Selected Abstracts of Thermal Spray Literature

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Applications

Atmospheric Corrosion

Coating Protection against Atmospheric Corrosion for Iron and Steel Structural Components: Status of Metallization in Japan. Low-velocity oxyfuel spray and arc spray coatings of Zn, Zn-Al, Al, and various Al-Si and Al-Mg alloys were tested in immersion and salt-spray conditions with artificial sea water for up to 6000 h. Coatings were tested as-sprayed or sealed with fluorocarbon, epoxy, or silicone sealants. Comparison and overview of coatings recommended by international and Japanese standards are considered. Coatings Al 99.8 outperformed Zn 99.9 and Zn-13Al ones while Al-(2.5-5.2)Mg and Al-(5-6)Si showed better corrosion resistance than Al 99.8 coatings. The silicone sealant offered better resistance than fluorocarbon and epoxy organic sealants.

G. Ueno and Y.L. Nava. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 191-197 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0868.

Thermally Sprayed Ternary Materials for Enhanced Corrosion Protection. Thermal spraying has been used to protect many steel structures from aqueous corrosion using zinc and aluminum, and to some extent their alloy coatings to provide galvanic protection. The lifetimes of the coatings can approach 50 years even when exposed in severe marine environments. Zinc coatings work by continuously sacrificing themselves and slowly dissipating over time. Aluminum coatings passivate more readily and form a barrier layer; the passivity makes them less able to protect damaged areas and to self-heal. A new ternary coating system involving aluminum, zinc, and magnesium has been shown to be capable of providing both a passive barrier layer as well as being able to give galvanically active protection. Salt-spray tests have shown that the resistance to red rust of these new coatings increases by 300% over similar thicknesses of the separate metal coatings. Processing by arc spray is straightforward, and both adhesion and deposition efficiency are better than where zinc is sprayed alone. Substrate: mild steel.

T. Lester, S.J. Harris, D. Kingerley, and S. Matthews. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 183-189 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0867.

Automotive Powertrain

Novel Powertrain Applications of Thermal Spray Coatings. Recent innovations in equipment, processes, and diagnostics make thermal spray coatings both practical and desirable for use in large-scale automotive manufacturing. The advent of rotating devices and surface preparation methodologies such as high-pressure waterjet, electrodischarge machining, and chemical fluxes permit thermal spray coating applications on cylinder bore and valve seat areas of engines. Low-carbon steel alloy composite and aluminum bronze coatings have been successfully tested on cylinder bores. The Fe-Fe_3O_4/Ni-NiO-CrO composite coating obtained by spraying carbon steel and nickel-base alloy wires using a two-wire arc gun works well as a valve seat material.

O.O. Popoola, R.C. McCune, and M.J. Zaluzec. Cited: *Surf. Eng.,* Vol 14 (No. 2), 1998, p 107-112 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0939.

Biomaterials

Measurement of the Crystallinity of Hydroxyapatite Deposited by Plasma Spray. As part of a characterization and mechanical research about hydroxyapatite (HA) plasma deposits for hip prosthesis, we addressed the problem of determining their crystallinity. A traditional normalization method employed by several laboratories is based on x-ray diffraction by a powder mixture of the investigated HA sample with a standard of crystalline powder, namely Al_2O_3. This method is quite unsatisfactory, as it very often delivers unreasonable results. In order to overcome these difficulties we investigated some new methods for determining the crystallinity of HA sample, which are based on x-ray diffraction. All these methods provide reasonable results. Plasma spray of HA on titanium substrate.

F. Rustichelli, E. Girardin, N. Antolotti, S. Bertini, and B. Yang. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 703-706 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1344.

Oriented Thermal Sprayed Hydroxyapatite Coatings. The successful integration of biomaterials is dependent upon the sequence of cellular events which are in turn influenced by the material chemistry and surface characteristics. Hydroxyapatite belongs to the class of bioactive ceramics and produces an intimate contact with bone. It is mostly used in the form of a plasma sprayed coating on dental implants and orthopedic prosthesis. Previous work on retrieved hydroxyapatite coatings has shown that apatite crystals grow epitaxially from the crystalline hydroxyapatite surface and meet with randomly oriented mineralized collagen fibers. This bonding produces biointegration of the implant in the surrounding bone. Coatings produced by plasma spraying have become known to consist of an amorphous, crystalline phase and possibly other phases. Hydroxyapatite is a thermally sensitive material and thus requires good control to avoid undesired phases. A further step in controlling coating performance is possible by controlling crystal orientation. This work reports an investigation on the coating parameters to produce an orientation of these crystals within the individual lamellae.

K.A. Gross and B. Ben-Nissan. Cited: 24th Annual Meeting of the Society for Biomaterials (Proc. Conf.), San Diego, CA, 22-26 April 1998, *Transactions of the 24th Annual Meeting of the Society for Biomaterials,* Society for Biomaterials, 1998, p 37 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-C-0137.

Biomedical

Plasma Spraying under Vacuum—A Gentle Coating Technique. The article describes using plasma spraying under vacuum. Sulzer Metco applies porous titanium coatings to produce biocompatible, high fatigue strength prostheses for cement-free implantation while maintaining the implant properties. Especially critical here are the characteristics of the special Ti powder employed.

A. Salito, F. Brime, and U. van Osten. Cited: *Metallurgia,* Vol 65 (No. 5), May 1998, p 171, 173 [in English]. ISSN 0141-8602. PHOTOCOPY ORDER NUMBER: 199809-58-0964.

Cast Alloy Cylinder Bores

Advantages for Automotive Industry of Plasma Spray Coating of Al-Si Cast Alloy Cylinder Bores. In the automotive industry the need for lower manufacturing costs, the use of fewer strategic materials, and the need for easier, faster, and more environmentally sound coating processes is growing. This has led to the examination of a plasma powder spray process used in the application of coatings for surface modification. The present paper examines the use of the plasma powder spray process in coating aluminum-silicon cylinder block bores using a rotating plasma gun capable of producing coatings of reliable microstructure and integrity. Properties and microstructures of the applied coatings are presented and test results show that the necessary bond strength of the coating can be achieved without the use of a bond coat. Surface preparation before coating and surface finishing methods after coating are also discussed. Experience in Europe, Japan, and the United States shows that the plasma powder spray process offers a performance-proven and cost-effective solution for the coating of cylinder bores.

G. Barbezat and G. Wuest. Cited: *Surf. Eng.,* Vol 14 (No. 2), 1998, p 113-116 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0940.

Corrosion

Integration of Wire Arc Spray Technology for Corrosion Protection of General-Purpose Bombs at the Kadena AB Bomb Renovation. The design, development, installation, and operation of an automated wire arc spray system for corrosion protection of general-purpose bombs at the U.S. Air Force Kadena Bomb Renovation Plant, Okinawa, Japan, is described. The zinc/aluminum metallized coating sealed with industrial water-borne direct-to-metal (DTM) acrylic latex paint replaces the previous solvent-borne primer/topcoat combination to yield an environmentally compliant lifetime corrosion protection coating system that eliminates the requirement for stripping and recoating bombs every five years. A conservative 20-year life-cycle cost analysis verifies substantial cost savings for the Air Force using metallized coatings for this application.

D.H. Neale. Cited: *1997 Tri-Service Conference on Corrosion. II* (Proc. Conf.), Wrightsville Beach, NC, 17-21 Nov 1997, Naval Surface Warfare Center-Carderock Division, 1997, p 9.62-9.73 [in English]. PHOTOCOPY ORDER NUMBER: 199808-58-0823.

Corrosion Behavior

The Corrosion Behavior of a Cermet Coating Applied by HVOF Spraying. Many of the state-of-the-art thermal spray coatings (e.g., plasma, HVOF) have been developed with wear resistance as a primary aim. However, these coatings are increasingly being required to function in environments where corrosive attack is possible. This paper comprises a description of a study of the corrosion a WC-based coating containing 10% Co and 4% Cr as the metallic binder. The coating, in the form of test coupons, involving a substrate of superduplex stainless steel, has been exposed to seawater at ambient temperature (18 °C) and 50 °C. The corrosion behavior and detailed corrosion mechanisms have been investigated using electrochemical monitoring techniques supported by precise posttest microscopical examination using light microscopy, scanning electron microscopy, atomic force microscopy, and x-ray microanalysis. Results have shown the corrosion resistance of the coating material to be critically dependent on the temperature of the solution and that important changes in corrosion mechanisms arise as a function of the temperature.

A. Neville and T. Hodgkiess. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 161-166 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1236.

Corrosion Resistance

Corrosion Resistance of HVOF WC-Co and TiC/Ni-Ti Coatings Sprayed on Commercial Steel. Corrosion, erosion, and abrasion damage are frequently found in equipment used in service in the oil and gas industries. This represents a challenge to materials engineers because of the deterioration of equipment and increased maintenance costs. Much work is being done on the evolution of corrosion of different types of coatings. The aim of the present work is to study the corrosion behavior of two different coatings sprayed using high-velocity oxyfuel technology. A commercial steel was coated with a CDS 1927 (WC-12Co) or TiC/Ni-Ti powder using a Plasma-Technik CDS-100 thermal spray gun. The powder was sprayed onto a cylindrical specimen of 34Cr4Mo commercial steel 25.4 mm in diameter and 25.4 mm high. The corrosion potential versus time and potentiodynamic polarization were studied in an ASTM standard cell with three electrodes. Air-saturated seawater was used as the electrolyte.

J.M. Guilemany, J.M. De Paco, J. Fernández, and J. Sanchez. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 133-135 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0944.

Corrosion Resistance of Titanium

Corrosion Resistance of Thermal Sprayed Titanium Coating with Resin Seal in Chloride Solution. Corrosion behavior of a flame sprayed titanium coating sealed by some resins was investigated in 3.5% NaCl solution by an electrochemical polarization measurement and an immersion test. The composition and structure of the sprayed film was also analyzed by SEM and EPMA. Although an as-sprayed titanium had no resistance to the corrosion because of its porosity, the sprayed titanium sealed with epoxy or silicon resin showed an excellent resistivity against the chloride corrosion. Despite that almost half the titanium changed to oxide, nitride, and carbide through the gas flame spraying, the conversion of the metal to the compounds had little effect on corrosion resistivity. The sprayed and sealed titanium coating obtained by a conventional on-site thermal spraying is expected to become an economical material for chloride containing environments. Substrate: carbon steel.

K. Ishikawa, T. Suzuki, S. Tobe, and Y. Kitamura. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 203-208 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1239.

Galvanic Effects

An Assessment of Galvanic Effects in Thermal Sprayed Coating Systems. This paper focuses on the influence and role of galvanic interactions in the corrosion behavior of thermally sprayed coated components. Coatings, of different chemistry and applied by various processes (including HVOF) to substrates of carbon steel or stainless steel, have been utilized to facilitate study of galvanic corrosion phenomena both between coating and substrate and also within the coating itself. The experiments have involved the measurement of galvanic currents between separate specimens and also the microscopical examination of galvanic interactions on single specimens. Galvanic corrosion effects, on both a macroscale or microscale, have been observed, and the implications of these for coating and coating/substrate integrity are discussed. Coatings include Inconel, other nickel-base alloys, and cermets.

