Selected Abstracts of Thermal Spray Literature

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Analysis

Enthalpy Determination

Application of VDTA Thermoanalyzer for Determination of Heats of Transformation in the Metallic Plasma Coatings. The coatings of Fe-5 mass% B system prepared by plasma and gas-flame spraying were investigated. A procedure for quantitative determination of enthalpy of the structural-phase transformations in reference metal (Zn, Sn, Ag, Cu, Fe) specimens at temperature up to 1400 °C was elaborated on the basis of VDTA device. Satisfactory assurance was supported by the enthalpy estimation of transformation of system under study from amorphous state to crystalline one.

L.K. Doroshenko. G.M. Grigorenko, and V.G. Vasil'ev. Cited: *Avtom. Svarka,* Vol 11, Nov 1995, p 30-34 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199608-11-0801.

Application

Biomedical

A Study on Titanium-Coated Stainless Steel for Implants. Titanium coatings were deposited onto 317L stainless steel by low-pressure plasma spray (LPPS) process. The microstructure of the coatings and coating/substrate interfaces had been analyzed. The mechanical and electrochemical properties also had been measured. The results indicated that the thermal spray process did not take effect on the metallurgical properties of substrate and the titanium coatings had good bonding strength with the substrate. The structure of the coatings is titanium phase with few titanium oxides.

K.S. Zhou, R.J. Hong, D.Z. Wang, and, M.R. Zhu. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 193-198 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1367.

Bioceramic Powders and Coatings by Thermal Spray Techniques. Thermal spraying techniques have matured considerably over the past three decades. In recent years, the application of thermal spraying has shifted to many nonaerospace industries. Among these new applications is the biomedical field. Thermal spraying provides an effective and economical means for depositing calcium phosphate based bioceramic coatings on implants. These coatings, with hydroxyapatite (HA) as one of the prime phases, can aid the fixation process of biomedical implants. Past research has shown that plasma spraying normally induces undesirable phase changes to the HA feedstock. Hence, the coatings usually contain many bioinert or bioresorbable phases. This report investigates the dual function of thermal spray techniques to perform spheroidization of powders and deposition of biomedical coatings. The combustion flame was used to produce fine spheroidized HA powders while plasma spray and HVOF were used to prepare dense coatings using the flame spheroidized powders. This clearly illustrates how one thermal spray technique can supplement other thermal spray techniques. Particular attention is directed toward the powder processing capability to produce dense spherical particles of hydroxyapatite (HA) and composite HA-ZrO_2. The coating microstructure improved with the use of flame spheroidized powders. The spheroidized HA (SHA) powder provides better flowability and stability that influences deposition and phase formation in the coating. The benefits of thermally spheroidized powder was shown by the quality of the thermally sprayed coatings using plasma and HVOF.

P. Cheang and K.A. Khor. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 181-186 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1599.

Vacuum Plasma Spray Deposition of Titanium Particle/Glass-Ceramic Matrix Biocomposites. The vacuum plasma spray technique (VPS) has been successfully employed to coat Ti-6Al-4V substrates with bioactive glasses and Ti-particle/glass-ceramic matrix biocomposites. The composites were prepared by sintering, under an Ar flow, green bars of bioactive glass powders and 30% volume Ti particles. The bioactive glasses have the two following compositions: SCB (48.8SiO_2-48.8CaO-2.4B_2O_3) and TSCB (46.6SiO_2-48.7CaO-2.5B_2O_3-2.2TiO_2) (mol%). The VPS bioactive coatings were characterized by means of scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), x-ray diffraction (XRD), and mechanical tests (Vickers indentations and tensile and shear tests). Their bioactivity was tested by soaking the samples in a simulated body fluid (SBF) and by analyzing the growth of hydroxylapatite (HA) by SEM, EDS, and XRD. Leaching tests of calcium, silicon, and phosphorus in SBF were made by inductively coupled plasma-atomic emission spectroscopy (ICP-AES, Perkin-Elmer 5000) to study the *in vitro* bioactivity of the samples versus time. Each coating was found to be bioactive and well bonded to the substrate; the composites showed better mechanical properties than the pure glass matrices and the hydroxylapatite coatings deposited by the same VPS technique.

M. Ferraris, F. Brossa, L. Paracchini, and P. Rabajoli. Cited: *J. Am. Ceram. Soc.,* Vol 79 (No. 6), June 1996, p 1515-1520 [in English]. ISSN 0002-7820. PHOTOCOPY ORDER NUMBER: 199608-57-1537.

Boiler Tubes

Application of Thermal Spray Coating to Boiler Tubes in Refuse Incineration Plants. A spray coating method was developed to obtain higher corrosion resistance for boiler tubes (carbon steel) used in refuse incineration plants. As a first step in this development, the corrosion resistance of a plasma sprayed coating was investigated. Based on the results, a detonation spray method has been developed to achieve high corrosion resistance and to save the production cost for spray coating of boiler tubes. Plasma sprayed coating with self-fluxing alloy material has sufficient corrosion resistance in the actual plant. However, this coating needs a post-processing fusing treatment. A two-layer coat with 50Ni-50Cr material for base coat and Cr material for surface coat, applied by the detonation spray method presented better corrosion resistance in a laboratory test. This coating can be used without fusing treatment. The two-layer coating system described above has been tested in the actual plant. This plant has been operating for about two years without any problems, and the coated tubes are expected to have a longer useful life.

K. Yamada, K. Kakeda, M. Koyama, M. Ohsawa, T. Ohtsuka, and K. Tohyama. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 223-228 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1370.

Cathodic Protection

New Anode in Cathodic Protection for Concrete Reinforcing Bar. A new anode system, hot spraying zinc coating, which was used in cathodic protection for concrete reinforcing steel bar, was introduced. The combined strength between zinc coating and concrete substrate, the electrochemical protection performances of zinc coating, etc., were studied. This sacrifical anode system was very applicable to corrosion protection of concrete reinforcing bar, because it could maintain cathodic polarization potential of reinforcing bar and potential decline field 4 h depolarization.

N. Gao, X. Liu, and Z.H. Liu. Cited: *Mater. Prot. (China),* Vol 28 (No. 12), Dec 1995, p 8-9 [in Chinese]. ISSN 1001-1560. PHOTOCOPY ORDER NUMBER: 199608-35-1607.

Corrosion Resistance on Rebars

Low-Cost, Corrosion-Resistant Coatings for Steel Rebars and Components. This research is a follow-up study from a previous SHRP-IDEA project in which a corrosion-resistant Si-Ti coating on steel rebars was produced using fluidized bed technology. The current project scaled up the coating process. A bench-scale reactor system was designed and shown feasible for coating 3 ft long steel rebars. Further research has shown that a strong and coherent coating also could be produced by a plasma spray process or simply by spray painting metal powder mixture (along with a flux) followed by low heat treatment (~600 °C). The results demonstrate that corrosion resistance coatings of various metals and alloys such as Si, Ni, Ti, and Ti-Ni can be formed on steel rebars by fluidized bed chemical vapor deposition (FBR-CVD), paint-and-heat, or FBR-plasma spray techniques. The paint-and-heat process appears most suitable for commercial application. Data on microstructural characteristics of the coated steel surface and corrosion resistance are presented.

A. Sanjurjo, P. Jayaweera, K. Lau, and D. Lowe. Cited: *Gov. Res. Announc. Index,* 1995, p 12 [in English]. ISSN 0097-9007. PHOTOCOPY ORDER NUMBER: 199609-58-1449.

Economic Impact of Gas Turbines

Economical Advantages of HVOF-Sprayed Coatings for the Land-Based Gas Turbine Industry. The coating of blades and vanes with MCrAlY-overlays is a commonly used method of improving the high-temperature and hot-corrosion resistance of the blading in land-based gas turbines. Furthermore, in the area of reconditioning it is in some cases necessary to rebuild the blades and vanes by using base-material-like coatings such as nickel-base superalloys IN 738LC or IN 939. Within the last years such coatings have been produced mainly by vacuum plasma spraying (VPS)/low-pressure plasma spraying (LPPS). Recently, however, there is an increasing interest in high-velocity oxygen fuel spraying (HVOF) for these coatings because of lower costs for thin coatings and small parts, the straightforward process, and such features as high-particle velocities, low flame temperatures, and qualities that are comparable with VPS sprayed coatings. In this paper results of blade and vane coatings applied with HVOF in the reconditioning area are presented and compared with VPS coatings. The comparison comprises cost calculation, coating characteristics such as bending tests, thermal shock tests, metallography and oxygen distribution.

M.C. Nestler, W.M. Balbach, and T. Koromzay. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 101-106 [in English]. ISBN 1241-3074 PHOTOCOPY ORDER NUMBER: 199609-58-1360.

Gas Turbines

Development and Applications of Low-Pressure Plasma Sprayed Coatings on Gas Turbine Engine Components. Chromalloy has been applying low-pressure plasma sprayed (LPPS) coatings on gas turbine components for 20 years. A variety of coatings, such as MCrAlY overlays for oxidation and hot corrosion at high temperatures, bond layers for thermal barrier coatings to enable engines to operate at higher temperature and efficiency, buildup coatings for repair and recovery of the original dimensions, and composite coatings to improve wear or erosion resistance, can be deposited by LPPS process. This paper reviews the LPPS technology applicable to gas turbine components. The performance of LPPS coatings is also discussed in comparison with coatings processed by other methods. The analysis is based on the microstructure and properties of the coatings and the safety and environmental advantages of the LPPS process.

X.X. Guo, R. Fenton, G. Milidantri, and X.M. Zheng. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 73-77 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1357.

Hard Chromium Replacement

Economically Viable Hard Chromium Alternatives. There is nothing that can replace all applications for chromium, although almost every supplier of surface treatment processes claims to have an alternative for it. While all of the claims may have some merit, there are only a few viable alternatives with a reasonable potential market. "Dry coating" alternatives (thermal sprays and vacuum coatings) have good potential because they avoid all of the environmental problems of wet chemical methods, albeit not without their own problems.

K.O. Legg. Cited: *Plat. Surf. Finish.,* Vol 83 (No. 7), July 1996, p 12-14 [in English]. ISSN 0360-3164. PHOTOCOPY ORDER NUMBER: 199610-58-1560.

Heat Exchanger Tubes

Application of High-Velocity Flame Sprayings for the Heat Exchanger Tubes in Coal-Fired Boilers. One very successful method for preventing the erosion of boiler tubes is the high-velocity flame spraying (HVFS) coating such as detonation-gun process; Jet-Kote process and DJ-Gun process because HVFS produces poreless high-quality coatings with strong adherence to base material. The quality of coatings depends on the powder properties such as morphology and size distribution. The coating properties were improved and tested in both laboratory and several actual plants. Various HVFS coatings have been successfully applied to many components of coal-fired boilers.

Y. Fukuda and M. Kumon. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 107-110 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1361.

