_2 coating changes its structure into more dense and nonporous, and more stable to thermal failure and cracking if a suitable SiO_2 doped. The bonding of laser remelted ZrO_2 ceramic coating together with adhesion layer is found to be of metallurgical nature. The thickness of adhesion layer and metallurgical bonding interface may be evidently increased. With the increase of the laser output, the ceramic coating, adhesion layer, and a certain depth of substrate surface are able to be fused. A liquid Zr_6Fe_{30} phase may be formed between ceramic coating and adhesion layer.

H.C. Chen, Z.Y. Liu, and Y.Z. Zhuang. Cited: *Acta Metall. Sin.*, Vol 29 (No. 8), Aug 1993, p B358-B362 [in Chinese]. ISSN: 0412-1961. PHOTOCOPY ORDER NUMBER: 199401-57-0074.

Laser Glazing of Plasma Sprayed ZrO_2-Coatings. The experiments show that the result of the laser glazing process of plasma sprayed ZrO_2 coatings is strongly influenced by the laser parameters such as intensity and traverse speed. The influence of the laser parameters on the melted depth and the track width can be predicted using FEM-simulation. Smooth and continuously melted tracks with low surface roughnesses (<10 μm) and low melted depths (50-100 μm) can be produced using high intensities (>4 kW/cm^2) and high traverse speeds (>200 mm/s). The glazed layers are characterized by a crack network on the surface due to the high thermal stresses during the laser process. It is confirmed that this crack segmentation is dependent upon the solidification rate. High traverse speeds therefore result in a much smaller segmentation than low speeds. By pre- or post-heating with a second laser beam, the thermally induced stresses can be reduced, but, due to the great different of the material properties of substrate and coating, cracking of the layers cannot be avoided completely, up to now.

B. Grunenwald, F. Dausinger, and H. Hugel. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 423-428 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0048.

Process

Vacuum Arc

Reactive Gas Pressure Effect on Vacuum Arc Erosion of Titanium and Zirconium Alloys With Silicon. The paper deals with the process of vacuum electric arc deposition of titanium-silicon and zirconium-silicon alloy coatings. The effect of nitrogen or oxygen pressure in an interelectrode gap on erosion of cathodes of mentioned alloys with 68-92%Si and on chemical composition of produced plasma flux is under consideration. Critical values of pressure were determined which constituted 1×10^{-1} Pa for erosion in cathode sports of the first kind and 1×10^{-2} Pa for erosion in thermal cathode sports. The pressure higher than critical one promotes a decrease of coefficient of electrotransport. Spectroscopic analysis of plasma flux revealed metal atoms and gas ionized molecules which testified to the fact that chemical reactions proceeded only on the surface of plasma flux condensation.

I.A. Ivanov, I.N. Zhoglik, and G.A. Mrochek. Cited: *Elektron. Obrab. Mater.*, (No. 2), Feb 1993, p 20-21 [in Russian]. ISSN: 0013-5739. PHOTOCOPY ORDER NUMBER: 199312-58-1440.

HVOF

Study on Improvement of High Temperature Resistance of HVOF Sprayed Cr_3C_2 Cermet Coatings. In recent years longer life of boiler tubes in high temperature erosive environment is increasingly required. To meet this requirement Cr_3Cr_2-NiCr alloy cermet coatings were applied to fluidized bed boiler tubes with HVOF (high velocity oxygen fuel) thermal spray process. The coatings were evaluated using EPMA, x-ray diffraction analysis, high temperature hardness tester, etc. Thus the effects of the microstructure of coatings on high temperature erosion resistance of the coatings have been clarified. This leads to establishing the optimum spray parameter and powder characteristics. The results of the field tests of coatings conducted based on the above optimum conditions endorsed the lab test. This coating has already been commercialized.

M. Sasaki, F. Kawwakami, M. Nakagawa, T. Kudo. Cited: Conference: 1st Int. Conf. Processing Materials for Properties (Honolulu), 7-10 Nov 1993, Warrendale, PA, 1993, p 1093-1096 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0147.

HVOF of Ceramics

Ceramic Coatings Obtained by Means of HVOF Thermal Spraying. The aim is to characterize the microstructure of coatings obtained by means of thermal spraying techniques. The spraying powders are (W,Ti)C-Ni and the substrates are aluminum-base alloys. Depending on the initial powder, the coating will react and form a microstructure with specific bonding characteristics. The present system obtained by hypervelocity spraying (HVOF) produces nickel-rich regions (in which tungsten, Ti and carbon are dissolved), undissolved carbides and titanium oxide. The resulting coating is dense, homogeneous and its bonding with the substrate is continuous.