T. Hodgkiess and A. Neville. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 167-173 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1237.

General Topics

Materials, Technologies, and Equipment for Plasma Powder Surfacing the Parts of Ship, Power, Petrochemical Fixture, and Valves of Internal Combustion Engines. The powders, based on Fe, Ni, Co, Cu, and plasma-powdered surfacing processes for machine components and different mechanisms are elaborated. The iron-base powder successfully replaces the powders of Ni- and Co-base alloys in surfacing the fixture components. The powders of R6M5 and R18 tool steels are used in surfacing the cutting tools. The components, operating under intensive abrasive wear conditions, are surfaced with the high-vanadium iron-base powders with high content of carbon. The copper-base powders are applied in friction pairs.

E.F. Perepletchikov. Cited: *Avtom. Svarka*, Vol 1, Jan 1998, p 53 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199809-55-2100.

HVOF Spray Forming

Thermal Spray Forming Using the HVOF Technique. The feasibility of using the HVOF process for the thermal spray forming of free-standing components has been investigated. HVOF spray forming offers a number of potential advantages compared to the established procedure of plasma forming, including increases in component density, and reduction in material decomposition during spraying. Using blends of carbide and superalloy powders in various proportions, HVOF spraying has been successfully used to form free-standing cylinders and cones of various lengths and thicknesses. Microstructural examination of the spray formed material has shown a homogeneous distribution of carbides in the superalloy matrix, with very low levels of porosity. Refinement of the procedure has allowed reduction of the matrix content and the forming of fragile materials.

J.M. Guilemany, J. Libre, J.M. de Paco, Z. Dong, M.J. Dougan, and J.R. Miguel. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 929-933 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-54-1235.

Infrastructure

Automated Thermal Spray Technology for Rehabilitation and Maintenance of Civil Works Infrastructure. Conventional corrosion protection of steel structures has usually involved the application and reapplication of lead-base paint (LBP), a material now known to be highly toxic and likely to find its way into the environment. LBP is no longer used in the field, but repair crews, nearby communities, and the environment may be exposed to unacceptably high levels of lead as the substrates of older structures are prepared for repainting during routine M&R operations. Conventional dust-containment enclosures used on-site during surface preparation (abrasive blasting) are often inadequate. The most effective containment technologies, on the other hand, tend to be expensive and cumbersome. All of these factors make surface preparation and recoating slow, technically difficult, physically demanding, and hazardous to the worker and the environment. Automated technologies have the potential to address all aspects of these interrelated infrastructure M&R problems. An example of such a technology is the Automated Thermal Spray System (ATSS). The ATSS utilizes a triaxial array of linear motion actuators to form a robot capable of performing preprogrammed sequences. The demonstration proved that the ATSS can successfully remove deteriorated lead-based paint from a steel bridge and then apply a protective coating (e.g., zinc) to the exposed surface.

V.F. Hock, R. Benary, R. Ganertz, and H. Herman. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 435-444 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0874.

Low-Friction Cobalt-Base Coatings

Low-Friction Cobalt-Base Coatings for Titanium Alloys. Protective coatings adapted for titanium alloys that come into frictional contact with one another are described. Among the many coatings investigated, the best ones are cobalt-base. The coatings are sprayed only on one of the rubbing surfaces. During rubbing, a small part of the coating transfers to the unprotected titanium alloy surface. The rubbing pair is thus essentially composed of two cobalt alloy-base surfaces. This leads to low coefficient of friction and little or no damage to the rubbing surfaces. The coatings find particular application in the protection from adhesive and fretting wear, galling, and seizure of gas turbine and jet engine parts or the like made from titanium alloys. Coatings include a number of cobalt-base alloys, such as Stellite and Tribaloy compositions, and boron nitride particle reinforced cobalt alloy composites, among others.

K. Hajmrle and A.P. Chilkowich. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 127-130 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0865.

Piston Ring

Thermal Sprayed Piston Ring Coatings for Tomorrow's Heavy-Duty Engines. Plasma arc sprayed coatings are under development at Perfect

Circle Europe because of the large number of possible coating materials, ensuring a wide range of tribological properties. Spraying parameters are of great importance in improving coating structure and hence coating wear, adhesion, cohesion, and corrosion resistance. First of all the plasma gas was studied; experiments were then conducted to optimize the spraying parameters. To a greater extent than the spraying parameters, it was found that the powder formulation has a major influence on the coating tribological properties. Several powders have been studied with the aim of reducing the ring-liner system wear. Tests on idealized specimens coupled with engine tests help to characterize the tribological behavior of some molybdenum-base coatings.

M. Delaët. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 117-123 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0941.

Thermoelectric Material

Thermal Spraying as a Forming Process of Thermoelectric Material. The direct conversion of heat into electric current is still a less-developed form of energy conversion. Thermoelectric material working in a temperature gradient is able to induce a voltage that can drive a serial resistor. New research activities try to broaden the employment of thermoelectric generators from spacecraft technologies to terrestrial applications. The main problem at the moment is the lack of economic production methods, rather than the low efficiency of conversion. After an overview about the basics of thermoelectrics and possible applications, the paper presents thermal spraying as an alternative processing method with first attempts to realize graded structures. Aluminum-doped and Co-doped $FeSi_2$ has been consolidated by APS, SPS, VPS, and HVOF spraying. The microstructure, phase composition, and oxygen input have been investigated and set into relation to thermoelectric properties.

E. Lugscheider, E. Müller, J. Schilz, C. Herbst, and G. Langer. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 35-39 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-62-1588.

Titanium Anodes on Concrete

Characterization of Electrochemically Aged Thermal Spray Titanium Anodes on Concrete. Steel-reinforced concrete slabs coated with a thermal sprayed titanium anode were used to simulate impressed current cathodic protection systems. The titanium anodes were activated with a cobalt nitrate catalyst and subjected to accelerated electrochemical aging representing approximately 23 years at 0.00215 A/m^2 (0.2 mA/ft^2). During the aging experiment, current was kept constant at 0.0215 A/m^2 (2 mA/ft^2), voltages were recorded, and water was applied periodically when voltages exceeded compliance levels. At the end of the experiment, coating resistivity, adhesion strength, and titanium-concrete interfacial chemistry were determined. Results show that the coating resistivity increases, and adhesion strength decreases with electrochemical aging. Voltages for the slabs varied with the relative humidity. Electrochemical reactions at the titanium-concrete interface caused deterioration of the cement paste by leaching of calcium compounds. Accelerated aging results are compared to similar ones for an uncatalyzed titanium anode and to results from the Depoe Bay Bridge.

B.S. Covino, G.E. McGill, S.J. Bullard, W.K. Collins, S.D. Cramer, and G.R. Holcomb. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 151-160 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-35-1752.

Characterization of Thermal Sprayed Titanium Anodes for Cathodic Protection. Thermal sprayed titanium coatings were investigated as anodes for impressed current cathodic protection systems for steel-reinforced concrete structures. The coatings were applied by twin-wire thermal spraying using air and nitrogen as atomizing gases. The coatings were nonhomogeneous due to oxidation and nitridation of the molten titanium with the atmospheric gases oxygen and nitrogen. The primary coating constituents were αTi (containing interstitial nitrogen and oxygen), γTiO, and TiN. Nitrogen atomization produced coatings with less cracking, more uniform chemistry, and lower resistivity than air atomization. Testpiece substrates: concrete and Pyrex.

G.R. Holcomb, G.E. McGill, S.J. Bullard, L. Collins, B.S. Covino, S.D. Cramer, and R.D. Govier. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 141-150 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-35-1751.

Tribological Behavior for Engines

Thermal Spray Coating Developments for Piston Rings to be used in Tomorrow's Duty Engines. Extended life and higher performance are being required for heavy-duty diesel engines that have to run more than 1 million km. The higher combustion pressures (~160 bar) and temperatures (up to 300 °C), due to more turbocharged engines with increased power output and lowered fuel consumption, have resulted in the replacement of standard hard chromium plate with plasma arc sprayed coatings that also ensure improved scuff resistance. Increased corrosion resistance when using high sulfur fuels is needed to sustain or extend the present service life. Reducing the amount of exhaust gas pollutants from diesel engines is now a social concern from the viewpoints of environmental conservation, air pollution, and influence on human health. In order to lower the amount of particulate emission, mainly composed of unburnt fuel and oil, it is desirable to reduce oil consumption; this depends largely upon the sliding surface profiles of piston top rings. Several powders are studied with the aim to reduce the ring-liner system wear. Tests on idealized samples coupled with engine tests help us to characterize the tribological behavior of some molybdenum-base coatings.

M. Delaet and C. Coddet. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 1-9 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0861.

Tubular Ozone Generator

Combined Metallurgical and Ceramic Coating in the Development of Tubular Ozone Generators. Ozone, the three atomic form of oxygen (O_3) is used for the treatment of potable and waste water, for bleaching processes, and in various chemical oxidation reactions. In general, ozone is generated by silent discharge. Because it is not chemically stable, and therefore would decay during transportation, it is produced in discharge tubes on the site at the rate at which it is needed. The goal of this research project is the development of a novel efficient ozonizer tube that cuts down the production costs and thus causes ozone to be an economically competitive alternative in comparison to traditionally used chlorine compounds. A successful technical solution with metal coated glass tubes, developed by the German companies Euroflamm and Schott Gerätetechnik is in serial use. A superior materials and process technology has been developed by IFKB. Borosilicate glass tube sprayed (metallized) on the inner surface with aluminum or aluminum-silica alloy coating, and with a dielectric oxide ceramic—alumina, titania, zirconia/calcium oxide, zirconia/yttria.

R. Gadow, C. Friedrich, A. Killinger, and A. Voss. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century*, Vol 2, ASM International, 1998, p 1083-1089 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-C-0118.

Book

Thermal Spray Conference

Thermal Spray: A United Forum for Scientific and Technological Advances. 128 papers selected and abstracted for Metals Abstracts; 37 papers selected and abstracted for *Engineered Materials Abstracts*.

C.C. Berndt, Ed. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, 1020 pages, 8½ by 11 in., illustrated [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-72-0381.

Composites

Functionally Graded Materials

Plasma Processing of Functionally Graded Materials. II. Deposit Formation. Two sets of plasma spray processing conditions were utilized in the investigation of graded layers, consisting of NiCrAlY and PSZ. Following the optimization of the plasma spray parameters and particle characteristics, the deposition efficiencies (DEs) of various powder species was examined. Selection of the best-suited powders for coating production were selected based on the DE results. The base DEs were corrected by conducting the analyses using predeposited substrates as targets. Individual mixed coating layers were prepared and their compositions confirmed by image analysis. The effects of standoff distance and substrate temperature were also seen to have an effect on the DE and thus the coating formation. It is suggested that two-feeder, single-injector plasma processing may not be the optimal method for the formation of FGMs.

T.J. Jewett, H. Herman, J. Margolies, S. Sampath, and W.C. Smith. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 607-612 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1340.