Joining of Materials

Joining of Ceramics and Metals by Thermal Spray Coatings Using Mixed Powders. For ceramics joining to metals, relaxation of thermal stress caused by expansion coefficient difference between ceramics and metals, and reaction at the interface are necessary. So, soft metals are inserted for relaxation of thermal stress and brazing alloys containing active metals are used for reaction between ceramics and metals. In this study, thermal spray coatings are applied to joining of ceramics and metals. Thermal spray coatings are formed by low-pressure plasma spray system. Mixed powder of Ag-Cu-Ti alloy and Al_2O_3 are sprayed on carbon substrate peeled off the substrate and used as ceramics substrate and S45C is used as metal substrate. Test pieces are joined at reduced pressure of 10^{-3} to 10^{-4} Pa and analyzed by SEM/EPMA and DSC.

T. Kuwashima, A. Ohmori, M. Kawahara, S. Tachibana, and I. Takahashi. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 199-204 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-55-1511.

Lightweight TiC/Ti Wear Resistant

Lightweight TiC/Ti Wear-Resistant Coatings for Lightweight Structural Applications. Lightweight coatings based on titanium and titanium carbides produced by plasma spraying can be used to improve and modify the tribomechanical properties of aerospace structural materials. Although plasma-sprayed WC/Co coatings have been applied with success in many cases, such as primary wear-resistant materials, their high densities preclude their use in applications that mandate reduction in weight. In the present investigation, the sliding wear resistance of plasma-sprayed, metal-bonded TiC coatings on Al 7075 substrates was studied. Coatings containing 50, 70, and 90 vol% TiC in a Ti matrix produced from physically blended powders of Ti and TiC were compared. Metallographic evaluations showed that dense coatings with good bonding to Al 7075 substrates can be obtained. Coatings from commercial purity (CP) Ti powders sprayed in air under atmospheric conditions, however, indicated considerable oxidation of the particles. Under dry sliding conditions, the coefficient of friction (COF) values of the Ti/TiC containing/Al 7075 substrate system were lower than high-velocity oxygen fuel (HVOF) sprayed 75% Cr_3C_2/25%NiCr coatings on steel and were comparable to coatings of WC/Co. Vacuum plasma-sprayed TiC/Ti coatings with 90 vol% TiC also exhibited better wear resistance than HVOF sprayed 75%Cr_3C_2/25%NiCr.

M. Mohanty and R.W. Smith. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 384-394 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1182.

Mid-Span Dampers

Performance Evaluations and Selection of Tungsten Carbide Thermal Spray Coatings for Mid-Span Dampers. A comprehensive experimental research program was conducted at Volvo Aero Corporation in Trollhättan, Sweden, to evaluate coating crack resistance in bending, low-cycle fatigue properties of the coating and substrate, coating performance in jet engine tests, and microstructures for a wide range of coating compositions and application processes. Coating residual stress distributions were evaluated at the University of Tulsa. Eleven coatings were ranked according to their performance relative to the other coatings in each evaluation category. Results from the bend and low-cycle fatigue evaluations were compared to the experimentally evaluated residual stresses. Comparisons of rankings indicate a strong correlation between performance and the residual stresses in the coatings. Results from the program were used for selecting a suitable coating system for final in-service use. Two important criteria for a suitable coating system are that the coating will not fail while in-service and the coating will not induce crack propagation into the substance of the mid-span damper, compositions, and application processes.

J. Wigren, D.J. Greving, E.F. Rybicki, J.R. Shadley, and L. Pejryd. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 113-118 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1362.

Paper and Printing Industry

The Application of High-Power, High-Velocity Plasma Coatings on Rolls for the Paper and Printing Industries. PlazJet, a 200 kW (steel) plasma spray process, was evaluated for coating rolls used in printing and paper making. Coatings of alumina-40% titania and high-purity chromium oxide were sprayed at 12 lb/h (5.5 kg/h) and 18 lb/h (8.2 kg/h), respectively. The process yielded significant time and cost savings compared to conventional plasma spray, offering important advantages on large rolls. The high-power process produced high-particle velocities that resulted in high-density (low-porosity) coatings with very high hardness, improved bond strength, and excellent finishing capability. These coating properties will enable rolls to better resist wear and corrosion.

G. Irons, D. Poirier, and A. Roy. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 205-209 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1601.

Self-Lubricating Coating

Preliminary Evaluation of PS300: a New Self-Lubricating High-Temperature Composite Coating for Use to 800 °C. This paper introduces PS300, a plasma sprayed, self-lubricating composite coating for use in sliding contacts at temperatures to 800 °C. PS300 is a metal bonded chrome oxide coating with silver and BaF_2/CaF_2 eutectic solid lubricant additives. PS300 is similar to PS200, a chromium carbide based coating, which is currently being investigated for a variety of tribological applications. In pin-on-disk testing up to 650 °C, PS300 exhibited comparable friction and wear properties to PS200. The PS300 matrix, which is predominantly chromium oxide rather than chromium carbide, does not require diamond grinding and polishes readily with silicon carbide abrasives, greatly reducing manufacturing costs compared to PS200. It is anticipated that PS300 has potential for sliding bearing and seal applications in both aerospace and general industry.

C. DellaCorte and B.J. Edmonds. Cited: "Preliminary Evaluation of PS300: A New Self-Lubricating High Temperature Composite Coating for Use to 800 °C," TM-107056, NASA Centre for Aerospace Information, Baltimore, MD, 1995 [in English]. PHOTOCOPY ORDER NUMBER: 199609-57-1589.

Sink Rolls in Galvanizing

Development of HVOF Sprayed WC-Co Coating for Sink Rolls in Galvanizing Bath. In order to protect the sink rolls used in continuous hot-dip galvanising, sprayed WC-Co cermet coating was formed on mild steels by high-velocity oxygen fuel spraying process, and its durability in the molten Zn bath (mainly 753 K) containing 0 to 3 wt% Al was investigated on the basis of the constitutional change measured by SEM and EDS. By immersion in the molten Zn bath, the diffusion layer is grown under the surface of the sprayed coatings that may depend on the interdiffusion of Co and Zn atoms. The phenomenon of which this diffusion is suppressed with Al in the bath is observed. Thereupon, the relationship between the thickness of diffusion layer and immersion period is discussed in regard to durability.

Y. Kobayashi, Y. Takatani, T. Tomita, Y. Harada, A. Nakahira, and K. Tani. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 211-216 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1368.

Steam Turbines

$NiCr-Cr_3C_2$ and NiCr-TiC High Wear Resistant Coatings for Protective Applications in Steam Turbines. Different types of thermal spray processes were investigated to produce wear resistant surface coatings using different $NiCr-Cr_3C_2$ powders. Agglomerated powders were investigated and powders produced by self-propagating high-temperature synthesis. Coating properties were judged in order to optimize the system material spray process application. The obtained research results will lead to improved erosion-resistant surface coatings for use in steam turbines.

E. Lugscheider, C. Herbst, P. Remer, A. Verstak, Y. Borisov, A. Chernishov, K. Yushchenko, S. Steinhäuser, and B. Wielage. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 235-240 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1372.

Subsea Piping

Corrosion Control of Subsea Piping Systems using Thermal Sprayed Aluminum Coatings. The operating performance of thermal sprayed aluminum (TSA) coatings has been well documented in seawater environments. The performance of these coatings in saline muds has not been previously quantified. This type of data is required for applications involving subsea piping systems. Four- and twelve-month exposure tests were conducted in natural Gulf of Mexico sea mud, and the performance of TSA coatings quantified in terms of their ability to adequately cathodically protect various amounts of bare steel. Performance has been further quantified by determining their corrosion rate and corresponding life in these environments.

S.L. Wolfson. Cited: *Mater. Perform.,* Vol 35 (No. 7), July 1996, p 32-36 [in English]. ISSN 0094-1492. PHOTOCOPY ORDER NUMBER: 199610-35-1976.

TBC Design

Thermal Barrier Coatings Design for Gas Turbines. Thermal barrier coatings applied to hot section components (F9X14) of land-based gas turbines were investigated by paying attention to coating design. A concept of multilayered thermal barrier coatings, which showed both high thermal barrier ability and durability, was suggested. Computer-aided interactive system, which enabled convenient analysis of thermal stresses for the multilayered thermal barrier coatings, was developed for optimizing coating materials and their thickness. Next, the thermal barrier ability and durability for coatings were confirmed by experiments. The variation of the thermal barrier ability was examined during thermal cycling test, and it was confirmed that effective thermal conductivities of the thermal barrier coatings tended to decrease for microcracking and/or oxidation of coating during thermal cycling test. On the other hand, the durabilities of the thermal barrier coatings were evaluated by the thermal cycling test, and it was indicated that the durabilities of coatings remarkably depended on an oxidation at the interface between bond and top coating. The multilayered thermal barrier coatings, which had oxidation-resistant layer between the bond and top coating by preoxidation or prealuminizing treatment, was useful for having high durabilities.

M. Takahashi, Y. Itoh, and M. Miyazaki. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 83-88 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1358.

Turbine Blades

Upgrading of Turbine Blade Reliability by Vacuum Arc Coating. The method of plasma arc spraying in vacuum is applied for aircraft engine blade coating with corrosion and heat-resistant layers of CoCrAlY and ZrO_2/Y_2O_3 compositions. Initially the coating 60 to 70 μm thick of CoCrAlY alloy was deposited and heat treated to ensure a stable structure. The surface layer of ZrO_2/Y_2O_3 ceramics was produced in vacuum chamber in the presence of oxygen on plasma spraying of Zr-10%Y alloy cathode. Examination of two-layer coatings on EI893 alloy samples confirms their suitability for the purpose.

I.V. Burov, V.G. Kuznetsov, S A. Leont'ev, I.S. Polipanov, A.I. Rybnikov, A.A. Solomatnikov, and V.G. Valuev. Cited: *Svar. Proizvod.,* Vol 5, May 1995, p 13-16 [in Russian]. ISSN 0491-6441. PHOTOCOPY ORDER NUMBER: 199609-58-1408.

Water Purification Systems

Electrochemically Active Thermal Sprayed Coatings for Water Purification Systems. Experiments on thermal spraying of active coatings for electrochemical production anodes are described. Study on the effect of spraying material compositions, particle sizes, and technology of spraying the anode coatings on the active chlorine current efficiency is presented. The results obtained are compared to the indices achieved with the oxide-Ru-Ti anodes.

Yu. Borisov, V. Maksimov, A. Slipchenko, V. Slipchenko, V. Balakin, A. Ilienko, and A. Murashov. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 141-144 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1595.

Wear Resistance

Aerospace Wear and Corrosion-Resistant Coatings—A Perspective. The paper discusses the need to combat wear and corrosion and to analyze wear types with regard to weight, longer working life, demands on performance, and so forth. Details of various surface coatings are provided, and their properties are discussed. Also examined are several R&D programs on new-generation coatings. It is concluded that surface-coating engineers should be part of the design team in the manufacturing process.

T. Amos. Cited: *Aircr. Eng. Aerosp. Technol.,* Vol 68 (No. 3), 1996, p 23-25 [in English]. ISSN 0002-2667. PHOTOCOPY ORDER NUMBER: 199610-35-1947.

Book

Thermal Spray Conference

Thermal Spraying—Current Status and Future Trends. 98 papers selected and abstracted for Metals Abstracts.