J.M. Guilemany, N. Llorca-Isern, and J. Nutting. Cited: *Powder Metall. Int.*, (No. 4), Aug 1993, p 176-179 [in English]. ISSN: 0048-5012. PHOTOCOPY ORDER NUMBER: 199311-57-1399.

Induction Plasma

On the Induction Plasma Deposition of Tungsten Metal. The central particle injection and long residence time characteristics of induction plasma have given rise to the complete melting of tungsten particles injected into an Ar-H_2 plasma under soft vacuum conditions. The influences of process variables such as power level, chamber pressure, and spray distance on splat morphology, apparent density, and deposition efficiency have been studied. Dense W deposits with no oxidation have been obtained. Scanning electron microscopy (SEM) micrographs reveal a well-flattened lamellar structure in deposits. Radiative cooling is observed to play a significant role in the plasma spraying of this refractory metal.

X.L. Jiang, R. Tiwari, F. Gitzhofer, and M.I. Boulos. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 265-270 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-58-1270.

Diamond Films

Diamond Films Made by DC Plasma Jet. High quality diamond films can be deposited on molybdenum, tungsten, silica glass, and silicon wafer by dc plasma jet CVD process. Nucleation and growth of diamond films are on the base of a layer of carbide phase when the substrates are carbide-forming materials. Such factors as substrate temperature, composition of reactive gas, gas flow rate and the position where substrates were fixed in the plasma jet are some key factors affecting the nucleation and growth of diamond in this process.

K. Zhou, J. Wang, D. Wang, P. Han, and B. Feng. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 479-484 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0052.

Particle Separation

Separation Mechanism of Cu/Ceramics MA Composite Powders in DC Plasma Spraying. The separation phenomena of ceramic phase from metal phase have often been recognized in dc plasma spraying of uniformly mixed mechanically alloyed (MA) metal—ceramic powders (Cu/alumina, zirconia) on SUS304 stainless steels. The separation mechanism of the MA composite powder materials during plasma spraying was investigated. Some methods for restraining the separation were also applied. The results obtained are summarized as follows: (1) The wettability between metal and ceramic material, surface tension of each material melted, and the acceleration force of the plasma to the molten particles have affected this separation phenomenon. (2) Separation was recognized even in the Cu/TiC MA powder material system, which had good wettability between metal and ceramic materials. (3) Separation was well restrained by both the application of the CuO/alumina powder materials system and spraying in the low power plasma conditions.

M. Fukumoto, H. Tsunekawa, M. Umemoto, and I. Okane. Cited: J. Jpn. Inst. Met., Vol 57 (No. 9), Sept 1993, p 1078-1082 [in Japanese]. ISSN: 0021-4876. PHOTOCOPY ORDER NUMBER: 199311-57-1390.

Reactive Spray Synthesis

Synthesis of Titanium Nitride/Ti Composite Layer by Reactive Low Pressure Plasma Spray. The aim was to synthesize titanium nitride/Ti composite layers on a substrate of austenitic stainless steel plates by a reactive low pressure plasma spray. It was effective for making much titanium nitride compounds synthesize in the layer to lower the chamber pressure, to shorten the distance between the substrate and the gun, and to increase the spray current as much as possible. It was also effective to mix argon gas with N_2 gas for synthesizing more titanium nitride compounds in the layers. The structure of the composite layer was composed of the crystallized titanium in which fine titanium nitride or Ti_2N particles dispersed, and it was thought that these particles hardened the composite layers. The durability to an abrasive wear of the coated composite layers in this experiment, however, was inferior to that of the sprayed WC layer, and this was presumed to be caused by the structure in which the binding force between the matrix of Ti and the titanium nitride or Ti_2N particles was weak.

S. Kuwano, T. Mano, and S. Murata. Cited: Conference: 1st Int. Conf. Processing Materials for Properties (Honolulu), 7-10 Nov 1993, The Minerals, Metals & Materials Society (TMS), Warrendale, PA, 1993, p 1201-1204 [in English]. PHOTOCOPY ORDER NUMBER: 199401-57-0023.

Review

Thermal Spraying, Physical Vapour Deposition—Alternatives to Electroplating? Original Title: [Thermisches Spritzen, Physikalische und Chemische Gasphasenabscheidung—Alternativen zur Galvanotechnik?]. The thermal spraying process is first defined and explained and it is pointed out that there are a number of different ways in which thermal spraying may be done. Examples given are flame, plasma and powder spraying. These are all described and illustrated. Part of the article is devoted to the coating and basic materials. Applications are enumerated. Environmental problems are discussed and a comparison with electroplating is given. Physical Vapour deposition (PVD) is defined and treated extensively, including its ecological problems, comparison with electroplating, its process description, coating and basic raw materials, and examples of applications.