Plasma Processing of Functionally Graded Materials. I. Process Diagnostics. An investigation into the dependency of the formation of functionally graded materials (FGMs) on process variables was carried out. The initial stage of the investigation involved a complete analysis of the plasma spray parameters used in the fabrication of an FGM constructed of NiCrAlY and partially stabilized zirconia (PSZ). In-flight particle temperature, velocity, and trajectory data were gathered for individual powders, as well as mixtures of the particle species, over a range of spray parameters. These data were combined with material-specific properties such as flowability, apparent density, particle morphology, and size distribution. The end result of the studies allowed for size matching of the particle species so as to ensure both species were molten at the nominal spray distance and possessed coincident impact velocities. Following the initial investigation, two spray conditions were selected for further analysis. Individual layers of specific powder mixture ratios were deposited as well as a complete FGM structure. The resulting structures were then compared based on their deposition efficiencies, porosity levels, compositional homogeneity, and microstructures.

W.C. Smith, J.R. Fincke, W.D. Swank, T.J. Jewett, and S. Sampath. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 599-605 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1339.

Diagnostics

Equipment to Measure Particle Behavior

In-Flight Particle Concentration and Velocity Measurements in Thermal Spraying Using a Nonintensified CCD Camera. Plasma spraying is a complicated process involving many partly interdependent parameters, which are in industrial spray environments difficult to optimize without laborious and time-consuming experiments. In this work a nonintensified CCD camera without any external illumination is used for in-flight particle visualization. Particle visualization is based purely on the spontaneous light emitted by the hot particles. The motivation for this work is to outline the possibilities to develop a CCD-based, low-cost and rugged in situ measurement system suitable also for industrial use. The measurement method has been tested with Plasmatechnik A3000S plasma spraying equipment using fused and crushed Al_2O_3 powder. Using digital image processing techniques, relative particle concentrations and particle velocities have been calculated from the acquired images. These results have been correlated with wear resistance and deposition efficiency of the coatings produced with different powder feed rate and powder port adjustments. Coatings were also produced using both new and worn electrodes. The benefits and limitations of the method are discussed, and the measurement results are compared against measurements made using laser sheet illumination, which can give information concerning also the colder and/or smaller particles not visible for the passive CCD system.

J. Vattulainen, R. Hernberg, J. Knuuttila, T. Lehtinen, and T. Mäntylä. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 1, ASM International, 1998, p 767-772 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E4-C-0447.

Particle Behavior

In-Flight Particle Characteristics of Plasma Sprayed Dense Yttria-Stabilized Zirconia. The influence of input spray parameters on the state of plasma sprayed zirconia powder is studied. The particle temperature, velocity, and diameter are measured using an integrated optical monitoring system. The monitoring system allows the investigation of the particles behavior in the spray jet. The collected information is correlated to coating characteristics such as deposition efficiency, microstructure, and thermal diffusivity. Results show that, by monitoring the state of sprayed particles, a better understanding of the coating microstructure and properties can be achieved.

L. Leblanc and C. Moreau. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 1, ASM International, 1998, p 773-778 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E4-C-0448.

Wire Arc Spraying

Diagnostic Development for Control of Wire Arc Spraying. This research has focused on characterization of the wire arc spray process with the goal of achieving improved process controls. Arc voltage and current traces have been analyzed on-line using an oscilloscope and a personal computer with LabView software. The characteristic features of the arc voltage fluctuations are correlated with the molten metal droplet formation process using a high-speed Laser Strobe video system operating in synchronization with the oscilloscope trigger. Voltage minima occur when larger globules of molten metal leave the wire tip. Analysis of the voltage fluctuations indicate that they are neither random nor periodic and that they can be described based on chaos theory. This approach may be used for achieving a further understanding of the dynamic nature of the process and for the development of control algorithms. Example: spraying stainless steel on aluminum.

J. Sheard, J. Heberlein, E. Pfender, and K. Stelson. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 613-618 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0877.

Feedstock

Ceramic/Polymer Nanocomposites

Structure and Properties of HVOF Sprayed Ceramic/Polymer Nanocomposite Coatings. Ceramic/polymer nanocomposites promise to be a new class of materials that will have wide application either for surface protection, providing low friction and inert corrosion barriers, or where tailored electrical and magnetic properties with increased abrasion and wear resistance are required. The high-velocity oxyfuel (HVOF) combustion spray process has been used to successfully process polymer/ceramic nanocomposites at 5 to 20 vol% of reinforcement. The latest results of process-structure-property relationship studies in silica and carbon black reinforced nylon 11 coatings are presented. It was found that the improvement in mechanical properties depends on the distribution and surface chemistry of the particulates and on the increase in matrix crystallinity due to the particulates. Materials studied as free-standing specimens and as coatings on aluminum.

E. Petrovicova, R. Knight, R.W. Smith, and L.S. Schadler. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 877-883 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1347.

Fusible Ni-B-Si Alloys for Corrosion Resistance

New Fusible Alloys with Enhanced Corrosion Resistance. Fusible Ni-B-Si alloys with a variety of alloy additions (Cr, Mo, Cu, etc.) have been in service for many years as fused coatings with moderate corrosion resistance. Both gas- and water-atomized powders have been used with the spray and fuse and with the plasma transferred arc process to produce coatings. As the severity of corrosive industrial environments has increased, for example, in waste-burning boilers, existing alloys have not provided the desired service performance. This study was undertaken to develop a new family of alloys with improved corrosion resistance without sacrificing usability, wear resistance, or cost effectiveness. A range of compositions was prepared and evaluated for deposition characteristic, microstructure, hardness, wear resistance, and corrosion resistance in various media. The resulting alloy has an exceptional combination of wear and corrosion resistance in comparison to conventional alloys, when tested under comparable conditions. Substrate: carbon steel.

I. Kretschmer, P. Heimgartner, P.A. Kammer, and R. Polak. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 199-202 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0869.

Nickel-Base Self-Fluxing Alloy

Abrasive Wear Characteristics of Ni-Base Self-Fluxing Alloy Spray Welding Overlays. The results of low stress, pin-on-disk, and high-stress grinding abrasive wear tests on coatings produced by plasma and oxyacetylene flame spray welding are presented. FNi15A and FNiWC35 Ni-base self-fluxing alloys were selected as typical spray welding materials for abrasive wear resistance. The abrasive wear resistance mechanisms of welded overlays produced by various materials and processes were also characterized by hardness tests, microstructural and compositional analyses, and through analysis of the effect of different kinds of abrasive on the wear resistant of Ni-base self-fluxing spray welding overlays. Results showed that FNiWC35 overlays exhibited improved resistance under low stress abrasion, but the relative wear resistances of FNiWC35 and FNi15A still depended primarily on the type and hardness of the abrasive medium used. For the same material, the abrasive wear resistance of oxyacetylene flame sprayed overlays was higher than that produced by plasma spray welding. The wear resistance of the plasma spray welding overlays depended not only on the material, but also strongly on the spray welding process parameters. Substrate: mild steel Q235.

Z. Ding, R. Knight, and R.W. Smith. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 91-95 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0864.

PMMA

Degradation of In-Flight PMMA Particles During Thermal Spraying. Kinetic and heat transfer analysis have been undertaken in order to predict the decomposition of polymer feedstock particles during thermal spraying. Thermogravimetric measurements indicated that the decomposition of PMMA had an order of reaction of unity and an activation energy of 135 kJ/mol[1]. The polymer decomposition temperature is shown to be a function of the particle residence time in the flame and is much higher than in conventional polymer processing. This has an important influence on process modeling, because the choice of decomposition temperature used in the heat transfer analysis has a major effect on the calculated temperature profiles. The work shows that realistic predictive data can only be obtained by using the dynamic decomposition temperature. Application of the model indicates that only the surface layers of the polymer feedstock particles undergo significant decomposition during plasma spraying and that the feedstock injection position is an important control parameter.

T. Zhang, Y. Bao, and D.T. Gawne. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century*, Vol 1, ASM International, 1998, p 517-522 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-P-0116.

Polymer

Flame Spraying of Polymers. Statistical design-of-experiment studies of the thermal spraying of polymer powders are presented. Studies of the subsonic combustion (i.e., flame) process were conducted in order to determine the quality and economics of polyester and urethane coatings. Thermally sprayed polymer coatings are of interest to several industries for anticorrosion applications, including the chemical, automotive, and aircraft industries. In this study, the coating design has been optimized for a site-specific application using Taguchi-type fractional-factorial experiments. Optimized coating designs are presented for the two-powder systems. A substantial range of thermal processing conditions and their effect on the resultant polymer coatings is presented. The coatings were characterized by optical metallography, hardness testing, tensile testing, and compositional analysis. Characterization of the coatings yielded the thickness, bond strength, Knoop microhardness, roughness, deposition efficiency, and porosity. Confirmation testing was accomplished to verify the coating designs. Deposition onto grit-blasted carbon steel substrates.

D.J. Varacalle, S.M. Kirk, D.P. Zeek, D.M. Benson, and K.W. Couch. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 231-238 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1242.

Polymeric Anticorrosion Coating Technology. There are several kinds of techniques for polymeric coatings, such as air spray, airless spray, brushing, electrostatic deposition, fluidized-bed dipping, thermal spray, etc. The coating materials also consist of two types of polymeric materials of thermoplastics and thermosets. In this paper, the anticorrosion coating technology as well as the specification and requirements for coating materials are described for field applications.

B.I. Min. Cited: *RIST J. R&D*, Vol 11 (No. 2), June 1997, p 179-191 [in Korean]. ISSN 1225-486X. PHOTOCOPY ORDER NUMBER: 199808-35-1579.

Thermal Spray Coating for Polymeric Materials. Powder coating technology such as electrostatic deposit and fluidized-bed dipping, of polymeric materials grow fast in coating industries because of the improved quality, increased productivity, environmental compliance, and economical reasons. However, these conventional powder coating technologies have a limit to apply the technology for the large structures at field, because the substrates have to be heated in the large furnaces to make coating films. The thermal spray coating technology of polymeric materials are studied, because the technology may overcome this limit and provide better anticorrosion properties. In this article, the thermal spray coating technology studied in our laboratory are introduced with the test and application results.

Y.H. Park, J.Y. Cho, J.H. Lu, and B.I. Min. Cited: *RIST J. R&D*, Vol 11 (No. 2), June 1997, p 170-178 [in Korean]. ISSN 1225-486X. PHOTOCOPY ORDER NUMBER: 199808-35-1578.

Recycled Material

Recycled Hard Metal-Base Wear-Resistant Composite Coatings. The abrasion-erosion wear resistance of composite coatings from self-fluxing Ni-base alloy and WC-Co hard metal powders is evaluated. The resistance of thermal sprayed and melted NiCrSiB-(WC-Co) coatings was found to be markedly higher than that of NiCrSiB and slightly higher than that of comparative welded coatings. Microstructural and surface analyses were used to describe the coatings and the wear damage. Based on the principles of creating wear-resistant coatings and on experimental studies of wear resistance, high wear-resistant, composite NiCrSiB-(WC-Co) coatings were fabricated. These coatings exhibited 300% higher wear resistance than 0.45% C steel. Substrate was a 0.45C structural steel.

P. Kulu and J. Halling. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 173-178 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-58-0948.