A. Ohmori. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-72-0387.

Diagnostics

Laser Interferometry

Experimental Investigation by Laser Interferometry Measurements on Sprayed-Particle Velocity in Plasma Jets for Atmospheric and Low-Pressure Sprayings. The sprayed velocities of powders injected into an atmospheric plasma jet from a DC plasma torch are measured by the laser interferometry and LDV (laser Doppler velocimetry), respectively. The laser interferometry of which measurement system consists of a He-Ne laser and a Fabry-Perot interferometer make use of the Doppler effect of scattered light from the sprayed particles. This technique has an attractive advantage of relatively low cost compared with commercial LDV and L2F (Laser DUal FOcus) systems. The measured velocities by the laser interferometry show the comparable reliability to those by LDV. The sprayed velocities of particles in low-pressure spray plasma are also measured by the laser interferometry to make a comparison between APS and LPPS The maximum particle velocity is approximately 130 m/s, and its peak value is formed at a spray distance about 80 mm for the typical operating conditions in APS. The peak velocities are present at almost the same axial position for several operating conditions to find the influences of operating parameters, and beyond this position for several operating conditions to find the influences of operating parameters, which cannot be a critical parameter influencing the coating quality without considering particle melting state. The input power, argon flow rates and hydrogen flow rate play an important role in determining sprayed particle velocities for both in APS and in LPPS, and the ambient pressure among other operating parameters affects the particle (Al_2O_3-TiO_2) most significantly.

B L. Choi, S.I. Lee, S.H. Hong, and Y.H. Kim. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 445-450 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1728.

Feedstock

Iron Alloy Powders

Iron Alloy Powders for Gas-Thermal Spraying the Wear- and Corrosion-Resistant Amorphous Coating. The iron-base powders are developed to apply coatings by the methods of plasma, gas-flame, and explosive spraying. An amorphous structure formation favors the improvement of wear and corrosion resistance as well as adhesive strength with a metal base. The coatings may be applied to hardening and repairing the internal combustion engine components, oil, chemical, and boring equipment in place of the costly nickel powder coatings.

Cited: *Avtom. Svarka,* Vol 12, Dec 1995, p 50 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199608-57-1468.

Particle Size Selection

Particle Size Selection for Plasma Deposition of Low-Temperature Materials. Heat transfer calculations show that the temperature gradients developed within in-flight polymer particles during plasma spraying are considerably greater than those of metals and ceramics. This effect in conjunction with the low decomposition temperatures of polymers place more stringent requirements on plasma processing. This work shows that a suitable balance may be achieved between maximizing the degree of melting and minimizing degradation by the control of the feedstock particle size. The results indicate maximum quality in polyamide coatings (on carbon steel) in terms of density, tensile properties, and wear resistance at a particle size of 38 to 53 μm, which is consistent with the theoretical predictions.

Y. Bao and D.T. Gawne. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 383-388 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1725.

Polymer Coatings

Thermal Spray High-Performance Polymer Coatings. Thermal spray coatings on large components and composite substrates using recently developed thermoplastic and thermoset powders are commercially available today. This relatively small but growing technology, which has been available since the 1980s, is now gaining momentum. Improvements in equipment that can heat, melt, and discharge polymer powder materials including with fillers such as fibers, powder metals, and ceramics, allow thermal spray operators to coat metal, wood, plastics, composites, glass, and even paper with high-performance coatings. Thermal spray coating can provide improved resistance to abrasion, corrosion, temperature changes, and weathering in high-technology applications from aircraft engines to the maintenance of steel structures.

T.D. Fender. Cited: *Mater. Technol. (UK),* Vol 11 (No. 1), Jan-Feb 1996, p 16-20 [in English]. ISSN 1066-7857. PHOTOCOPY ORDER NUMBER: 199608-57-1494.

Quenching of Zirconia-Based Liquids

Chemical and Structural Characterization of Quenched Ceria (Yttria) Stabilized Zirconia or Hafnia Ceramics for Plasma Coatings. A process of quenching the zirconia-cerium oxide, hafnia-cerium oxide and zirconia-yttria-cerium oxide liquid solutions tends to simulate the plasma spraying effects in air. New chemical composition and crystal structure of as-quenched and annealed materials are described.

A. Rouanet, A. Cornu, T. Priem, R. Ranc, E. Rigal, G. Peraudeau, and F. Sibieude. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 507-512 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-12-1000.

Thermal Plasma Synthesis

Thermal Plasma Synthesis of Ceramic Powders and Coatings. Three types of injection-plasma processing (IPP) are characterized and the problems relating to IPP are reviewed. To demonstrate the feasibility and prominent features of IPP, special attention is given to radio-frequency (RF) and hybrid-plasma processing, which is discussed in conjunction with recent research concerning the synthesis of ceramic powders (Si_3N_4, SiC) and coatings and ZrO_2 (Al_2O_3) on as-rolled 304 stainless steel. "Super-high-rate deposition of ceramics" and "RF-plasma spraying of ceramics" are proposed as two distinctive candidates for the future development of IPP in the field of ceramic technology.

T. Yoshida. Cited: *Combustion and Plasma Synthesis of High-Temperature Materials* (Proc. Conf.), San Francisco, CA, 23-26 Oct 1988, VCH Publishers, New York, 1990, p 328-339 [in English]. ISBN 0-89573-756-6. PHOTOCOPY ORDER NUMBER: 199608-57-1408.

Tungsten

Air Plasma Spraying of Tungsten Coatings. The air plasma spray process is being investigated for the applicability to fabricate tungsten coatings and monoliths for applications in space power and propulsion, including heat pipes, solar absorption cavities, and reactor fuel clad structures. In this study, experiments were conducted using a statistical design of experiment methodology. The parameters varied included secondary to total gas flow ratio, total flow, and spray distance. The attributes evaluated were thickness, porosity, deposition efficiency, and grain structure. An optimized coating design based on minimum porosity was predicted by the statistical analysis. (Substrates tested were aluminum, graphite, and stainless steel). The coatings were characterized using image analysis and SEM. The as-sprayed coating microstructures were characterized by a mixture of lamella and partially melted tungsten particles. As-sprayed porosity of the coatings ranged from 1 to 13%, based on image analysis.

D.J. Varacalle, Jr., L.B. Lundberg, B.G. Miller, and W.L. Riggs II. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 377-382 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1460.

High-Velocity Oxygen Fuel

Analysis by CFD

Analysis of a High-Velocity Oxygen Fuel (HVOF) Thermal Spray Torch. II. Computational Results. The fluid and particle dynamics of a high-velocity oxygen fuel (HVOF) torch are analyzed using computational fluid dynamic (CFD) techniques. The thermal spray device analyzed is similar to a Metco Diamond Jet torch with powder injection. The details of the CFD simulation are given in a companion paper. This paper describes the general gas dynamic features of HVOF spraying and then discusses in detail the computational predictions of the present analysis. The gas velocity, temperature, pressure, and Mach number distributions are presented for various locations inside and outside the torch. The two-dimensional numerical simulations show large variations in gas velocity and temperature both inside and outside the torch due to flow features such as mixing layers, shock waves, and expansion waves. Characteristics of the metal spray particle velocity, temperature, trajectory, and phase state (solid or liquid) are also presented and discussed. Particle velocities and temperatures are shown to be lower for this type of torch than previously believed.

W.L. Oberkampf and M. Talpallikar. Cited: *J. Therm. Spray Technol.,* Vol 5 (No. 1), March 1996, p 62-68 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-57-1352.

Blocking of Nozzles

Factors of Blocking Phenomenon on the Internal Surface of Jet Kote Gun Nozzle. In the Jet Kote system, one of the typical high-velocity oxygen fuel (HVOF) thermal spraying systems, it has been an unsolved problem that a part of spray powder deposits on the internal surface of the gun nozzle. The goal of the present study is to solve this problem. As the first step, the effect of variations in the key spraying conditions, such as the melting point of spray powders, particle size, internal surface roughness of the gun nozzle, nozzle length, and fuel/oxygen flow rate, upon the deposition of spray powder was examined. On the basis of these results, the factor of the deposition was analyzed. Spray powders used are Sn-7.5Sb-3.5Cu, Al, Cu-10Al, Ni-17Cr-5Al-0.5Y, WC-12Co, Al_2O_3 and Mo. State of the deposits is influenced by the melting point of spray powders, particle size, internal surface roughness of gun nozzle, and fuel flow rate. Spraying with a shorter (76.2 mm) nozzle is prone to form more deposits than that with a longer (152.4 or 304.8 mm) nozzle. The deposition tends to occur on the internal surface near the tip region at the nozzle exit. The blocking occurred in the Jet Kote spraying of NiCrAlY and can be controlled by finishing the internal surface of the nozzle finer and by selecting coarser size powder (diameter of 38 to 45 μm). The behavior and the properties of powders in the nozzle complicate determination of the causes for blocking phenomenon of spray powders on the internal surface of Jet Kote gun nozzle.

K. Sakaki, N. Saito, and Y. Shimizu. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 301-306 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1451.

Heat Transfer

Heat Transfer between WC-Co Coating and Aluminum Alloy Substrate during High-Velocity Oxygen-Fuel (HVOF) Spraying. Mathematical simulation of the heat transfer between a WC-Co coating and an aluminum alloy (Al-4%Cu) substrate during HVOF spraying is provided. The simulation includes the investigation of temperature evolution, coating solidification, fusion and solidification in the substrate interfacial region, and particular features of the substrate-coating thermal interaction. Optimal thermal conditions for forming the coating structure are estimated. The results obtained are used in another work to predict the structural parameters, which agree well with the experimental data.

V.V. Sobolev, J.A. Calero, J.M. Guilemany, and F.J. Villuendas. Cited: *J. Therm. Spray Technol.*, Vol 4 (No 4), Dec 1995, p 408-414 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1184.

Microstructure

Amorphous Coatings

Characterization of Plasma Sprayed Fe-10Cr-10Mo-(C,B) Amorphous Coatings. Alloys of Fe-10Cr-10Mo containing a large amount of carbon and/or boron were plasma sprayed by low-pressure plasma spraying (LPPS) and high-energy plasma spryaing (HPS). The as-sprayed coatings obtained by the LPPS process are composed of only an amorphous phase, while as-sprayed coatings obtained by the HPS process are a mixture of amorphous and crystalline phases. The amorphous phase in these coatings crystallizes on tempering at ~773 to 873 K, and the crystallization temperatures depend on the content of carbon and boron. Thermal stability of the amorphous phase containing boron is higher than those phases containing carbon. A very fine mixed structure of ferrite and carbide, borocarbide, or boride is formed by decomposition of the amorphous phase, bringing about a hardness of 1200 to 1400 DPN (Vickers hardness). The coatings containing carbon retain a hardness of >1000 DPN, even on tempering at temperatures of 1073 K or higher. The anodic polarization behavior of the coatings exhibits an activation-passivation transition in 1 *N* H_2SO_4 solution. The active and passive current densities of the as-sprayed amorphous and tempered crystalline coatings containing carbon is lower than the coatings containing boron. The corrosion resistance of the as-sprayed and crystallized coatings containing carbon is superior to a SUS316L stainless steel coating.