K.K. Schweitzer. Cited: *Galvanotechnik*, Vol 82 (No. 1), Jan 1991, p 103-118 [in German]. ISSN: 0016-4232. PHOTOCOPY ORDER NUMBER: 199311-58-1296.

Air Pollution

Q&A Title V Operating Permits. Title V of the Clean Air Act Amendments (CAAA) signed into US law by George Bush in November 1990, requires states to adopt new permit programs. The Title V permits are the means by which the objectives of the CAAA are achieved, including limitations on emissions of air toxics under Title III and VOCs under Title I. Title V permits will regulate the operation and modification of sources of air pollution. An article explains the rules of applying for a Title V permit.

J. Schweitzer. Cited: *CI on Composites*, Feb-March 1994, p 12-13 [in English]. PHOTOCOPY ORDER NUMBER: 199402-D4-0006.

Lead Policy

Lead and the Environment. European Community Legislation. What Does the Commission Have in Store? In order to comply with EC environmental policy, the nonferrous/lead business will need to develop coherent policies on an international basis. Main aspects should include classification, health and safety at the workplace and industrial pollution. Missing data will need to be generated through a critical review of all substances and their various uses and applications. Manufacturers will have to demonstrate their capability to produce and market their products in a responsible way.

A. Franckaerts. Cited: 11th Int. Lead Conf. (Venice), 24-27 May 1993, Lead Development Association, London, 1993, p 2.2/1-9 [in English]. PHOTOCOPY ORDER NUMBER: 199402-G4-0011.

OSHA Regulations

OSHA's New Confined Spaces Entry Regulation. The US Occupational Safety and Health Administration (OSHA) estimates that >60 workers died from confined-space related injuries in 1992. While >1.5 million employees enter confined spaces every year, OSHA's data suggests that no current standards effectively prevent workers from atmospheric and mechanical hazards. OSHA's definition of a confined space is any that allows human access, has limited means of entry and/or exit, and is not large enough for continuous employee occupancy. In foundries, affected spaces would include resin, gas and scrubber solution storage tanks, mullers, pits under furnaces, sand silos and shakeout units with limited access. OSHA has begun to restrict access to these types of confined spaces with a new regulation that it expects will prevent 54 deaths and >10,000 injuries/year. The new regulation governing workplace practices in confined spaces (29 CFR Part 1910.146), which took effect last April, is expected to affect >200,000 worksites, including foundries. The new standard creates safety requirements, including a permit system, for entry into potentially hazardous confined spaces.

D. Selchan. Cited: *Modern Casting*, Vol 84 (No. 2), Feb 1994, p 38 [in English]. ISSN: 0026-7562. PHOTOCOPY ORDER NUMBER: 199402-S4-0013.

Plastics Industry

[US] Industry Opposes New Workplace Safety Bills. In the US lobbyists for the plastics industry and other business groups are pushing to stop bills updating and strengthening workplace safety rules. A coalition of >400 companies and industry groups, including the Society of Plastics Industry Inc., is lobbying to defeat the Comprehensive Occupational Safety and Health Reform Act in the House of Representatives. Arrayed against that coalition are labor unions—which see the strengthening of the Occupational Safety and Health Administration as an important issue—and some key congressional Democrats. The Clinton administration also supports the bills, a move widely seen as an olive branch to unions because of the administration's support last year for the North American Free Trade Agreement. The plastics industry's chief concerns are the bills tightening of rules on workplace exposure to pollutants and increased regulation and record-keeping. A Washington-based foundation puts the total private-sector cost of complying with the bills at $57B.

J. Gardner. Cited: *Plastics News (Detroit)*, Vol 5 (No. 49), 7 Feb 1994, p 10 [in English]. ISSN: 1042-802X. PHOTOCOPY ORDER NUMBER: 199402-P4-0005.

Process

Simulation of the Process of Gas-Thermal Coatings Formation on a Metallic Substrate. The experimental and theoretical model of the solid phase interaction process for metallic porous materials sprayed in oxygen atmosphere in developed. The co-influence of the heat flow density heating the substrate, the dropping frequency of deposited particles and the porosity of a substrate on the maximum value of adhesion was found. The model can be considered as base of the engineering method for prediction of adhesion strength of gas-thermal deposited coatings.