Recycled Polymer

Production of Recycled Polyethylene Terephthalate Coatings by HVOF and Plasma Spray. Polyethylene terephthalate (PET) is a polymer with high melting (265 °C) and glass transition (67 °C) temperatures, insensitive to moisture and common solvents. Also it has a wide range of mechanical properties attainable by variations of molecular weight, orientation, and crystallinity. Due to these characteristics allied with the glasslike transparency, light weight, and unbreakable character, PET is used to form high-performance bottles for carbonated soft drinks, wines, beers, and food packing. This characteristic leads to other situations. The consumption of energy and natural resources together with the environmental problems caused by disposable plastics, lead engineering and materials scientists to try to find different ways to recycle plastics. The characteristics of PET seem to make it useful as a material for coating. Thermal spraying of polymer coatings is increasing in importance. There are many possibilities of applications of polymer coatings, because they protect against corrosion, wear, abrasion, resist solvents, and so forth. Also, the possibility of using recycled plastics seems to be very attractive as a new branch for engineering and materials scientists. This work has two objectives. The first is to develop recycled PET powder for thermal spraying systems using soda bottles as starting material. The second is to verify if this recycled PET powder is a proper material to be used in thermal spraying to produce coatings of 100% recycled material. PET coatings sprayed onto 1020 steel bars using HVOF system and a plasma spray system.

R.S. Lima, C.P. Bergmann, M.D. Lima, and A.S. Takimi. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 215-221 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1326.

Spheroidization of Alumina

Statistical Design of Experiments for the Spheroidization of Powdered Alumina by Induction Plasma Processing. The principal factors controlling the spheroidization process of Al_2O_3 powder in the induction plasma are the position of the powder injector, the powder feed rate, and their interactions. A higher level of powder feed rate (4.2 kg/h) has been achieved at the r.f. plate power of 40 kW with the application of response surface methodology (RSM). Under these loading conditions, the spheroidization of the Al_2O_3 powder of −44+15 μm size attained 94.9%, while for Al_2O_3 of −89+44 μm size, 83.3% spheroidization was achieved.

X. Fan, M. Boulos, and F. Gitzhofer. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 247-253 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-57-1393.

Spheroidized Hydroxyapatite

Plasma Spraying of Combustion Flame Spheroidized Hydroxyapatite (HA) Powders. Tailoring powder characteristics to suit the plasma spray process can alleviate difficulties associated with the preparation of hydroxyapatite (HA) coatings. Commercial HA feedstock normally exhibit an angular morphology and a wide particle size range that present difficulties in powder transport from the powder hopper to the plasma spray gun and in nonuniform melting of the powders in the plasma flame. Hence, combustion flame spheroidized hydroxyapatite (SHA) was used as the feedstock for plasma spraying. Spherical particles within a narrow particle size range are found to be more effective for the plasma spray processes. Results show coatings generated from spheroidized HA powders have unique surface and microstructure characteristics. Scanning electron microscope (SEM) observation of the coating surface revealed well-formed splats that spread and flatten into disk configurations with no disintegration, reflecting adequate melting of the HA in the plasma and subsequent deposition consistency. The surface topography is generally flat with good overlapping of subsequent spreading droplets. Porosity in the form of macropores is substantially reduced. The cross-section microstructure reveals a dense coating comprised of randomly stacked lamellae. The tensile bond strengths of the SHA coatings, phase composition, and characteristics of the coatings generated with different particle sizes (125-175 μm, 45-75 μm, 20-45 μm, and 5-20 μm) showed that a high bond strength of ~16 MPa can be obtained with SHA in the size range from 20 to 45 μm. This can be improved further by a postspray treatment by hot isostatic pressing (HIP). However, larger particle size ranges exhibited higher degrees of crystallinity and relatively higher HA content among the various calcium phosphate phases found in the coatings. Application is to coating of surgical implants. Experimental substrates were steel plates, Ti-6Al-4V and 316L stainless stubs.

K.A. Khor, P. Cheang, and Y. Wang. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 254-260 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-57-1394.

TiC-Ni Base Powders

Sprayability and Properties of TiC-Ni Base Powders in the Detonation Gun and HVOF Processes. Agglomerated and sintered TiC-Ni based powders were sprayed by detonation gun spray (DGS) and high-velocity oxyfuel (HVOF) spray processes. Influence of the binder content (20 and 27 vol%) and some alloying elements, such as Mo, Co, and N on the coating properties were investigated. The coating structures and properties were investigated by optical microscopy, hardness measurements, x-ray diffraction analysis, and by rubber-wheel abrasion wear test. It was found that alloying the hard phase with Mo and N leads to an improvement of the coating properties. Alloying of the binder phase with Co did not affect the coating properties. Porosity in the powder granules was found to be beneficial in order to melt more efficiently the particles in the DGS process and especially in the HVOF process. HVOF spraying of powders with the higher binder content of 27 vol% was found to be advantageous for the preparation of coatings with dense microstructures and good wear resistance.

P. Vuoristo, L.-M. Berger, M. Nebelung, and T. Mäntylä. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 909-915 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1287.

WC Particle Size and Matrix Composition

Influence of WC Particle Size and Matrix Composition on the Behavior of WC-Co-Cr Coatings Sprayed by the HVOF Process. WC-Co-Cr powders with different WC particle size have been sprayed by the HVOF process. At constant spraying conditions, the powders give coatings of different quality. The deposition efficiency during spraying of powders containing large WC particles was found to be low compared to powders with finer WC grains. In addition, the amounts of porosity and cracks were different. The coatings have been characterized by different methods. Erosion and erosion-corrosion tests showed that the WC particle size also influence the wear resistance of the coatings. Small WC particle size was found to be beneficial. Chemical composition of the matrix was also found to be decisive for the coating properties. An increase of the chromium content improved the erosion-corrosion resistance. Substrate: duplex stainless steel 22Cr (SAF 2205).

J. Berget, E. Bardal, and T. Rogne. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 783-789 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1277.

Manufacturing

Composite Polymer Coatings

Influence of a Filler Composition and Conditions of Flame Spraying on a Structure and Mechanical Properties of Composite Polymer Coatings. The problem of protecting the surface of structures and products exposed to wear and aggressive media continues to be urgent at the current stage of technology development. The processes of thermal spraying of coatings are being more and more widely introduced for solving this problem. Among the various fields of thermal spraying, polymer coatings are given ever greater attention. Both thermoplastics (polyolefins, polyamides, fluorine-containing polymers, etc.), and thermosetting plastics (polyepoxides, polyurethanes, etc.) are used for thermal spraying. Thermal sprayed polymer coatings have found application as decorative finishing of products for various purposes, protection from atmospheric corrosion and corrosion in liquid media (seawater, in chemical, petrochemical, food, and medical industry), and protection from wear in the friction pairs under the conditions of corrosion-mechanical wear. The further development of this field consists of creating polymer-based composite coatings and, in particular, metal-polymer coatings (MPC). Proceeding from the available results of metal-polymer materials development, it can be assumed that MPC should demonstrate better performance, compared to the polymer and metallic ones, owing to the combination of the positive properties of polymers and metals. The influence of the presence of additional components in spraying of polymer-based coatings on the processes of polymers oxidation and destruction has not been studied, however. In thermal spraying of MPC, these processes can have special features, as the temperature of heating of the filler particles can significantly exceed the temperature of destruction of the polymer binder. Hence, the need to study the features of the process of formation of thermal sprayed coatings from filled polymers and their physicochemical, mechanical, and service properties.

Y. Borisov, A. Skorokhod, V. Korzhik, and I. Sviridova. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 239-242 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199807-C1-P-1838.

Composites

Layered Al/SiC Metal-Matrix Composite Processed Using Spray Atomization and Deposition. Layered 6061 Al/SiC MMC was fabricated using a spray atomization and deposition processing technique. This technique involves spray atomization of molten metal, injection of reinforcing ceramic particulates, and codeposition of atomized metal droplets and injected reinforcing particulates. The layered structure in the 6061 Al/SiC MMC was produced by alternating 6061 Al alloy droplet deposition and SiC particulate injection on a rotating substrate that was operated using a hydraulic system. The spray deposited and layered 6061 Al/SiC MMC was then consolidated using hot isostatic pressing to reduce porosity while preserving the layered structure. Microstructural characterization revealed that the layered 6061 Al/SiC MMC exhibited a functionally gradient material behavior with nondiscrete interfaces between high and low volume fraction layers. The overall mechanical properties of the layered MMC were evaluated in terms of fracture toughness, strength, modulus, and damping capacity.

M. Wu, W.H. Hunt, J.J. Lewandowski, E.J. Lavernia, and J.J. Zhang. Cited: *Processing and Fabrication of Advanced Materials IV* (Proc. Conf.), Cleveland, OH, 29 Oct-2 Nov 1995, Minerals, Metals and Materials Society/AIME, 1996, p 441-456 [in English]. ISBN 0-87339-337-6. PHOTOCOPY ORDER NUMBER: 199808-62-1537.

Continuous Fiber Reinforced Titanium Metallic/Intermetallic Composites Fabricated by the Arc Spray Technique. The arc spray composite fabrication technique was developed at NASA Lewis Research Center to provide a practical processing alternative for commercial production of metallic and intermetallic composites. This processing route provides good control of composite architecture through uniformity of fiber spacing and elimination of fiber movement that can occur during consolidation in other processing approaches such as foil/fiber or powder cloth. One issue that must be evaluated in thermal spray composite processing techniques is the degree to which fiber damage may occur during the thermal spraying. Arc spray fabrication of silicon carbide (SCS-6) reinforced titanium composites was examined to determine the relationships between process variables and fiber surface damage. Statistically designed parametric studies of process variables were conducted using several titanium matrices including the α_2 intermetallic alloy Ti-13Al-22Nb (wt%) and the metastable beta metallic alloy Ti-15V-3Cr-3Al-3Sn (wt%). Fiber damage was quantified by measuring both changes in the fiber tensile strength as well as loss of the protective carbon coating (SCS layer). Results have revealed important process variable effects and interactions and suggest means to minimize fiber damage during composite fabrication. Also noted: Ti-64 as matrix.

C.L. Bowman, R.M. Aikin, and J.W. Pickens. Cited: *Processing and Fabrication of Advanced Materials IV* (Proc. Conf.), Cleveland, OH, 29 Oct-2 Nov 1995, Minerals, Metals and Materials Society/AIME, 1996, p 343-353 [in English]. ISBN 0-87339-337-6. PHOTOCOPY ORDER NUMBER: 199808-62-1531.

Functionally Gradient TiN

Fabrication of Functionally Gradient TiN Coating by Means of Reactive Plasma Spraying. The fundamental nature of the nitriding process of solid-state Ti alloy by r.f. plasma has been investigated. A linear relationship was recognized in the relation between thickness of the nitride layer and square root of nitriding time. Therefore, the present plasma nitriding process seemed to be diffusion dominated. The diffusion rate of nitrogen in the Ti alloy, R_d, was estimated from the experimental results obtained, and the plasma spraying of Ti powder was conducted with a deposition rate less than R_d. By using this process, it was possible to fabricate a thick nitride coating with high deposition rate. It revealed that the degree of nitriding of the coating could be controlled by changing the coating deposition rate. Based on this result, a functionally gradient coating, whose compositional configuration changed from coating/substrate interface to coating surface, was fabricated by changing the deposition rate. From the results of wear tests, it was found that the wear-resistance property of the nitride coating was equivalent to that of a nitrided layer on the Ti alloy.