K. Kishitake, H. Era, and F. Otsubo. Cited: *J. Therm Spray Technol.*, Vol 5 (No. 2), June 1996, p 145-153 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-58-1292.

Structure and Properties of Amorphous Magnetically Soft Plasma Sprayed Coatings. Plasma sprayed Co-Ni-Fe-Si-B coatings were studied for their structure and magnetic properties depending on coating conditions. Microscopic examination showed that the coatings consisted of amorphous disklike and crystalline particles and contained 6 to 10% of voids. Amorphous coatings in an as-received state possess low magnetic properties that can be improved by annealing in magnetic field or by quenching. Low magnetic properties of initial coatings are noted to be due to the existence of independent disperse domain structure in each individual amorphous particle.

V.I. Kalita, I.B. Kekalo, D.I. Komlev, and V.E. Taranichev. Cited: *Fiz. Met. Metalloved.*, Vol 8 (No. 2), Aug 1995, p 35-48 [in Russian]. ISSN 0015-3230. PHOTOCOPY ORDER NUMBER: 199608-58-1279.

Amorphous Phase

Formation of an Amorphous Phase in Thermally Sprayed WC-Co. A WC-Co coating was sprayed by the high-velocity oxyfuel process using a feedstock of tungsten carbide clad with cobalt. The structure of the sprayed coating was characterized by x-ray diffraction (XRD), differential scanning calorimetry (DSC), and differential thermal analysis (DTA). It was found that an amorphous phase of Co-W-C ternary alloy observed as a large, broad peak in the XRD pattern can be formed in the as-sprayed WC-Co coating. The DSC, DTA, and XRD analyses revealed that the amorphous phase crystallized at a temperature of around 873 K to metallic cobalt, Co_6W_6C, and tungsten with appreciable precipitation of free carbon. The heat treatment of as-sprayed WC-Co coating at a high temperature of 1173 K suggests that annealing at a temperature higher than about 1104 K will promote the reaction of tungsten and cobalt with carbon to form the complex carbide Co_6W_6C. Coatings were sprayed onto a sand blasted steel surface.

C.J. Li, A. Ohmori, and Y. Harada. Cited: *J. Therm. Spray Technol.*, Vol 5 (No. 1), March 1996, p 69-73 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-57-1353.

Anisotropy of Porosity

Anisotropy of the Surfaces of Pores in Plasma Sprayed Alumina Deposits. Porosity is an important factor in determining the physical properties of plasma sprayed deposits. A significant fraction (2 to 15%) of the deposit volume consists of voids. These voids are in the form of pores between the splats and around any inclusions (unmelted particles) that may be present, and in the form of cracks within the splats. Neither the pores nor the cracks are spherical in shape, and the splat structure is circularly symmetric only when viewed from the spray direction. The microstructure of a plasma sprayed deposit contains significant anisotropy in the void shapes, and there may be significant alignment of some of these shapes along particular directions. In this research, the voids in plasma sprayed deposits (alumina) were investigated by measuring the specific surface areas of the voids from the terminal slope of small-angle neutron scattering, i.e., Porod scattering, by the deposits, and by means of Hg intrusion porosimetry. The results indicate that much of the void surface area is found perpendicular to the substrate and is associated with cracks. The second population of voids is found mostly parallel with the substrate and is associated with interlamellar pores. The surface areas measured by means of porosimetry were smaller than the surface areas derived from scattering and were probably influenced by the presence of closed porosity, by the void model and by the low precision for measuring small voids.

J. Ilavsky, A.N. Goland, C.C. Berndt, H. Herman, A.J. Allen, S. Krueger, and G.G. Long. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 483-488 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-12-0998.

Characterization of VPS Coatings

Microstructural Characterizations of Low-Pressure Plasma Sprayed CoNiCrAlY Coating. Transmission electron microscopy (TEM) studies of low-pressure plasma sprayed (LPPS) CoNiCrAlY coatings (on SUS304) have been carried out. Spherical γ'-phase with $L1_2$ structure was surrounded by β-phase with *B2* structure in an as-sprayed coating. In other words, γ'-phase was a primary phase during solidification. After homogenizing treatment at 1273 K for 4 h, γ'-phase disappeared and γ-phase with fcc structure coexisted with β-phase. The microvickers hardness of as-sprayed coatings were decreased by homogenizing treatment. By aging at 873 and 973 K after the homogenizing treatment γ'-phase was formed again. The microvickers hardness of the aged coatings was higher than that of the as-sprayed coating. These changes of the mechancial property were considered to be attributed to the ordering from γ- to γ'-phase and the α-Co precipitates in β-phase.

K. Noguchi, A. Chiba, M. Nishida, Y. Harada, and J. Takeuchi. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 459-464 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-12-0997.

Effects of Castable Encapsulation

The Effects of High-Pressure/Temperature and Castable Encapsulation Techniques on Various Plasma Sprayed Coatings. Accurate microstructural analysis of plasma sprayed coatings is possible only if proper metallographic specimen preparation techniques are followed revealing the true coating characteristics. Significant differences or variations in the coating microstructure created by variations in metallographic practices produces conflicting information pertaining to the integrity of the coating. Each step in the preparation process must not create coating damage that cannot be removed during subsequent operations. A study was conducted on cermet, metallic, and ceramic oxide plasma sprayed coatings specifically evaluating the effects of elevated-temperature/pressure and castable epoxy resin encapsulation on each coating. Each encapsulation procedure affected the coatings differently, and the observable differences are discussed in this paper.

G.A. Blann. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 519-523 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-21-0256.

Functionally Graded Materials

Functionally Graded Coating Materials. Metal-ceramic graded coatings consisting of NiAl and 8 wt% Y_2O_3 stabilized ZrO_2 have been developed. The design of the coatings was described. The chemical composition, mechanical, and thermophysical properties of the coatings were determined. The experimental results obtained indicated that the functionally graded coatings possess low thermal diffusivity, high thermal expansion coefficient, and good adhesive bonding to substrate. The engine test for coatings applied to the combustion components of diesel engines showed that the graded coating systems have excellent thermal shock resistance.

C.X. Ding, M.C. Chen, and Y.F. Zhang. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 27-29 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1351.

Laser-Glazed Coatings

Microstructures and Properties of Laser-Glazed Plasma-Sprayed ZrO_2-$YO_{1.5}$/Ni-22Cr-10Al-1Y Thermal Barrier Coatings. Thermal barrier coatings (TBCs) consisting of two layers with various yttria contents (ZrO_2-$YO_{1.5}$/Ni-22Cr-10Al-1Y) were plasma sprayed, and parts of the various specimens were glazed by using a pulsed CO_2 laser. All the specimens were then subjected to furnace thermal cycling tests at 1100 °C; the effect of laser glazing on the durability and failure mechanism of the TBCs was then evaluated. From these results, two models were developed to show the failure mechanism of as-sprayed and laser-glazed TBCs: model A, which is thermal stresss dominant, and model V, which is oxidation-stress dominant. For top coats containing cubic phase, cubic and monoclinic phases, or tetragonal, and a relatively larger amount of monoclinic phases, whose degradation is thermal stress dominant, laser glazing improved the durability of TBCs by a factor of ~2 to 6. Segmented cracks that occurred during glazing proved beneficial for accommodating thermal stress and raising the tolerance to oxidation, which resulted in a higher durability. Thermal barrier coatings with top coats containing tetragonal phase had the highest durability. Degradation of such TBCs resulted mainly from oxidation of the bond coats. For top coats with a greater amount of monoclinic phase, thermal mismatch stress occurred during cooling and detrimentally affected durability.

H.L. Tsai and P.C. Tsai. Cited: *J. Mater. Eng. Perform.*, Vol 4 (No. 6), Dec 1995, p 689-696 [in English]. ISSN 1059-9495. PHOTOCOPY ORDER NUMBER: 199608-57-1507.

Porosity Characterization

Effects of Spray Conditions on the Pore Structure and Quenching Stress in Plasma Sprayed Coatings. Effects of spray distance and substrate temperature on the microstructure of Ni-20Cr alloy deposits plasma sprayed in air were studied experimentally. The spray distance was changed from 60 to 300 mm, whereas the substrate temperature from 200 to 600 °C. Oxygen in the deposits increased almost linearly with the spray distance, whereas it did not change significantly with the substrate temperature. Pore size distributions measured by Hg porosimetry changed significantly both with the spray distance and substrate temperature. With a substrate temperature over 600 °C, especially, open porosity almost completeley diminished. SEM observation of samples treated by high-pressure infiltration of a Bi-alloy into the open porosity revealed that the interlamellar contact was significantly enhanced on a hotter substrate. Significant increase in the quenching stress in the temperature range suggests that the initial liquid/solid contact between a sprayed particle and the underlying coating surface is largely responsible for the observed structural change due to substrate temperature.

S. Kuroda and S. Kitahara. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 489-494 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-12-0999.

Process Effects on Structure

Effect of Spray Methods on the Lamellar Structure of Al_2O_3 Coatings. A thermally sprayed coating consists of flattened particles and has a layer structure. Porosity is inevitably formed in a coating, which includes the usually referred pores of micron order size and those of submicron size. Submicron size pores consist of nonbonded interface area between flattened particles and those gap areas from microcracks occurred in individual flattened ceramic particles. An electroplating technique has been developed to reveal the real pore structure of thermally sprayed Al_2O_3 coatings assisted by the distribution of Cu electroplated into the coating. The most significant aspect of such technique is to reveal visually the nonbonded interface area between flattened ceramic particles in a flame sprayed coating. In the present report, the electroplating technique is applied to Al_2O_3 coatings (on mild steel) sprayed by conventional plasma spraying, low-pressure plasma spraying, and detonation gun spraying to characterize quantitatively the coating structure using such structural parameters as mean lamellar bonding ratio and mean thickness of flattened particles. The effect of spraying method on the lamellar bonding between flattened particles is examined.

C.J. Li, Y. Arata, and A. Ohmori. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 501-506 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1729.

Relationship to Fatigue

A Microstructural Study of Fatigue Damage in Stainless Steel Coated with Plasma Sprayed Alumina. To evaluate the potential of prosthetic application, the SUS316L stainless steel rod specimen coated with plasma sprayed Al_2O_3 deposit has been fatigued in a physiological saline solution. Fatigue tests were conducted in push-pull loading, at a stress ratio of $R = -1$, and at frequencies of 2 and 30 Hz. In the *S-N* curve, the plasma sprayed Al_2O_3 coating brought about improvement in fatigue properties of the substrate metal. Plasma spraying was effective in the initial stages of crack propagation. The effect was more pronounced at 30 than at 2 Hz. It is believed that improvement in fatigue properties of the Al_2O_3 plasma sprayed specimen resulted from the residual compressive stresses due to the grit blasting which was carried out prior to plasma spraying and the corrosion-resistance of the Al_2O_3 deposit. It can be said that the Al_2O_3 plasma sprayed stainless steel is a promising material for implant application, if plasma spraying parameters are optimized.

M. Sugano, J. Kishimoto, H. Masaki, Y. Nasu, and T. Satake. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 145-150 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-31-3101.