V.M. Antziferov, A.M. Shmakov, and V.A. Basanov. Cited: *Fiz. Khim. Obrab. Mater.*, No. 1, Jan-Feb 1993, p 71-76 [in Russian]. ISSN: 0015-3214. PHOTOCOPY ORDER NUMBER: 199401-58-0070.

Substrate Preparation

Residual Stress

On the Effect of Plasma Spray Coatings on the Residual Stress State of Peened Compressor Blades. The aim of the present study was to examine the effect of plasma spraying upon the redistribution of peening residual stresses in coated aeroengine compressor blades made from Ti-6Al-4V, as well as the state of the residual stresses in the coating itself. It was found that the plasma spray coating procedure induces significant tensile residual stresses in the coated layer. The profile peaks at approximately one-third to one-half into the depth of the coating. The thermal process in the coating procedure causes the residual stresses to redistribute. Both the maximum compressive stress and the depth of the compressive layer are reduced. However, the stresses remain compressive and the amount of stress relaxation is only 15%.

K.-E. Lindenschmidt, M. Ferahi, S.A. Meguid, and P.-C. Xu. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 443-448 [in English]. PHOTOCOPY ORDER NUMBER: 199401-31-0615.

Tribological Properties

Mechanical and Tribotechnical Properties of Thermal Sprayed Coatings. A set of procedures including tests under the conditions of sliding friction, reverse friction and vibration was used to estimate the tribotechnical properties of thermal sprayed coatings. Under investigation were the coatings of metal alloys, oxides, carbides, composite powders and mechanical mixtures. The tribotechnical properties of the coatings were used as a basis to work out the recommendations on the reasonable applications of certain kinds of the coatings.

K.A. Yushchenko, Yu.S. Borisov, E. Lugscheider, B. Lyashenko, and G. Brailovskii. Cited: Conference: Surface Engineering (Bremen, Germany), 1993, DGM Informationsgesellschaft mbH, Oberursel, Germany, 1993, p 23-32 [in English]. PHOTOCOPY ORDER NUMBER: 199401-58-0024.

Evaluation of Corrosion Characteristics of Plasma-Spray Ceramic Coated Steel. To make clear the performance of plasma-sprayed ceramic coating, several investigations concerning degradation characteristics including tribological and adhesive strength are being conducted. Corrosion characteristics of plasma-sprayed ceramic coating, which is used for various applications as thermal barrier and anti-erosive coatings, were evaluated from electro-chemical viewpoints. As a result, it was recognized that the zirconia top coat layer contained a lot of pores and cracks. The corrosion damage of plasma-sprayed ceramic coating was brought about by the anodic dissolution of under coat NiCrAlY layer at the boundary between the zirconia top coat and the under coated layer. Various electrochemical examinations about the corrosion characteristic of plasma-sprayed ceramic coating indicated the following facts. Under freely corroding conditions, plasma-sprayed ceramic coating makes little contribution to improve the corrosion characteristics of matrix metals (SUS304 steel), especially in 3% NaCl aqueous solution. Therefore, for evaluating the corrosion resistance of plasma-sprayed ceramic coating, the anodic dissolution by corrosive media, which come into the boundary layer through open voids in the top coat ceramic layer, is extremely important.

Y. Kimura, T. Yagasaki, T. Yoshioka, and M. Kanazawa. J. Soc. Mater. Sci., Jpn., Vol 41 (No. 465), June 1992, p 945-950 [in Japanese]. ISSN: 0514-5163. PHOTOCOPY ORDER NUMBER: 199312-57-1492.

Tribology

Study of Fracture and Erosive Wear of Plasma Sprayed Coatings. Double cantilever beam (DCB) and short bar (SB) specimens were used to determine the critical strain energy release rate (G_{Ic}) of plasma-sprayed coatings of ZrO_2 -base ceramic and WC/Co coatings on 0.45% carbon steels. Erosion rates were measured for various erosive conditions. By comparing the G_{Ic} data and erosion rate (E_v) data with x-ray diffraction and fractographic analysis, fracture and erosion mechanisms of plasma-sprayed coatings were

proposed. Based on the erosion models for brittle materials, a proportional relationship between the erosion rate, E_v, and G_{Ic} was derived.

D.Z.Guo and L.J. Wang. Cited: *J. Therm. Spray Technol.*, Vol 2 (No. 3), Sept 1993, p 257-264 [in English]. ISSN: 1059-9630. PHOTOCOPY ORDER NUMBER: 199311-62-1623.