M. Fukumoto, Shi. Itoh, and Sho. Itoh. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 306-318 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-57-1012.

Mechanical Properties

Adhesion

Adhesion of Plasma Sprayed Al_2O_3-TiO_2 Layer at High-Temperature. Three kinds of alumina-titania powder mixtures were produced by various manufacturing methods. The powders were plasma sprayed onto grit-blasted copper substrates. The plasma sprayed layers were investigated by thermal cycling from 1073 K to room temperature. Adhesion was evaluated by peeling tests in high-frequency vibration. The powders and sprayed layers were examined using scanning electron microscopy and optical microscopy to evaluate adhesion between the sprayed layers and substrates. The highest adhesion was obtained from the layers sprayed with clad alumina powder surrounded by titania onto a Cu substrate that had been blasted with mixed grits 0.3 to 2.5 mm in size. These layers are <20 μm thick and contain several microcracks at ~10 μm intervals.

M. Sasaki, T. Miyazaki, M. Nakagawa, and R. Urao. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 139-143 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-57-1383.

Composites Structures

Mechanical Properties of Spray Formed Composite Structures. In this study, ethylene methacrylic acid copolymer (EMAA) was used as the matrix to produce EMAA/Al_2O_3 and EMAA/NiCr composite coatings from dry-blended powder mixtures. This work was conducted to determine processing concerns when using similar-sized reinforcement particles of different density in a flame spray process. This work has utility for applications that require a reduction in mechanical wear and/or to confer upon a polymeric deposit a certain functional property by the introduction of value-added powder. Free-standing coatings were produced to test the mechanical properties of the sprayed deposit. The effects of the filler content on the secant modulus, yield stress, and tensile strength are discussed. The differences in deposition efficiencies among the EMAA, Al_2O_3, and NiCr are highlighted with respect to particle size and density.

J.A. Brogan, A. Claudon, C. Coddet, and C.C. Berndt. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 2, ASM International, 1998, p 1173-1178 [in English]. PHOTOCOPY ORDER NUMBER: 199809-C1-D-2253.

Hydroxyapatite Coatings

Fracture Behavior and Tensile Adhesive Properties of HA Coatings. The attractive bioactive properties of HA are significantly reduced upon plasma spraying because of the phase transformation that accompanied the deposition process. One major factor in the extent to which the transformation occurs is the morphology and physical state of the HA raw powders. This paper reports the study on the influence of powder morphology and property on the fracture behavior and tensile adhesive strength of plasma sprayed HA coatings. Three types of powders were used in the study: calcined HA (CHA), spray dried HA (SDHA), and flame spheroidized HA (SHA). The particle size range of 53 to 75 μm was employed for all three types of powders to effect an accurate comparison of the powders. Results show that the cohesive bond strength of the SHA coating was the highest because of the denser microstructure created by well-formed lamella splats. A correspondingly lower bond strength was recorded with less coherent coatings generated by agglomerated CHA and SDHA powders. Substrate: Ti-64.

K.A. Khor and P. Cheang. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 769-774 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1275.

Nanoindentation

Nanoindentation Study of Thermal Spray Deposits. The nanoindentation technique has been applied to thermal sprayed metal, cermet, and ceramic deposits. The hardness and elastic modulus were determined from the load-displacement curves. Each test was implemented by varying the penetration depth (100, 200, 300, and 400 nm) in the same test location, and at least 20 tests were performed. The results were compared to those from microindentation tests. The nanoindentation test, essentially, measured the submicrometer scale properties of thermal spray deposits, which can be considered as "near-intrinsic" properties of the coatings. Thus, these measurements exclude most of the microstructural factors that influence the "macroscale" properties. The nanoindentation test exhibits significantly greater hardness and elastic modulus values than the microindentation test. Plasma sprayed deposits were alumina doped with 13% titania (AT13), Ni-5Al (NA5), and the cermet chromium carbide-25 wt% NiCr (CN25).

S.H. Leigh, M.K. Ferber, L. Riester, and C.C. Berndt. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 723-729 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1345.

Stress Development

Measurement of Stress Development During HVOF Thermal Spray. Direct and quantitative observation of the stress generation during HVOF spray is carried out by measuring the curvature of substrates in situ during spraying. A high-pressure HVOF gun is used to spray SUS316L, Hastelloy C, and WC-12%Co powder onto SUS316L substrates. The observed curvature data indicate that there are three regimes of stress evolution during the HVOF spray: (1) generation of compressive stress on the substrate surface at the beginning of spraying, (2) stress buildup in the coating during spraying, and (3) superposition of stress due to the mismatch in the thermal expansivity between the coating and the substrate as the specimen cools down to room temperature after fabrication. Compressive stress ranging from 70 to 400 MPa is observed in the second regime during the HVOF spray; the value depending on the powder materials and spray conditions. Microstructural observation reveals that a significant portion of the coatings consists of poorly molten particles. Beneath the coatings formed by the HVOF process, a thin layer of increased hardness exists within the substrate.

S. Kuroda, H. Fukanuma, S. Taira, Y. Tashiro, and H. Yumoto. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 805-811 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1279.

Wear Characteristics

Mechanical and Tribological Properties of Plasma Sprayed Cr_3C_2-NiCr, WC-Co, and Cr_2O_3 Coatings. Mechanical properties such as Young's modulus and fracture toughness of plasma-sprayed Cr_3C_2-NiCr, WC-Co, and Cr_2O_3 coatings were measured. The tribological properties of the three kinds of coatings were investigated with a block-on-ring self-mated arrangement under water-lubricated sliding. Furthermore, the influence of the mechanical properties on the tribological properties of the coatings were also examined. It was found that the Young's modulus, bend strengths, and fracture toughness of the coatings were lower than the corresponding bulk materials, which may be attributed to the existence of pores and microcracks in the coatings. Among the three kinds of coatings, the magnitude of wear coefficients, in decreasing order, is Cr_3C_2-NiCr, WC-Co, and Cr_2O_3, and the wear coefficient of Cr_2O_3 coating was $<1 \times 10^{-6}$ mm^3 N/m. The wear mechanisms of the coatings were explained in terms of microcracking and fracturing, and water deteriorated wear performance of the coatings. The higher the fracture toughness and the lower the porosity and length of microcracking of the coating, the more the wear resistance of the coating. Coatings were deposited on 1Cr18Ni9Ti stainless steel substrates.

J. Li, C. Ding, J. Huang, and Y. Zhang. Cited: *J. Therm. Spray Technol.,* Vol 7 (No. 2), June 1998, p 242-246 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-57-1392.

Metallography

Sealing

Increase in the Reliability of Thermal Sprayed Coatings. The characterization of the effectiveness of sealing was studied by metallographical investigations as well as comparing the investigations with respect to the corrosion and wear behavior of the used thermal sprayed coatings and last but not least by measuring of the insulation resistance of the coating system. The obtained results show that there are differences between the used sealants, and it is possible through a mechanical treatment of sealed coatings to remove the sealants from the coatings. In the corrosion test, the sealants show their efficiency. The sealants insulate the open porosity and prevent the corrosion attack owing to the interconnected pores. Example materials: plasma sprayed alumina/titania coatings and flame sprayed chromium steel coatings; phenolic resin, methylacrylic resin, and polyurethane resin sealants in various solvents.

S. Steinhäuser, U. Hofmann, B. Wielage, and G. Zimmermann. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 491-497 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1260.

Microstructure

Alumina Splat

Analysis of Nucleation, Phase Selection, and Rapid Solidification of an Alumina Splat. A numerical model has been developed to study the rapid solidification of an alumina splat in thermal spray deposition. The model focuses on the melt undercooling, the selection of the various phases of Al_2O_3, and the subsequent nonequilibrium rapid solidification process. A thin molten layer is assumed to be brought into contact with the substrate at time $t = 0$. One-dimensional heat transfer is considered through splat and substrate along with a thermal contact resistance between them. The classical theory of nucleation kinetics is used to determine the nucleation temperature, assuming that nucleation takes place heterogeneously on the substrate surface. The most likely nucleated crystalline phase is investigated, based on the nucleation kinetics of various phases. Once the particular phase is identified and the nucleation temperature is calculated, the solidification starts assuming a planar interface between the solid and the liquid. Nonequilibrium kinetics of the chosen phase is applied at the moving interface to calculate the interface velocity from the interface melt undercooling. In this paper, the effect of splat variables on the solidification and cooling process of the splat are analyzed. Special attention is paid to the value of the wetting angle between the growing nucleus and the substrate, which affects greatly the nucleation temperature. Substrates: steel and alumina.

A. Vardelle, S. Sampath, G.X. Wang, and C. Robert. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 635-643 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1341.

Decarburization of HVOF Coatings

Structural Characterization of Chromium Carbide-Nickel Chromium Coatings Obtained by HVOF Spraying. Chromium carbide-nickel chromium coatings produced by HVOF spraying are widely used for high-temperature wear- and erosion-resistant applications. Examination of the literature shows that while the mechanical properties of these coatings have been widely investigated, there has been little research into the physical processes occurring during HVOF spraying of this system, such as carbide dissolution, liquid-metallic phase oxidation, decarburization, and rapid solidification. The purpose of the present work has been to perform a systematic characterization of the chromium carbide-nickel chromium system in both the initial powder and as-sprayed states with a variety of spraying conditions using optical, scanning, and transmission electron microscopy, electron microprobe, and x-ray diffraction. The presence of amorphous and nanocrystalline phases has been demonstrated. The nanocrystalline structures tend to be Ni rich, with the amorphous phases rich in Cr. Carbides of the form Cr_3C_2 were found to be dissolved slightly during spraying, increasing the Cr and C contents of the liquid metallic phase. There was no evidence of chromium carbide oxidation. Substrate: low-alloy steel 34Cr4Mo, UNS G-41350.

J.M. Guilemany and J.A. Calero. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 717-721 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1272.

Effect of Thermal Contact Resistance

On the Spreading and Solidification of Molten Particles in a Plasma Spray Process: Effect of Thermal Contact Resistance. The spreading and simultaneous solidification of a liquid droplet upon its impingement onto a substrate permitting thermal contact resistance has been numerically simulated; the effect of contact resistance and the importance of solidification on droplet spreading are investigated. The numerical solution for the complete Navier-Stokes equations is based on the modified SOLA-VOF method using rectangular mesh in axisymmetric geometry. The solidification of the deforming droplet is considered by a one-dimensional heat conduction model. The predictions are in good agreement with the available experimental data, and the model may be well suited for investigating droplet impact and simultaneous solidification permitting contact resistance at the substrate. We found that the final splat diameter could be extremely sensitive to the magnitude of the thermal contact resistance. The results also show that for the condition of higher Reynolds and/or higher Stefan numbers the effect of solidification on the final splat diameter is more important.

M. Pasandideh-Fard and J. Mostaghimi. Cited: *Plasma Chem. Plasma Process.,* Vol 16 (No. 1), March 1996, p 83S-98S [in English]. ISSN 0272-4324. PHOTOCOPY ORDER NUMBER: 199809-54-1276.