Relationship to Wear

On the Relationship between the Microstructure and the Wear Characteristics of Selected Thermal Spray Coatings. The general lamellar microstructure of thermal spray coatings is well known, as is the complexity of the chemical and crystallographic phase content of all but the simplest of coatings. While the impact of these complexities on the wear characteristics of the coatings has been recognized for some time, there have been relatively few studies of the details of this phenomena. In this study a few selected thermal spray coatings with similar total chemical composition, but different microstructures, are considered in light of the impact of these differences on their erosive, abrasive, and adhesive wear behavior. The coatings include primarily tungsten carbide and chromium carbide base cermets (on 422SS). The differences in microstructure have been generated as a result of different powder types, deposition processes, and deposition parameters. The significance of relatively subtle changes in microstructure on the selection of coatings for specific applications is discussed.

R.C. Tucker, Jr. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 477-482 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-31-3355.

Microstructure and Wear Properties of Arc Sprayed Tungsten Carbide Coating. Tungsten carbide thermal sprayed coatings are commonly used in industries for components that require abrasion resistance. Such coatings are commonly produced by either plasma or high velocity oxyfuel (HVOF) sprayed processes. However, with the commercially available tungsten carbide cored wire, tungsten carbide coatings can be produced more economically by electric arc spraying process. This paper presents the effects of arc spraying process on the changes of coating microstructure and its wear performance. Wear property of the coating was studied using the block-on-ring method, in accordance with the ASTM-G77 standard. Mechanical properties, such as microhardness and bonding strength of the coatings are also presented. Tungsten carbide retained in the coating was examined using the microscopes with image analyzer and energy dispersive spectrometer (EDS).

K. Wira, C.W. Lim, and N.L. Loh. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 465-470 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-31-3354.

Sealing of TBCs

Sealing and Strengthening of Plasma-Sprayed ZrO_2 Coating by Liquid Manganese Alloy Penetration Treatment. The penetration phenomena of liquid Mn alloy into porous ZrO_2 (8 wt% Y_2O_3) coating, plasma sprayed on SS400 steel substrate, was studied by heating in a vacuum atmosphere, and the possibility of improving the mechanical properties of the coating by heat treatment with liquid Mn alloys were examined. It was found that liquid Mn alloys, such as Mn-Cu, Mn-Sn, and Mn-In, rapidly penetrated the coating and formed a chemical bonding interface between the coating and the substrate. The densification of the ZrO_2 coating occurred when ZrO_2 particles were sintered with liquid Mn alloy that penetrated the porous coating. It was revealed that the dense coating was free of porosities and that its hardness increased greatly after heat treatment with Mn alloys, compared with as-sprayed ZrO_2 coating. Moreover, the fracture toughness of the coating reached the same levels as those of sintered PSZ (Y_2O_3).

A. Ohmori, Z. Zhou, K. Inoue, K. Murakami, and T. Sasaki. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 549-554 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1730.

WC-Co on Aluminum Alloys

Formation of Structure of WC-Co Coatings on Aluminum Alloy Substrate during High-Velocity Oxygen-Fuel (HVOF) Spraying. The work concerns the mathematical simulation of the structure formation of the WC-Co coating on aluminum alloy (Al-4% Cu) substrate during high-velocity oxygen-fuel (HVOF) spraying. Variations of the solidification velocity, thermal gradient, and cooling velocity in the coating and substrate interfacial region are studied. Formation of the amorphous and crystalline structures in the coating and of the crystalline structure in the substrate interfacial region is discussed. Behavior of the crystal size and intercrystalline distance with respect to the thermal spray parameters is analyzed. Optimal conditions for the development of fine and dense crystalline structure are established. Results agree well with experimental data.

V.V. Sobolev, J.A. Calero, and J.M. Guilemany. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 401-407 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1183.

Modeling

Control of Arc Power

Programming of Plasma Powder Surfacing of Shafts. An attempt was made to develop a simple mathematical model of plasma-powder coating of machine parts (shafts) and to use it as a basis for designing methods of surfacing control, which assures production of coatings with uniform composition and physical and mechanical properties. Computer control of plasma arc power was found to result in stable conditions of coating formation. Calculation results accomplished for 40 mm shaft coating with stainless steel K18N19 powder are confirmed by experiments.

V.P. Lyalyakin, B.B. Nefedov, and V.A. Steshenko. Cited: *Svar. Proizvod.*, Vol 6, June 1995, p 4-6 [in Russian]. ISSN 0491-6441. PHOTOCOPY ORDER NUMBER: 199609-55-1588.

HVOF

Analysis of a High-Velocity Oxygen Fuel (HVOF) Thermal Spray Torch. I. Numerical Formulation. The fluid and particle dynamics of a high velocity oxygen fuel torch are analyzed using computational fluid dynamic techniques. The thermal spray device analyzed is similar to a Metco Diamond Jet torch with powder feed. The injection nozzle is axisymmetric with powder and a carrier gas injected on the centerline, premixed fuel and oxygen fed from an annulus, and air cooling injected from an annulus along the interior surface of the aircap. The aircap is a conically converging nozzle that achieves choked flow conditions at the exit; a supersonic, underexpanded jet develops externally. A two-dimensional, axisymmetric geometry is assumed; the equations for mass, momentum, and energy conservation are solved for both the gas and the particle phases. The combustion process is modeled using approximate equilibrium chemistry with dissociation of the gas with a total of nine species. Turbulent flow is modeled by a two-equation model for turbulent kinetic energy and dissipation rate that includes compressibility effects on turbulent dissipation. Particles are modeled as a lumped heat-capacity system and are considered to melt upon attaining the required latent heat of fusion. An iterative, implicit, finite-volume numerical method is used to solve the coupled gas and particle equations inside and outside the torch. A companion paper presents the results of the numerical simulation and discusses in detail the gas and particle dynamics.

W.L. Oberkampf and M. Talpallikar. Cited: *J. Therm. Spray Technol.*, Vol 5 (No. 1), March 1996, p 53-61 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-58-1184.

HVOF Fuel Process

Numerical Modeling of Combustion and Flow Characteristics in HVOF Systems with Chemical Equilibrium Approach. In the HVOF processes, the thermal and kinetic energies are obtained by the combustion of a fuel gas with an oxidant. Therefore, it is very important to determine the thermodynamic properties of combustion products in the combustion chamber because the flow properties are calculated on these bases. The main objective of this study was the development of a computation code able, on the one hand, to calculate combustion phenomena and flow properties of gas and particles, and, on the other hand, to optimize processing parameters. This paper presents the aspects related to the combustion phenomena and to the gas flow properties. Three different flow approaches were achieved in the internal and the external flow: calorifically perfect gas flow, frozen flow, and equilibrium flow. The numerical applications showed considerably different results on flow properties.

Y.M. Yang, C. Coddet, and H. Liao. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 399-404 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199610-34-0939.

Numerical Simulation of HVOF

Numerical Simulation of Gas and Particle Flow in a High-Velocity Oxygen-Fuel (HVOF) Torch. A transient two-dimensional numerical simulation of Inconel spraying in a high-velocity oxygen-fuel (HVOF) torch barrel was performed. The gas flow is treated as a continuum multicomponent chemically reacting flow, whereas particles are modeled using a stochastic particle spray model, fully coupled to the gas flow. The calculated results agree well with experimental data and show important statistical aspects of particle flow in the torch.

C.H. Chang and R.L. Moore. Cited: *J. Therm. Spray Technol.*, Vol 4 (No. 4), Dec 1995, p 358-366 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-58-1036.

Patent

Feedstocks—Carbide

Thermal Spray Powder of Tungsten Carbide and Chromium Carbide. A thermal spray powder is formed as a mixture of tungsten carbide granules and chromium carbide granules. The tungsten carbide granules each consists essentially of tungsten carbide bonded with cobalt, and the chromium carbide granules each consists essentially of chromium carbide bonded with nickel-chromium alloy. The powder may be as-mixed with self-fluxing alloy powder. The powder preferably is sprayed with a high-velocity oxygen-fuel thermal spray gun.

B.E. Dulin. Cited: European Patent EP0657237, 14 June 1995, Conv. date: 5 Dec 1994 [in English]. PHOTOCOPY ORDER NUMBER: 199610-E4-C-0328.

Hot Workability

Enhancement of Hot Workability by Use of Thermal Spray Coatings. The invention relates to a process in which a metal or metal alloy is thermal spray coated onto a base alloy material prior to hot working. More specifically, the invention relates to the use of plasma coating of titanium over a Ti alloy plate for improved hot workability. This combination allows the crack-sensitive base alloy to be rolled with a minimum of surface and edge cracks. In addition, by using a plasma sprayed Ti coating there is a reduction in the roll force required to reduce the material during the hot-working process. The Ti coating layer is >0.25 mm thick.

P.A Russo and S.R. Seagle. Cited: U.K. patent GB2282608, 12 April 1995, Conv. date: 18 Dec 1992 [in English]. PHOTOCOPY ORDER NUMBER: 199610-58-1629.

Wear-Resistant Thermal Sprayed Layer. A wear-resistant thermal sprayed layer is provided that is suitable for the surface of a sliding member, for example, the inner circumferential surface of a steel cylinder liner. The thermal sprayed layer comprises steel containing 0.25 to 2.2 wt% C and <13.0 of one or more elements selected from chromium, molybdenum, tungsten, and vanadium. Nonfused particles are dispersed in an area ratio of 10 to 50% in the matrix of the layer. The hardness of the nonfused particles differs from the hardness of the matrix, with that of the matrix or of the nonfused particles, whichever is greater, having a Vickers hardness >400. The layer is produced from a powder mixture comprising two or more types of powder materials having different degrees of hardness after spraying, the powder of large particle size being the powder material of lesser hardness, and the powder of small particle size being the powder material of greater hardness.

T. Hazano, H. Fukotome, and N. Yamashita. Cited: U.K. patent GB2291071, 17 Jan. 1996, Conv date: 13 July 1995 [in English]. PHOTOCOPY ORDER NUMBER· 199610-58-1640.

Post-Processing

HIP of TiAl

Microstructure and Properties of Plasma Sprayed TiAl coatings after Hot Isostatic Pressing. Titanium aluminides have many attractive properties for application in aerospace engines and have the potential to substitute current nickel-base alloys used at intermediate temperatures. This can result in significant weight savings. Plasma spraying is a viable process for deposition of TiAl coatings. The coatings have the typical lamellae structure of thermally sprayed coatings, and within each lamella there is evidence of columnar grain growth. The coatings contained defects such as pores and unmelted or partially melted particles. Hot isostatic pressing (HIP) was used to densify plasma sprayed TiAl coatings. This process was performed in the temperature range 950 to 1100 °C and pressures of 50 to 200 MPa. This paper reports changes made in the microstructure and properties of plasma sprayed TiAl coatings after hot isostatic pressing (HIP). The coatings are examined using a scanning electron microscope and image analyzer. Fractured surfaces are also studied. The results showed that HIP can effectively reduce the porosity levels of the coatings and improve the mechanical properties of the coatings.

K.A. Khor, Y. Murakoshi, T. Sano, and M. Takahashi. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 555-560 [in English] ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1471.

Infiltration

Penetration Treatment of Plasma Sprayed ZrO_2 Coating by Liquid Manganese Alloys. The penetration phenomena of liquid manganese (Mn) alloy into porous ZrO_2 (8 wt% Y_2O_3) coating plasma sprayed on SS400 steel substrate was studied by heating in a vacuum atmosphere. The improvement in mechanical properties of the coating by heat treatment with liquid Mn alloys was examined. Liquid Mn alloys, such as Mn-Cu, Mn-Sn, and Mn-In, rapidly penetrated the coating and formed a chemical bond between the coating and the substrate. The densification of the ZrO_2 coating occurred when ZrO_2 particles were sintered with liquid Mn alloys that penetrated the porous coating. The dense coating was free of porosity, and its hardness increased after heat treatment with Mn alloys, compared with as-sprayed ZrO_2 coating. Moreover, the fracture toughness of the coating reached the same levels as those of sintered yttria-stabilized PSZ.

A. Ohmori, Z. Zhou, K. Inoue, K. Murakami, and T. Sasaki. Cited: *J. Therm. Spray Technol.*, Vol 5 (No. 2), June 1996, p 134-138 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-57-1505.

Process

Arc Modulation

Mechanisms Influencing on the Parameters of Plasma Coatings in a Modulated Plasma Arc. In a number of works, the perspective of applying plasma spraying technology of coatings with the arc current modulation of a torch has been shown. This work is an attempt to understand the physical mechanisms lying on the basis of using modulation The influence of acoustic disturbances on the electric parameters of the modulated arc is investigated, the estimate of the plasma disturbance parameters created by means of arc current modulation and an influence of these disturbances on thermodynamic parameters and dynamic viscosity of the modulated plasma jet are carried out. Thus, the phenomena providing modulation effects, both as in the plasmatrone itself and in the mechanisms influencing the plasma technology parameters have become understandable. It was shown that inserting hydrocarbons into the air plasma jet conduces to transition of the torch with vortex stabilization of the arc to the laminar spraying mode with a high coefficient use of powder. Influence of the detonation processes on the modulated arc is investigated. The obtained physical estimations are used for explanation of the sprayed characteristics of the coatings.

B.E. Goodman. Cited. *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 389-392 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1726.

Arc Spray

Aerodynamic Stabilization of the Arc in Two Wire Arc Spraying. Measurements indicated that subatmospheric gas pressure was present within the arc gap in the two wire arc spray process. Besides electromagnetic force, this aerodynamic effect contributes to the stabilization of the burning arc. The uneven distribution of gas pressure within the arc gap induces turbulent gas flow close to the electrode tip surface. This turbulent gas flow creates mixing effect of the thin molten metal (13% Cr steel) film melted by the electric arc on the electrode tip surface. The mixing effect has great significance when composite and cored wires are arc sprayed. Thick wire induces greater gas pressure reduction; it is not necessary to use thin wire when cored wires are arc sprayed.

J. Wen, W. Geng, A. Liu, S. Wen, and Z. Zhang. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 431-434 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1466.

Arc Spraying

Electric Arc Spray Forming of an Ni_3Al-Base Alloy. The present results show that it is possible to manufacture low porosity, homogeneous deposits by electric arc spraying of wires made from an Ni_3Al-base alloy, IC-218LZr. The electric arc spray formed deposit microstructure ranges from a lamellar splat/presolidified droplet columnar region near the chilled substrate surface, to an equiaxed region at higher top surface temperatures. The equiaxed region has a mean grain size of <50 μmm, porosity as low as 0.2% and low levels of microsegregation.

A.P. Newbery, B. Cantor, R.M. Jordan, and A.R.E. Singer. *Scr. Mater.,* Vol 35 (No. 1), 1 July 1996, p 47-51 [in English]. ISSN 1359-6462. PHOTOCOPY ORDER NUMBER: 199608-54-0798.

Detonation

Advanced Gas Detonation Coating Process DEMETON. Creating various processes to apply coatings to a base substrate is an essential part of modern manufacturing process and is an important direction in designing advanced materials with unique properties in the future. There are several different technologies to apply coatings to substrates including conventional plasma, vacuum plasma, wire arc metallizing, high-velocity oxyfuel (HVOF), and gas detonation processes. Among these processes, HVOF and gas detonation technologies are capable of creating premium quality coatings with low porosity and high adhesion to the substrate, suitable for applications in extreme wear, heat, and corrosion aggressive surroundings. There are several limitations of the HVOF process, including larger volumes of the combusted gases, high thermal flux to the sprayed substrate, and short lifetime of supersonic nozzle. These disadvantages are related to the fundamental nature of this technology of particle heating and acceleration. This article discusses considerations that affected the design decisions in the creation of the advanced gas detonation coating process DEMETON. Several possible detonation gas cycle diagrams are presented along with the phenomenological calculations of properties of the detonation wave in acetylene-oxygen and hydrogen-oxygen gas mixtures. With simple and inexpensive operation and excellent coating quality, this promising process represents important direction in coating technology and is used in various branches of industry.

E. Kadyrov, V. Kadyrov. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 417-424 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1464.

Development of Plasma Systems

Key Factors in the Development of Plasma Spray Systems and the Spray Process. Plasma spray has been well established in a wide spectrum of industries for several decades already. Atmospheric plasma spray (APS) is the most versatile of the various thermal spray processes because it is technically capable of and commercially suitable for producing coatings of almost any meltable or heat-softenable materials. Moreover, coatings can be deposited onto a very wide variety of substrate materials. In common with some other themal spray processes, two or more materials with widely differing properties can be APS-sprayed simultaneously to produce aggregate coatings with desirable combinations of properties that cannot be produced by other coating processes. Controlled atmosphere plasma spray (CAPS) is a relatively recent development that produces very special performance coatings for high technology applications. CAPS permits spraying in air, in vacuum, in an inert atmosphere, or in a reactive atmosphere, and at pressures ranging from low vacuum to positive pressures greater than atmospheric. Vacuum plasma spray (VPS) and low-pressure plasma spray (LPPS) are specialist categories of CAPS that operate at reduced pressure to produce high-performance coatings with very low porosity and oxide content.

S. Keller, R Clarke, A.R. Nicoll, and P. Tommer. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 275-281 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1450.

Diamond-Like Coatings

Metallographic Characterization of the Adhesion of Diamond-Like Coatings. Owing to their very high hardness, diamond-like carbon (DLC) coatings are prime candidates for protecting vulnerable structures against erosion and wear. However, delamination of DLC films from common materials of construction has been a persistent problem. Development of deposition processes that produce coatings more resistant to delamination would be facilitated by a simple way to assess DLC adhesion to substrates. A method in which process exemplars are exposed to cavitating water and then examined metallographically is described. On the basis of this assessment method, vacuum-arc-plasma deposition parameters that promote adhesive DLC coatings on 304 stainless substrates were quickly identified.

R.H. Richman, J.A. Maasberg, S. Anders, and I.G. Brown. Cited: *Advances and Applications in the Metallography and Characterization of Materials and Microelectronic Components* (Proc. Conf.), Albuquerque, NM, 23-26 July 1995, ASM International, Materials Park, OH, 1996, p 41-46 [in English]. ISBN 0-87170-570-2. PHOTOCOPY ORDER NUMBER: 199607-57-1330.

Flame Spraying

Coatings of Fe-B System Produced by Gas-Flame Spraying with Flux-Cored Wires and Flexible Cords. Gas-flame spraying with the use of flux-core wires and flexible cords of Fe-B system provides basically a component smelting and forms coatings with low porosity (up to 2 to 3%) and high microhardness (7.5 to 13.0 kH/mm^2). The coatings prepared have a predominantly amorphous structure with a volume fraction of amorphous phase up to 80%. In amorphization extent and density, such coatings are superior to the powder gas-flame and air-gas flame coatings that are characterized by oxygen lesser content.

Yu.S. Borisov, V.N. Korzhik, and I.A. Koz'yakov. Cited: *Avtom. Svarka,* Vol 12, Dec 1995, p 19-25 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199608-57-1465.

Hollow Cathode Plasma

Hollow Cathode Plasma Spray Stabilized by an Applied Magnetic Field. It is necessary to homogenize the sprayed particle energies to improve the quality and performance of coatings. The conventional DC plasma torch with radial injection of powders tends to have heterogeneous distributions of velocities, temperatures, and sizes of particles because of the irregularity of particle trajectory. On the other hand, the hollow cathode DC plasma torch has a potential to homogenize the distribution of sprayed particle energies, where the particle trajectory has a tendency to be the same as the plasma jet axis. This article deals with the stability of a hollow cathode DC plasma jet with the applied magnetic field. Although there are some problems about the instability of hollow cathode DC plasma jets and the shortness of electrode life, it has been found that rotation of the plasma arc around the electrode is effective in solving such problems. The plasma arc can be rotated around the electrode by a Rorenz force generated by an interaction of the plasma arc current and the applied magnetic flux. Stabilization of such plasma jets has led to the formation of coatings with axial injection of powders. Yttria-stabilized zirconia powder has been sprayed onto a steel substrate under atmospheric and low-pressure conditions. A high value of deposition efficiency has been obtained in the case of the low-pressure plasma spray process. The qualities of both coatings are the same as those obtained by conventional processes. These facts indicate that the hollow cathode DC plasma spray stabilized by an applied magnetic field is available for the practical use of high efficient and high-quality plasma spray coatings.

A. Notomi and Y. Takeda. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 321-324 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1724.

HVAF of WC-Cermet

Study of HVAF WC-Cermet Coatings. Hypersonic-velocity air-fuel system (HVAF) has been developed as a high-velocity flame spraying equipment requiring no oxygen and that has quite different features compared with oxyfuel HVOF system. Of the WC-cermet coatings in particular, the importance of high-velocity flame spraying processes has been recognized and many studies have been publicized on the HVOF processes only. Therefore, WC-cermet coatings (on SS41) produced by the HVAF process were investigated in view of physical and mechanical properties. As a result of the study, WC-cermet coatings produced by HVAF were found to be essentially unchanged by the spraying process, and negligible decarburization or dilution occurred.

K. Akimoto and Y. Horie. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 313-316 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1453.

HVOF at High Chamber Pressure

Extending the Limits of HVOF. Within the last years, many developments have taken place in the field HVOF. The number of different HVOF systems offered on the market is increasing. Nevertheless, all offered systems have a common goal: to accelerate the injected spray material to the highest possible velocity values with a limited heat input to achieve dense coating structures without deterioration or oxidation of the coating material. Independent of the fuel used or the design principle (chamber-stabilized mode or duct-stabilized mode), the question of the technological limits of this spraying technique can be raised. Key questions are: How high can the particle velocity be increased and what are the effects of such increases on the coating? Using a combustion process as the source for accelerating and heating the spray particles, an increase in the gas stream velocity is directly related to a decrease of the temperature and pressure conditions in the effluent hot gas stream. This paper reports the results achieved with a specially designed experimental gun that creates chamber pressures up to 1000 psi (70 MPa). Due to this capability, the particle velocities and the heat intput into the particles can be influenced over a wider range than previously studied. WC-Co 83-17 and NiCrMoNb 2294 were sprayed onto a mild steel.