Evolution of Oxidation During HVOF

Oxidation in HVOF Sprayed Steel. It is widely held that most of the oxidation in thermally sprayed coatings occurs on the surface of the droplet after it has flattened. The evidence in this paper suggests that, for the conditions studied here, oxidation of the top surface of flattened droplets is not the dominant oxidation mechanism. In this study, a mild steel wire (AISI 1025) was sprayed using a high-velocity oxyfuel (HVOF) torch onto copper and aluminum substrates. Ion milling and Auger spectroscopy were used to examine the distribution of oxides within individual splats. Conventional metallographic analysis was also used to study oxide distributions within coatings that were sprayed under the same conditions. An analytical model for oxidation of the exposed surface of a splat is presented. Based on literature data, the model assumes that diffusion of iron through a solid FeO layer is the rate-limiting factor in forming the oxide on the top surface of a splat. An FeO layer only a few thousandths of a micron thick is predicted to form on the splat surface as it cools. However, the experimental evidence shows that the oxide layers are typically 100× thicker than the predicted value. These thick, oxide layers are not always observed on the top surface of a splat. Indeed, in some instances the oxide layer is on the bottom, and the metal is on the top. The observed oxide distributions are more consistently explained if most of the oxide formed before the droplets impact the substrate.

M.F. Smith, R.C. Dykhuizen, and R.A. Neiser. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 885-893 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0882.

Fe-Cr-B-Base Coatings

The Structure and Properties of Two Fe-Cr-B-Base Coatings Sprayed Using HVOF. Two boron-rich Fe/Cr-base gas atomized powders (Armacor M and Armacor C) have been thermally sprayed using the HVOF process and the resultant deposits subsequently characterized, using x-ray diffraction, scanning electron microscopy (SEM), plan view transmission electron microscopy (TEM), and microhardness measurements. The wear and corrosion characteristics of the two alloy coatings have also been investigated by three-body abrasive wear (utilizing cross-sectional TEM to examine the worn surfaces) and potentiodynamic corrosion testing respectively. Results from microstructural analysis of the as-sprayed deposits revealed the presence of small chromium/iron boride precipitates within a predominantly amorphous matrix in the Fe-base Armacor M coating. The Fe-Cr-base Armacor C coating, however, consisted mainly of regions of nano- and microcrystalline material interspersed with chromium boride precipitation. Iron/chromium oxides have been observed within both of the alloy coatings studied. Both of these alloys exhibit good abrasive wear resistance when compared with other metallic-based HVOF sprayed coatings. Both Armacor M and Armacor C also exhibit extensive passivation on exposure to an acidic solution. The wear and corrosion test results are related to the microstructural observations. Substrate: stainless steel.

A.H. Dent, S.J. Harris, A.J. Horlock, and D.G. McCartney. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 917-923 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0883.

Hydroxyapatite

Studies on Diffusion Maximum in X-Ray Diffraction Patterns of Plasma Sprayed Hydroxyapatite Coatings. Study of an amorphous phase in plasma sprayed hydroxyapatite (HA) coatings is important owing to its unique characteristics and nonnegligible amount of the amorphous phase compared to crystalline HA. However, little is known about the component parts of an amorphous phase. It is known that amorphous phase usually appears as the diffusion maximum (D_{max}) in x-ray diffraction (XRD) patterns. Analyzing D_{max}, including the position (P_{max}) and area of D_{max}, we can indicate the component parts of an amorphous phase and their transitions. In this study, the variation of D_{max} in XRD patterns of the coatings during plasma spraying, in postheating, and in dissolving in vitro was studied with the aid of XRD. It was found that component parts of the amorphous phase in the coating varied with increasing thickness, consisting of two parts represented by D_{max1}, located between 29.4 and 29.8° (2χ), and D_{max2}, located between 31.0 and 31.4° (2χ). It was concluded that D_{max3}, located between 32.0 and 32.4° (2χ), should be referred to as nanocrystals of HA. In addition, the particle size of the starting powder may affect the component parts of the amorphous phase in the coating in addition to thickness. With vacuum heating (650 °C) and water vapor treatment at a low temperature (125 °C) in a saturated vaporic atmosphere, transition of the amorphous components was not as efficient as that at 490 °C with water vapor. The reason might be that the amorphous-to-crystalline HA conversion is dependent on both temperature and water vapor pressure. It was found that amorphous components were transformed completely into crystalline HA after heating at 490 °C with a partial water vapor pressure of 0.01 MPa for 2 h. It was concluded that the unstable amorphous components (D_{max1}, D_{max2}) converted into more stable nanocrystals of HA (D_{max3}). Degradation in vitro showed that D_{max3} was more stable than D_{max1} and D_{max2}. It was concluded that nucleation of apatite in vitro should be attributed to nanocrystals of HA (D_{max3}) except for the amorphous components. It is recommended that the optimal phasic contents of the plasma sprayed HA coating be mainly composed of crystalline HA and nanocrystals of HA (D_{max3}) in terms of the stability and biocompatibility of the coating.

W. Tong, Y. Cao, J. Chen, J. Feng, A. Yang, Z. Yang, and X. Zhang. Cited: *J. Biomed. Mater. Res.,* Vol 40 (No. 3), 5 June 1998, p 407-413 [in English]. ISSN 0021-9304. PHOTOCOPY ORDER NUMBER: 199808-61-0693.

Properties and Microstructure of Plasma Sprayed Hydroxyapatite Coatings Produced with Different Powder Feedstocks. Hydroxyapatite (HA) is a bioactive material with a calcium-to-phosphorus ratio that is comparable to that of natural bone. This similarity encourages rapid bone growth and bonding between bone tissue and the implant surface. Plasma spraying is an efficient coating method of depositing HA onto biomedical implants. However, the biocompatibility of HA changes after plasma spraying. This paper reports the preparation and characterization of HA coatings using different feedstocks such as agglomerated calcined HA (CHA) and dense flame spheroidized HA (SHA). The results indicate that the state of the starting powder in terms of geometry, shape, and structure can produce efficacious effects on the coating characteristics. Both calcined HA and flame spheroidized HA powders were plasma sprayed onto metallic substrates and stubs. Coatings generated from spheroidized HA (SHA) powders have unique surface and microstructure characteristics while the coatings produced with CHA are porous and contain unmelted particles. SEM observation of the coating surface reveals well-formed splats that spread and flatten to a disk configuration without disintegration. This reflects adequate melting of the HA in the plasma with good deposition consistency. The surface topography is generally flat with considerable overlapping of subsequent spreading droplets. Porosity in the form of macropores is substantially reduced compared to CHA coatings. The cross-section microstructure reveals a highly dense coating comprised of randomly stacked lamellae. The tensile adhesion test (TAT) recorded the highest cohesive strength in the flame spheroidized HA coating. This suggests that having a structurally stable powder that is both dense and spherical promotes mechanically strong and coherent coatings (on Ti).

P. Cheang and K.A. Khor. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 747-758 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-57-1021.

Image Analysis

Absolute Coating Porosity Measurement Using Image Analysis. This paper describes the procedure that has been developed for absolute porosity measurement using image analysis (IA). Because of the crumbly nature of the composite substrate, it was not possible to proceed with standard method. The IA conducted on optical microscopy did not show enough contrast between pores and other features to be automated. The IA conducted on scanning electron microscopy (SEM) with backscattered electron imaging gives enough contrast for automatic threshold determination. The SEM magnification is a parameter to be considered because it filters the information. Three frames at 500× magnification are enough for measuring the porosity of homogeneous supersonic induction plasma sprayed diameter 18 mm samples (thickness 50 to 100 μm). The established calibration almost shows a 1-to-1 ratio for the image analysis as measured porosity versus the Archimedean porosity. Application of this absolute porosity determination by IA can be found in the functionally graded materials (FGM), the composition of which is not constant over the layer thickness.

K. Mailhot, M.I. Boulos, and F. Gitzhofer. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century*, Vol 1, ASM International, 1998, p 917-922 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-C-0117.

Splat Morphology

Morphology of Splats of Thermally Sprayed Coatings. Different mechanisms of splashing of droplets impacting onto the substrate surface during thermal spraying are considered. It is shown that supercooling formed in the flattening droplet consists of the thermal supercooling and that arisen due to the high pressure developed upon the droplet impact. Solidification starts when the supercooling exceeds some critical value. With a "cold" substrate when its temperature is less than a transition temperature, the marked contribution to the supercooling is due to its high-pressure part. In this case, a regular disk-shaped splat will be formed in the central part of the flattening droplet and splashing will occur in the periphery. With a "hot" substrate, when its temperature exceeds the transition temperature the thermal supercooling is high enough, no splashing occurs and a regular disk-shaped splat is formed. Theoretical results agree with the experimental observations.

V.V. Sobolev. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century*, Vol 1, ASM International, 1998, p 507-510 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-C-0115.

Stability of WC-Co

Microstructural Stability of Thermal Sprayed WC-Co Composite Coatings in Oxidizing Atmospheres at 450 °C. The present work stems from a development program considering the use of WC-Co thermal spray coatings in galvanizing applications. In such applications, service conditions include exposure to air at 450 °C. It is generally accepted that WC-Co composites do not oxidize significantly in air at temperatures <500 °C. However, the present results show significant oxidation of such coatings at 450 °C in air and in contact with a molten galvanizing alloy. There appear to be two simultaneous oxidation reactions occurring, with WO_3 forming from the tungsten carbide and tungsten phases and $CoWO_4$ derived from the βCo and cobalt containing carbide phases.

D. Nolan, P. Mercer, and M. Samandi. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 124-128 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0942.

Substrate Condition

Effect of Substrate Condition on Splat Formation During Thermal Spray Deposition. Molybdenum and partially stabilized zirconia (PSZ) containing 8% Y_2O_3 splats were prepared on mild steel, glass, and stainless steel substrates at several substrate temperatures. Their morphologies were analyzed using scanning electron microscopy (SEM) and three-dimensional surface profilometry. With an increase in substrate temperature from room temperature up to 400 °C, the shape of molybdenum splat on steel substrate changes from fragmented morphology to a more contiguous disk-shaped morphology; on glass substrate, molybdenum splats morphology changes from marginally splashing to disklike morphology with the increase of substrate temperature. The flattening ratios of molybdenum splats are 2.4 and 4.5 on steel and glass substrates, respectively; this difference is considered arising from the splat solidification velocity difference. With increased substrate temperature from room temperature to 400 °C, the PSZ splats morphology changes from splashing to disklike, although significant amount of fragmented splats remains even at higher temperature. The average flattening ratio of PSZ splats made with substrate at 400 °C is 4.0. The mechanism of change in morphology of splats is discussed.

X. Jiang and S. Sampath. Cited: *Solidification 1998* (Proc. Conf.), Indianapolis, IN; San Antonio, TX, 15-17 Sept 1997; 16-18 Feb 1998, Minerals, Metals and Materials Society/AIME, 1998, p 439-448 [in English]. ISBN 0-87339-396-1. PHOTOCOPY ORDER NUMBER: 199809-58-0844.