M. Dvorak and J.A. Browning. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 405-409 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1462.

HVOF Fuel Gas Effects

The Role of the Fuel Gas in the HVOF Process. In high-velocity oxyfuel flame spraying (HVOF), a fast-flowing flame jet is generated by combustion of a fuel gas/oxygen mixture. In this flame jet, powder particles of the coating material are melted and sprayed at high velocity onto the components that are to be coated. The properties of the fuel gases usable for the process—propylene, propane, hydrogen, acetylene and ethylene—are compared here. WC-Co, Mo, and Al_2O_3 were utilized as coating materials to study how the differing properties of the fuel gases affect the deposition efficiency, the microstructure, and the properties of the coatings on steel. The results show that with the high-melting materials Mo and Al_2O_3 the use of acetylene is advantageous with regard to economy, and that for WC-Co the use of propane is more favorable.

H. Kreye, P. Heinrich, and S. Zimmermann Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 393-398 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1461.

HVOF Fuel Gas Selection

Investigation into the Relationship between Fuel Gas Selection, Wear Performance and Microstructure of HVOF Sprayed WC-Co Coatings. Four fuel gases (hydrogen, propylene, propane, and acetylene) are assessed for their effect on the microstructure, deposition for their effect on the microstructure, deposition efficiency, and wear performance of 83WC-17Co coatings, sprayed (on mild steel) by the top gun HVOF system. Initially, the manufacturer's standard parameters for each fuel gas were used. A second study investigates the influence of spraying parameters on the coatings deposited using propylene as the fuel gas. Wear performance, measured by a pin-on-disk test, is related to the amount of retained WC in the sprayed coating. It is proposed that the fraction of retained WC is related to the fuel gas power. The high power generated by hydrogen combustion, although producing the densest coating, results in the lowest level of retained carbide and poorest wear resistance.

M.D.F. Harvey, F.J. Blunt, S.B. Dunkerton, and A.J. Sturgeon. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 471-476 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1467.

HVOF with Natural Gas

New Performance for HVOF Thermal Spraying Systems with the Use of Natural Gas. Most HVOF spraying processes use propane or propylene as fuel gas. They are normally stored in liquid phase in a tank and vaporized before use by an electric heater. Gases in usual HVOF processes have to remain at a temperature higher than their boiling point to prevent them from being recondensed. The recondensation problem may introduce difficulties in flame ignition and in flow-rate control and cause damage to installations. The use of natural gas can eliminate this problem due to its very low boiling point. The physical properties of natural gas are very close to those of methane. Therefore, it is more favorable for thermal spraying than propane or propylene due to a better thermal conduction and diffusion between combustion products and powder grains. Experimental work was achieved with different powders. The results showed that the coatings obtained using natural gas are at least comparable or better than those obtained with propane. In addition, some other advantages such as lower pollution or better safety were also demonstrated.

Y.M. Yang, C. Coddet, and H. Liao. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 307-312 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1452.

Influence of Ambient Pressure

Plasma Spraying under Controlled Atmosphere up to 300 kPa. In order to understand the pressure effect on arc-plasma jet and to reveal the effectiveness of high-pressure plasma spraying (HPPS) as a coating tool (on SS41 steel), plasma spraying of yttria-stabilized zirconia was carried out with changing the chamber pressure from low (30 kPa) to high pressure (300 kPa) in specially designed equipment. The plasma flame length and the velocity of the particles were measured in situ and the coating characteristics including its microstructure, density, and hardness were studied. Temperature rise accompanied with the plasma flame shrinkage under high pressure has brought about effective heating of the zirconia particles, resulting in high deposition efficiency and densified coating with improved hardness, in spite of reduced particle velocity. HPPS was found to be suitable for thermal spraying of materials with a high melting point, such as zirconia.

S Sodeoka, T. Inoue, Y. Ono, M. Suzuki, and K. Ueno. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 283-288 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1721.

Preheating in VPS

Effect of Preheating on Coating Process in Low-Pressure Plasma Spraying. Low-pressure plasma spraying has recently been applied to production in various industries, owing to dense coating with few impurity contamination. Although it is known that low-pressure plasma sprayed coating has high bonding strength, the coating mechanism has not been comprehended sufficiently. In this study, the effect of preheating on the coating process in low-pressure plasma spraying has been investigated. Preheating at 1073 K, coupled with the plasma spraying causes short-time diffusion adjacent to the coating interface that is equivalent to the vacuum furnace heating at 1373 K. Moreover, low pressure plasma sprayed coatings, preheated at 837 K or above, consist of the top layer with higher blast errosion rate and excellent layers with lower blast erosion rate under it. It is believed that the in situ sintering phenomenon caused by sufficient preheating of the substrate and the subsequent spraying improve the cohesion strength between sprayed particles.

K. Honda, K.F. Kobayashi, I. Chida, Y. Itoh, and M. Saito. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 411-416 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1463.

Reactive Spraying

Reactive Plasma Spraying of High Nitrogen Stainless Steel. In order to improve the corrosion and wear resistance of stainless steel spray coatings, nitrogen enrichment is added to the high Mn and high Ni stainless steel spray coating by using reactive plasma spraying. Addition of Ni in the plasma gas is found to form high Ni coatings without decrease in Ni contents in feedstock materials. Moreover, by selection of the optimal spray conditions, Ni enrichment can be achieved in the spray process.

S. Oki, R.W. Smith, S. Gohda, P. Jokiel, and E. Lugscheider. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 561-564 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1472.

RF Spraying of Hydroxyapatite

Characteristics of a Radio-Frequency Thermal Plasma Spraying Method for the Coating of Hydroxyapatite. Radio-frequency plasma spraying has been developed for coating hydroxyapatite on ceramic substrates of zirconia and alumina for use in artificial joints and dental roots. Characteristics of coatings manufactured with the new spraying process were examined in terms of impurities, orientation factors, phases, and structures in coated films and of bond strength to the substrates.

T. Kameyama, K. Iwasaki, A. Motoe, K. Onuma, H. Tanizaki, and M. Ueda. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 187-192 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-57-1600.

Supersonic Arc

Supersonic Arc Spraying Process. Using supersonic hot gas stream as the atomizing media, a novel arc spraying process has been developed. The supersonic hot gas stream is generated by an air-alcohol internal burner The outside surface of the combustion chamber is cooled by the compressed air. The preheated compressed air then enters the combustion chamber as the oxidizing reactant. There is now aftercooling within the burner. This regenerative cooling makes the system work with very high thermal efficiency. The droplets of sprayed metals are protected by the supersonic combustion product from oxidation. Very high velocity and low oxidation of the atomizing gas stream results in high coating quality. In spite of added fuel consumption to the process operation, the economical nature of the arc spray is still retained.

J Wen, W. Geng, A. Liu, S. Wen, and Z. Zhang. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 317-320 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1454.

Properties

Adhesion of Arc Sprayed Zinc

Adhesion Mechanisms of Arc-Sprayed Zinc on Concrete. Arc-sprayed zinc coatings can provide cathodic protection against corrosion to steel reinforcement in concrete. Because the adhesion of sprayed Zn on concrete is of major concern, the parameters related to Zn deposition and concrete preparation that affect the adhesion have been previously investigated. However, little attention has been devoted to determining which basic mechanisms are responsible for the adhesion of molten Zn on concrete. Because the interaction of molten Zn droplets with the concrete surface is considered physical, the work focused on the influence of surface patterns on the adhesion of arc-sprayed Zn coatings. Concrete surfaces were characterized by image analysis and profilometry techniques to ascertain which surface pattern or components could affect the adhesion of Zn. A modified root mean square (RMS) surface roughness was derived to take into account the different surface morphologies seen by sprayed Zn droplets. This modified RMS surface roughness was found to be directly related to the measured bond strength of arc-sprayed Zn on concrete. After the surface profile on concrete is measured and the surface constituents are considered, the bond strength of arc-sprayed metals on concrete can be forecasted for given deposition parameters.

J.-G. Legoux and S. Dallaire. *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 395-400 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-58-1037.

Adhesion of Zinc

Long-Term Factors Influencing the Adhesion of Metallized Zinc to Concrete. Metallized zinc cathodic protection often is used to mitigate steel reinforcement corrosion in concrete. The zinc is flame or arc sprayed to the surface of the concrete structure to be protected. The metallized coating should be applied such that its adhesion to concrete is maximized. Factors believed to affect adhesion were investigated for pure zinc and a 85Zn-15Al alloy. On reinforced concrete samples polarized for more than 800 days at three different current densities, adhesion decreased. The reduction increased as a function of time and of the current density applied. When no current was applied, there was a small initial increase of adhesion with time. For the metallized samples that were freeze-thaw cycled, no loss of adhesion was found after 70 cycles.

R. Brousseau, M. Arnott, and B. Baldock. Cited: *J. Therm. Spray Technol.,* Vol 5 (No. 1), March 1996, p 49-52 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-58-1183.

Chromia Coatings

Study of Cr_2O_3 Coatings. II. Adhesion to a Cast-Iron Substrate. The interfacial indentation technique for determining toughness is applied to plasma sprayed Cr_2O_3 coatings. In this investigation, another adhesion test, i.e., the four-point bend test coupled with acoustic emission (AE), is performed. AE is monitored during the test from the initiation of load application until fracture in order to detect the damaging of the coating and to identify the different crack growth processes. The residual stresses of coatings are determined by a step-by-step hole drilling method. Correlation of the residual stresses and the two determined parameters to failure (crack length in the case of indentation test and failure displacement in the case of bending test) is discussed.

C.S. Richard, F. Decomps, and J. Lu. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 347-352 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1178.

Study of Cr_2O_3 Coatings. I. Microstructures and Modulus. Metallographic characterization was used to estimate the quality and, particularly, the adhesion of plasma sprayed Cr_2O_2 coating. The study focuses on the state of the substrate before spraying. During the process of spraying, the differential contraction generated between the various materials because of their different physical and mechanical properties determines the stresses inside the coating and at the interface between the coating and the substrate. The residual stresses thus influence the mechanical and thermomechanical behavior of the coated parts and their adhesion. These stresses are determined by a step-by-step hole drilling method (Part II of this paper), and Young's modulus is measured by two different methods: a dynamic ultrasonic test and a static four-point bend test. Part II of this paper is devoted to the adhesion of a Cr_2O_3 deposit on a cast iron substrate.

C S. Richard, F. Decomps, and J. Lu. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 342-346 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1177.

Corrosion Resistance of Cermets

Thermal Projection of High-Speed HVOF Chromium Carbide Cermets. Cermet coatings ($75Cr_3C_2$-25NiCr) were tested on F-1250 (34CrMo4) steel to improve corrosion resistance and wear at high temperatures. Hardness of the coatings was ~850 DPH-1 kg. Phases present in the original powder corresponded to $M_{23}C_6$- and M_3C_3-type carbides with variation in the proportion of carbides present. Adherence was above 80 MPa.