TiC-Ni + Ti and (Ti,W) C-Ni Powders

Structure-Property Relationships of TiC-Ni + Ti and (Ti,W) C-Ni Powders Manufactured by the SHS Process, and the Resultant HVOF Sprayed Coatings. The technology of thermal spraying is approaching maturity, and in the quest to reduce production costs while maintaining coating quality, attention is turning increasingly to more cost-effective routes for the manufacture of the starting powders. One such route is self-propagating, high-temperature synthesis (SHS), which reduces the required energy input for powder production. In this work, TiC-Ti + Ni and (Ti,W)C-Ni powders produced by the SHS process have been studied in the as-received and as-sprayed states to evaluate the suitability of SHS powders for the production of wear-resistant coatings. The starting powders and the coatings produced by atmospheric-plasma and HVOF spraying have been characterized using analytical (XRD, EDS) and microscopical techniques (optical, SEM). The technological properties of the as-sprayed coatings have also been characterized, including hardness, wear resistance (using a Rubber-Wheel test (ASTM G-65)), and corrosion resistance (in marine water environment). Substrate: low carbon steel.

J.M. De Paco, P. Smith, J.M. Guilemany, J.R. Miguel, J. Nutting, and F.J. Sánchez. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 935-942 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1289.

WC-Co Coatings

Microstructure and Abrasion Resistance of WC-Co Coatings Produced by High-Velocity Oxyfuel Spraying. Coatings have been produced by HVOF spraying of four different WC-Co powders, using two fuel gases and two oxygen contents in the flame, and characterized in terms of microstructure and resistance to abrasive wear. It is concluded that there is a close correlation between high levels of chemical reaction, occurring during spraying (and possibly during powder production), and poor wear resistance. Good wear resistance is favored by using low-porosity powders, which interact with the atmosphere less readily during spraying, and also by using a flame with a relatively low oxygen content. This probably minimizes the degree of reaction by ensuring that conditions are reducing. Use of propylene rather than hydrogen gives coatings with slightly better wear resistance, despite the fact that the flame temperatures are higher. It is concluded that, for this relatively small rise in temperature, the positive effect on intersplat cohesion seems to outweigh the negative effect of increased decarburization. Substrate: 316S11 stainless steel.

M.S.A. Khan, T.W. Clyne, and A.J. Sturgeon. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 681-690 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1270.

Zircon-Alumina Coatings

Phase Composition Changes in Annealed Plasma Sprayed Zircon-Alumina Coatings. Phase transformations and/or decomposition of deposited compounds have an indisputable influence on materials properties of plasma sprayed deposits. Using water-stabilized plasma, free-standing parts were manufactured from a mechanical mixture of zircon and alumina powders and annealed. The phase composition was determined by x-ray diffraction and the chemical composition was checked by x-ray microanalysis. $ZrSiO_4$ during plasma spraying decomposes into ZrO_2 and SiO_2. In the as-sprayed condition, after a relatively fast quenching, the following phases can be found: a very fine eutectic mixture of tetragonal and monoclinic ZrO_2, amorphous SiO_2, and a spinel phase of Al_2O_3. On annealing for 2 h at 1300 and 1500 °C the spinel Al_2O_3 transformed to corundum. At the same time, amorphous silica crystallized. Tetragonal ZrO_2 transformed to the monoclinic modification and together with SiO_2 formed again $ZrSiO_4$. At the highest annealing temperature, Al_2O_3 and SiO_2 partially reacted to form a small amount of mullite ($3Al_2O_3$,$2SiO_2$).

J. Dubsky, B. Kolman, and K. Neufuss. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 473-476 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199807-E4-C-0322.

Modeling

Cold Spray

Gas Dynamic Principles of Cold Spray. This paper presents an analytical model of the cold-spray process. By assuming a one-dimensional isentropic flow and constant gas properties, analytical equations are solved to predict the spray particle velocities. The solutions demonstrate the interaction between the numerous geometric and material properties. The analytical results allow determination of an optimal design for a cold-spray nozzle. The spray particle velocity is determined to be a strong function of the gas properties, particle material density, and size. It is also shown that the system performance is sensitive to the nozzle length, but not sensitive to the nozzle shape. Thus, it is often possible to use one nozzle design for a variety of operational conditions. Many of the results obtained in this article are also directly applicable to other thermal spray processes. Examples illustrate cold spraying of Cu and steel.

R.C. Dykhuizen and M.F. Smith. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 205-212 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-58-0951.

Flattening of Composite Particles

Engineering Formulas for Flattening of Composite Powder Particles During Thermal Spraying. Engineering analytical formulas describing variations of the final values of the splat thickness and radius during flattening of composite particles in thermal spraying are obtained. The effective values of the droplet parameters (impact velocity and viscosity) and the Reynolds number are introduced taking into account a composition of the composite particles. Analytical results obtained agree well with the experimental data available. (Example: flame spraying of cemented carbides WC-Co.)

V.V. Sobolev, J.M. Guilemany, and A.J. Martin. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 653-656 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1267.

HVOF of Nanomaterials

Analysis of Thermal Spray Method for Coating Nanoscale Materials. Thermal spray (TS) systems are a low-cost, versatile technology that can significantly improve the properties of base materials by coating them with high-performance materials. TS coating methods are simple and can be used for coating large surfaces at atmospheric pressures using materials that range from metal alloys and cermets to ceramics and polymers. TS guns deliver the plating materials to the substrates at high velocities (on the order of 1 to 1.5 km/s) and high temperatures. The total pressure of the particles impinging on the surface can reach 10 GPa for some of the TS systems. Lower sintering temperatures and higher ductility of nanoscale materials open a range of attractive and unique possibilities for high rate deposition of nanostructured coatings. The unique properties of nanoscale materials make deposition possible in operating regimes that are different from those of conventional micron-sized powders. We use a recently developed and validated three-dimensional simulation capability to model the TS systems' gas and coating powder flow for the TS process analysis, and to predict effective plating regimes of nanograined powders. The same capability can be used to design optimized TS systems and to optimize and control the coating process. We will discuss specific equipment and process solutions that will make nanoscale powders coating a viable industrial process. Coating particles: Inconel 718 and WC/Co powders.

S. Eidelman and X. Yang. Cited: *Advances in Coatings Technologies for Surface Engineering* (Proc. Conf.), Orlando, FL, 9-13 Feb 1997, Minerals, Metals and Materials Society/AIME, 1997, p 119-128 [in English]. ISBN 0-87339-371-6. PHOTOCOPY ORDER NUMBER: 199807-57-0942.

HVOF of WC-Co

Thermal Processes in HVOF Sprayed WC-Co Coating on a Copper Substrate. Mathematical modeling of the heat transfer between a WC-Co coating and a copper substrate during high-velocity oxygen-fuel (HVOF) spraying was undertaken. The modeling included the investigation of temperature variation, coating solidification, melting and solidification in the substrate interfacial region, and specific features of the substrate-coating thermal interactions.

V.V. Sobolev, J.A. Calero, and J.M. Guilemany. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 191-192 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-58-0949.

HVOF Sprayed WC-Co

Formation of Structure of HVOF Sprayed WC-Co Coating on a Copper Substrate. Mathematical modeling of the formation of the WC-Co coating structure and adhesion on copper substrate during high-velocity oxygen-fuel (HVOF) spraying is provided. Smooth (polished) and rough (grit-blasted) substrates are considered. Variations of solidification time, 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 investigated. Behavior of the crystal size and intercrystalline distance with respect to the thermal spray parameters and morphology of the substrate surface is analyzed. Optimal conditions for the development of fine and dense crystalline structure are determined. Mechanical and thermal mechanisms of development of the substrate-coating adhesion are discussed. Results obtained agree well with experimental data.

V.V. Sobolev, J.A. Calero, and J.M. Guilemany. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 943-948 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1290.

Impinging Dusted Plasma

Numerical Modeling of an Impinging Dusted Plasma Jet Controlled by a Magnetic Field in a Low-Pressure Condition. The present study is conducted to clarify the magnetic control characteristics of a particle-laden plasma jet impinging on a substrate for the improvement of a low-pressure plasma spraying process and its controllable optimization. The plasma jet is described by Eulerian approach, and each injected particle is described by Lagrangian approach respectively taking into account the compressible effect, variable transport properties, and plasma-particle interactions, coupled with the Maxwell's equations. The effects of the location of the applied radio-frequency electromagnetic field, and of the injected particle size on the particle trajectory, particle velocity, and its phase change are clarified by numerical simulation. It is concluded that the particle trajectory is influenced effectively, and the injected particle temperature can be controlled strongly by applying the radio-frequency electromagnetic field to the nozzle. The reasonable agreement of particle velocity between calculation and experiment is observed. Particles were alumina; applications include the production of functionally graded materials.

H. Nishiyama, S. Kamiyama, O.P. Solonenko, and M. Kuzuhara. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 1, ASM International, 1998, p 451-456 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E4-D-0445.

Particle Interaction with Plasma Jet

Mathematical and Computer Modeling of Particles Interaction with Plasma Jet in Low-Pressure Condition. On the base of gases molecular and kinetic theory a mathematical model of interaction between powder particles and plasma jet is developed. Three-dimensional description of plasma forming gas density distribution as well as particle motion in the plasma jet are a characteristic property of the model. A software for practical realization of the mathematical model is created. Said software provides the possibility to investigate an effect of low-pressure plasma spraying parameters on particle velocity and coordinates in the plasma jet. Computer simulation of particle velocity for powders from aluminum and tungsten oxides in argon plasma under 60 Mbar is conducted. A "Plasma-Technik" VPS unit is used for testing the developed model. Particle velocity measurement is made by a specially developed optical-electronic unit.

A. Ilyuschenko, V. Gurevich, S. Kundas, and V. Okovity. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 1, ASM International, 1998, p 523-527 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E4-C-0446.

Rapid Solidification

Modeling of Rapid Solidification During Splat Quenching. In thermal spray deposition, splats are formed by the impact of molten droplets on a solid substrate or a predeposited layer. This paper presents an integrated heat transfer and rapid solidification model for microstructure formation in a single splat. Heat and mass diffusion equations are solved with a moving dendrite tip/melt interface. A unified dendrite growth theory is introduced at the interface that employs the marginal stability criterion to determine the tip operating conditions of dendrites and is applicable to both free dendrite growth in an undercooled melt and constrained dendrite growth under a positive temperature gradient. The theory can predict the transition of solidification morphology, e.g., from dendritic to planar growth and therefore, the microstructure formation in the splat. The model is used to investigate the microstructure development of Al-4.5Cu alloy splats on a copper substrate. A microstructure map is developed based on the melt undercooling and thermal contact conditions between the splat and the substrate.

G.-X. Wang, H. Herman, V. Prasad, and S. Sampath. Cited: *Solidification 1998* (Proc. Conf.), Indianapolis, IN; San Antonio, TX, 15-17 Sept 1997; 16-18 Feb 1998, Minerals, Metals and Materials Society/AIME, 1998, p 485-496 [in English]. ISBN 0-87339-396-1. PHOTOCOPY ORDER NUMBER: 199809-58-0846.