J.M. Guilemany, N. Llorca, and A. Vizcaino. Cited: *Deform. Met.,* Vol 21 (No. 219), Jan-Feb 1995, p 9-13 [in Spanish]. ISSN 0210-685X. PHOTOCOPY ORDER NUMBER: 199607-58-1058.

Crack Growth Phenomena

Plasma Sprayed Coatings as Surface Treatment of Aluminum Adherends. Plasma sprayed coatings have been evaluated as surface treatments for aluminum substrates being prepared for adhesive bonding. Blends of an aluminum-silicon alloy and polyester give the best performance. To establish durability performance, wedge tests were done using four common epoxy adhesives without primers. In all cases, the 60% Al-Si/40% polyester coating gave results superior to those of FPL-etched specimens and, in some cases, performance equivalent to PAA specimens. This roughness provides excellent opportunity for mechanical interlocking or physical bonding and allows a complex interphase to be formed as the adhesive penetrates into the coating. Crack growth measurements and subsequent failure analysis using x-ray photoelectron spectroscopy (XPS) indicate that crack propagation occurs within this complex interphase. The results also show that the aluminum and polyester components are synergistic and blends of the two give better performance than either component by itself. The aluminum gives strength to the coating while the polyester provides toughness and improves moisture resistance.

G.D. Davis, J.D. Venables, G.B. Groff, D.K. Shaffer, and P.L. Whisnant. Cited: *Materials and Process Challenges: Aging Systems, Affordability, Alternative Applications,* Vol 41-I (Proc. Conf.), Anaheim, CA, 24-28 March 1996, Society for the Advancement of Material and Process Engineering, Covina, CA, 1996, p 291-302 [in English]. ISBN 0-938994-74-3. PHOTOCOPY ORDER NUMBER: 199607-55-1128.

Failure Analysis of Turbine Coatings

Failure Analysis of Some Plasma Spray Coated Superalloy Systems Subjected to the Synergistic High Temperature Damaged in Actual Gas Turbine or in Laboratory. In order to establish reasonable property evaluation methodology of advanced plasma spray coating system for the heavy-duty high-temperature applications, failure analysis was conducted for two kinds of thermal barrier coating (TBC) systems. One is a conventional YSZ system and the other is the developed CaO-SiO_2-ZrO_2 (C2S-CZ) system. The laboratory tests were composed of high-temperature oxidation, hot corrosion and corrosion-stress (creep) rupture tests. Degradation behavior of the YSZ and C2S-CZ systems was characterized; the former system was more sensitive to spalling of the ceramic top-coat layer which was attributed to a preferential oxidation and/or corrosion along the top-coat/metallic (MCrAlY) undercoat interface. The top coat of the latter system was more reactive with molten salt and resulted in compositional and structural changes with a new phase layer formation. On the basis of the failure mode analogy between the laboratory tests and in gas turbine practice, the relative importance of various factors affecting the degradation of TBC systems is discussed. In particular, the importance of considering the simultaneous stress-corrosion effect will be emphasized.

M. Yoshida, H. Taira, Y. Harada, and T. Aranami. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 89-94 [in English] ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-35-1739.

High-Temperature Oxidation

High-Temperature Oxidation Behaviour of Plasma Sprayed MCrAlY Coatings. Three MCrAlY (M=Co, Ni and CoNi) coatings were prepared by air and vacuum plasma spraying methods (APS and VPS) in order to measure such properties as density, microstructure, thermal expansion coefficient, and high-temperature oxidation properties. The as-sprayed APS samples (on Cu substrate) showed an abnormal temperature dependence on thermal expansion coefficients due to changes in microstructures accompanied by change in density, and with repeated measurements they tended to obey a normal temperature dependence. Oxidation rates of the VPS NiCrAlY were much higher than those of the VPS CoCrAlY and CoNiCrAlY, and the former had an α-Al_2O_3 scale and an Al-depleted subsurface layer thicker than those formed on the latter two. Further, in the case of the VPS NiCrAlY an yttrium-rich phase appeared within the reaction zone.

H. Taumi, T. Narita, M. Nakamori, and Y. Harada. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 453-458 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-35-1873.

Mechanical

Effect of Plasma Sprayed Alumina on the Strength, Elastic Modulus, and Damping of Ti-25Al-10Nb-3V-1Mo Intermetallic. The effect of a plasma sprayed Al_2O_3 coating on the bend strength, elastic modulus, and damping of Ti-25Al-10Nb-3V-1Mo intermetallic substrate was measured. Two coating thicknesses of 0.1 and 1.0 mm were used in the study. The average strength and Weibull coefficients of the intermetallic samples coated with the 0.1 mm Al_2O_3 coating were very similar to those of the uncoated intermetallic samples. On the other hand, the average strength of the samples coated with 1.0 mm Al_2O_3 was significantly lower than the strength of the uncoated intermetallic substrate. The lower strength of the 1.0 mm coated samples was attributed to the higher volume fraction of the Al_2O_3 coating (which has a lower strength than the Ti-25Al-10Nb-3V-1Mo substrate) and higher porosity in the 1.0 mm coating. The Young's modulus and damping values of the 0.1 mm Al_2O_3-coated intermetallics did not vary significantly from those of the uncoated substrate. However, the damping values of the 1.0 mm Al_2O_3-coated intermetallics were significantly larger than those of the uncoated substrate. The higher damping values measured for the 1.0 mm Al_2O_3-coated samples were attributed to the higher porosity in the thicker coating and to defects in the coating as a result of the spraying process.

R.U. Vaidya, A.K. Zurek, D.A. Bowles, M.W. Cantu, and A. Wolfenden. Cited: *J. Mater. Eng. Perform.*, Vol 4 (No. 3), June 1995, p 252-258 [in English]. ISSN 1059-9495. PHOTOCOPY ORDER NUMBER· 199608-57-1508.

Tensile Strength

Tensile Strength of Plasma Sprayed Alumina and/or Zirconia Coatings on Titanium. The heat treatment effect on the characteristics and tensile strength of plasma sprayed alumina, yttria-stabilized zirconia (YSZ), and mixtures of alumina and YSZ coatings on titanium was investigated. The as-sprayed structures of alumina and YSZ coatings consists of α and γ alumina phases, and cubic and tetragonal zirconia phases, respectively. The tensile strength of the coatings containing a large amount of YSZ is increased from 25 to 50 MPa by heat treatment at 800 °C. The 60% YSZ-Al_2O_3 coating showed the highest tensile strength. The tensile strength increase of the YSZ-containing coating by heat treatment is caused by formation of 10 to 100 nm wide microcracks. The interface adhesion strength between the heat-treated titanium substrate and the alumina-containing coating is increased by chemical reaction at the interface. Thus, a heat-treated alumina and zirconia mixture coating may be favorable in obtaining high tensile strength due to microcrack formation in the coating and the chemical reaction at the interface.

K. Kishitake, S. Baba, and H. Era. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 353-357 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1179.

Tribology of Composites

High-Temperature Tribological Properties of Plasma Sprayed Metallic Coatings Containing Ceramic Particles. Plasma sprayed metal-base coatings containing ceramic particles were considered for high-temperature sealing of a moving metal component with a dense silica-base ceramic preheated at 800°C. Selected metal powders (NiCoCrAlY, CuNi, CuNiIn, Ag, Cu) and ceramic particles (boron nitride, Zeta-B ceramic) were agglomerated to form suitable spray powders. Plasma sprayed composite coatings and reference materials were tested in a modified pin-on-disk apparatus in which the stationary disk consisted of a dense silica-base ceramic piece initially heated at 800 °C and allowed to cool during tests. The influence of single exposure and repeated contact with ceramic material on coefficient of friction, wear loss, and damage to the ceramic piece was evaluated.

S. Dallaire and J -G. Legoux. Cited: *J. Therm. Spray Technol.,* Vol 5 (No. 1), March 1996, p 43-48 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199608-58-1182.

Ultrasonic Characterization

Ultrasonic Characterization of Elastic Anisotropy in Plasma Sprayed Alumina Coatings. An ultrasonic, nondestructive contact measurement technique was used to detect and characterize the elastic anisotropy of a free-standing, plasma sprayed alumina coating. Following this initial evaluation, a computer-assisted, ultrasonic anisotropic test bed was used to determine the anisotropic elastic stiffness constants of coatings produced by plasma gun currents of 600 and 400 A The results showed that the plasma sprayed alumina coatings are transversely isotropic, i.e., isotropic in the spraying direction. These coatings were characterized by five independent elastic stiffness constants. Coatings produced at 600 A plasma gun current showed higher elastic stiffness constants than those produced at 400 A plasma gun current. This increase appeared to be related to a decrease in the porosity content of the coatings produced at the higher plasma gun current.

S. Parthasarathi, E.J. Onesto, K. Sampath, and B.R. Tittmann. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 4), Dec 1995, p 367-373 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199607-57-1180.

Review

Comparison to Vapor Methods

An Overview of Thermal Spray Coatings Compared to Physical and Chemical Vapor Deposited Coatings. The field of thermal spray coatings is continuously evolving technically and many new applications are being developed. At the same time other methods of coating are also being developed. These include new types of chemical vapor deposition (CVD) and physical vapor deposition (PVD) coatings. Each type of coating has its own niche, but there are many potentially overlapping areas. Thus, it is important to understand the relative technical and economic merits of each type to guide the selection of coatings for a given application, the investment in plant and equipment, and the research and development of new coatings. This paper presents an overview of the relative characteristics or properties of the major thermal spray coating processes and materials as compared to those prepared by CVD and PVD. Included in the thermal spray coatings are plasma, high-velocity oxyfuel, and detonation gun coatings. The CVD coatings include high-temperature thermally activated coatings and plasma-assisted coatings. The PVD coatings included are e-beam evaporation, cathodic arc, sputtering, ion implantation and plating, and the major variations of these. A comparison is made of both processes and the coatings and economics of their production and use.

R.C. Tucker, Jr. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 253-258 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1374.

General

Thermal Spraying. I. Powder Consolidation—from Coating to Forming. Thermal spray is a microsolidification consolidation process for metals, intermetallics, ceramics, polymers, and composites. Thermal spray processing has become an important powder-consolidation technique, and innovations are now yielding novel ways of manufacturing new materials and material combinations. This article, the first of two parts, reviews thermal spray processes, describes their characteristics, and describes the attributes of the materials sprayed by such processes. Part I presents the range of thermal spray processes and the materials systems that are able to be produced, leading from a coating to a forming technology.

R.W. Smith and R. Knight. Cited: *JOM,* Vol 47 (No. 8), Aug 1995, p 32-39 [in English]. ISSN 1047-4838. PHOTOCOPY ORDER NUMBER: 199608-58-1313.

Technology in China

Applications of the Latest Thermal Spraying Technology in China. Thermal spraying has reached a status of a technical discipline in engineering during the last decade worldwide and in China as well. This paper deals with the latest developments of thermal spraying equipment, materials and processes, and their applications in China in recent years.

X. Binshi, Z. Sheng, and L. Shican. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 1 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Osaka, Japan, 1995, p 133-136 [in English]. ISBN 1241-3074. PHOTOCOPY ORDER NUMBER: 199609-58-1364.

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