Self-Fluxing Coatings

The Spraying Process Model Using Simultaneous Fusion by Extended Arc of Plasma Self-Fluxing Coatings. In order to improve the exploitation properties of machine components with coatings of self-fluxing alloys of Ni-Cr-B-Si system, these components underwent fusion. The refined procedure for calculating a fusion depth with allowance made for dependence of heat conductivity coefficient of the coating material upon temperature and porosity is suggested. The isotherms are plotted and used in calculations of conditions for coating spraying. The discrepancy between the calculated and experimental data is less than 10%.

A.A. Puzryakov, S.A. Semenova, I.N. Solov'ev, V.A. Vakhalin, and A.F. Puzryakov. Cited: *Svar. Proizvod.*, Vol 3, March 1998, p 14-15 [in Russian]. ISSN 0491-6441. PHOTOCOPY ORDER NUMBER: 199809-55-2116.

Simulations of Multiple-Splat Spreading

Dynamic Simulations of Multiple-Splat Spreading and Solidification. A high-resolution numerical model has been developed to simulate the simultaneous spreading and solidification of single and multiple splat on a cold substrate. The model combines the level set formulation with curvilinear adaptive finite volume scheme to predict the deforming shape of the splat's free surface as well as the solidification interface shape and dynamics. An adaptive grid generation captures the solidification front and the level set formulation allows the free surface deformation caused by merging and separation. Numerical results on spreading, merging, and solidification of a single splat and two splats are presented to demonstrate the capability of the scheme. It also shows that this model can be extended to predict porosity in thermal spray coatings. Nickel deposited on nickel.

V. Prasad, S. Sampath, and H. Zhang. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 645-652 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0879.

Postprocessing

Hot Isostatic Pressing

Postprocessing of Thermal Sprayed Coatings Using Hot Isostatic Pressing. Thermal sprayed coatings are currently being used in the Navy and in private industry to improve corrosion and wear resistance. While these coatings have several attractive features, there are also limitations. Two characteristics of thermal sprayed coatings that limit applications include porosity in the coating and the lack of metallurgical bonding between the coating and the substrate. In general, it has been shown that porosity is detrimental to corrosion performance. The lack of metallurgical bonding has precluded the use of thermal sprayed coatings in critical applications due to concern over debonding. The intent of the work described herein was to establish the feasibility of postprocessing thermal sprayed coatings to decrease porosity levels and to establish metallurgical bonding between the coating and the substrate material. After reviewing several potential techniques for postprocessing the coatings, hot isostatic pressing (HIP) was selected due to its potential to reduce porosity and produce metallurgical bonding in a single step. Coatings applied using conventional flame spray and high-velocity oxy-fuel (HVOF) techniques were postprocessed using two sets of HIP parameters. As-sprayed and postprocessed coatings were then comparatively evaluated metallographically, in bond strength tests, and in laboratory corrosion tests.

D.A. Davis, R.A. Hays, D.M. Aylor, and R.L. McCaw. Cited: *1997 Tri-Service Conference on Corrosion. II* (Proc. Conf.), Wrightsville Beach, NC, 17-21 Nov 1997, Naval Surface Warfare Center-Carderock Division, 1997, p 9.30-9.46 [in English]. PHOTOCOPY ORDER NUMBER: 199808-58-0822.

HVOF Sprayed Fusible Coatings

The Effects of Postheating an HVOF Sprayed Fusible Coating. Fusible coatings of nickel-chromium alloys with various amounts of boron and silicon are commonly used for severe load applications. The coating is normally sprayed, then fused by heating to the point of liquation. The fusing process causes powder coalescence and increases density. At the same time, the high fusing temperatures creates a "brazed" bond that gives these coatings extremely high adhesive bond strengths. The improved bond strength is the result of the metallurgical bond as compared to the majority of thermal spray coatings, which rely only on mechanical bonding mechanisms. The fusing operation is very sensitive, especially when a hand torch fuse is required. To circumvent these problems, a study was conducted to see if high-density HVOF sprayed coatings might achieve fused quality by furnace heating to temperatures well below the liquation point. Various times and temperatures were surveyed. Bond strength tests of coatings sprayed to heavy thicknesses, hardness and impact tests, and metallography were used for evaluation. It was determined that heating as low as 1500 °F for 3 h could improve the properties of an as-sprayed HVOF coating to where it developed characteristics very similar to that of a fused coating.

L. Moskowitz. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 519-525 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0876.

Laser Processing for Beryllium

Laser Processing of Thermal Sprayed Beryllium. The feasibility of using laser-processing techniques to consolidate thermal sprayed beryllium deposits has been investigated. During these experiments both continuous wave CO_2 and pulsed Nd-YAG lasers have been used to consolidate inert plasma sprayed and vacuum plasma sprayed beryllium deposits. Density of as-sprayed beryllium has been increased from <90% of theoretical to 100% through laser consolidation. Also, critical issues such as depth of consolidation and key processing parameters have been identified. A metallurgical analysis of these results is presented. Substrate used was copper.

J.S. O'Dell, J.E. Hanafee, and T.N. McKechnie. Cited: *Mater. Manuf. Process.*, Vol 13 (No. 2), March 1998, p 213-227 [in English]. ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199808-58-0794.

Laser Treatment

Effect of Laser Treatment on Tungsten Carbide Coatings. A CO_2 laser operating in continuous mode was employed to refuse tungsten carbide coatings plasma sprayed onto a substrate of steel. Wear tests block-on-ring type and hardness estimations were carried out for both treated and untreated coatings. The results show an increase in the wear resistance and hardness of the coatings after laser treatment. The remelting with laser eliminates the porosity and homogenizes the coatings of tungsten carbide, although holes can be formed in the borders of the zone affected by the treatment and sometimes traverse cracks can appear. The hardness of the coating increases considerably with the treatment, resulting uniformly in all the coating. This increase is independent of depth. Significantly, wear resistance is superior for the laser treated coating and this resistance becomes more prominent with high loads and at low speeds.

J. Mateos, M. Cadenas, J.M. Cuetos, E. Fernández. Cited: *Surface Treatment: Computer Methods and Experimental Measurements* (Proc. Conf.), Oxford, UK, 15-17 July 1997, Computational Mechanics Publications, 1997, p 239-246 [in English]. ISBN 1-85312-469-9. PHOTOCOPY ORDER NUMBER: 199807-57-0937.

High-Performance Superaustenitic Surface Alloy Using Plasma Coating and Laser Treatment. Stainless steels are required for many applications for ship building as well as for offshore structures such as oil exploration. AISI type 304 stainless steel is not very suitable for such applications as it has a strong tendency for pitting and crevice corrosion. Even type 316 and 317 stainless steels, which have, respectively, 2.5 and 3.5% Mo are not very effective in these environments. Commercially available stainless steels, viz., Avesta 254 SMO, are being employed for such applications because of its strong resistance to pitting and crevice corrosion. This is mainly because of high Mo concentration (6.5%). Such steels are not only costly but are prone to form deleterious phases such as delta ferrite and sigma during welding or other heat treatment operations. Hence, an alternative technique to restrict Mo at the surface is needed. In the present work, surface alloys consisting of an austenitic stainless steel with Mo content as high as 10 to 12% have been formed on stainless steel type 304 substrates. These steels show enhanced passivity and strong resistance to pitting corrosion.

A.S. Khanna, M.B. Deshmukh, and K. Sridhar. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 511-518 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-56-0731.

Sealing

Improving Wear and Corrosion Resistance of Thermal Sprayed Coatings. Thermal sprayed coatings are used in various applications often dedicated to corrosion and wear protection. Pores and other coating imperfections reduce corrosion and wear resistance and/or necessitate higher coating thicknesses. To improve the quality of thermal sprayed coatings, various posttreatment processes can be used. Characterization of the efficiency of sealing was studied by metallographic examination and comparative investigation of the corrosion and wear behavior of the thermal sprayed coatings used with and without sealing and also by measuring the insulation resistance of the coating system. The results differ among the sealants. It is possible to remove the sealants from the coatings by mechanical treatment. Corrosion tests of the sealants demonstrate their efficiency in closing the interconnected pores and, consequently, preventing corrosion. In the experiments here described, 13% Cr steel coatings were sprayed onto substrates of 0.45% steel with 90%Ni-10%Al primer coatings.

B. Wielage, U. Hofmann, S. Steinhäuser, and G. Zimmermann. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 136-138 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0945.

Process

Spray Diffusion

Spray Diffusion: New Method for Surface Modification Combined with Thermal Spray and Heat Treatment. This paper describes postheat treatment reaction diffusion between thermal sprayed aluminum and several kinds of substrate. The alloy layer formed by the spray diffusion process depends strongly on the composition of the substrate. It was found that appropriate surface properties can be obtained by selecting substrates of suitable composition and/or by selecting appropriate interlayers between the substrate and Al top coating. First, formation of alloy phases between an Al spray coating and a pure iron or plain carbon steel substrate by spray diffusion was examined in order to obtain fundamental information. Second, an 18Cr-08Ni austenitic stainless steel substrate was selected for testing. Finally, interdiffusion of multiple-layered coatings with Ni-Cr-Mo alloys and Al onto stainless steel substrates was investigated.

S. Oki, G. Ueno, and S. Gohda. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 155-158 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0947.

Cold Gas-Dynamic Spray Method

Deposition of Nickel-Aluminum Bronze Powder by Cold Gas-Dynamic Spray Method on 2618 Al for Developing Wear-Resistant Coatings. In an emerging thermal spray process a coating is formed by exposing a metallic or dielectric substrate to a high-velocity jet of solid-phase particles, which have been accelerated by a supersonic gas jet at a temperature much lower than the melting or softening temperature of the particle material. This is known as "cold gas-dynamic spray" (CGDS) method. Using this method, 2618 Al substrates were coated with nickel-aluminum bronze powders (–100 and –400 mesh) in an effort to obtain improved wear resistance. The coatings have been examined for their microstructure, hardness, and bond strength. Triple lug shear tests performed on coated panels provided quantitative measurement of the coating/substrate interfacial shear strength. The steady-state wear rates were determined using the pin-on-rotating ring test at a pressure of 690 kPa and a sliding velocity of 9 m/s. The wear resistance of the nickel-aluminum bronze coatings is discussed in conjunction with scanning electron microscopy (SEM) examination of the wear tracks and metallography of the polished transverse cross sections. Though the coatings are not completely free from porosity, they exhibit high interfacial shear strength and wear resistance due to the low temperature, ballistic impingement of the powders in the CGDS method. The –400 mesh powder coating shows higher interfacial shear strength and wear resistance in comparison with the –100 mesh powder coating.

R.B. Bhagat, M.F. Amateau, J.C. Conway, B. Jones, A. Papyrin, and B. Stutzman. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 361-367 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0870.

Combination Thermal Spraying/Nitriding

Process Combination Thermal Spraying/Nitriding—Wear, Corrosion Resistance, and Coating Structure. Components that require both nitriding and a locally thermal sprayed coating or nitrided components that should be reworked are usually nitrided before spraying and the area to be coated is masked during nitriding or is prepared before spraying by locally removing the nitrided layer by grinding. Seen technically, advantages are to be expected if the nitriding process can be carried out after spraying. Moreover a postnitriding of thermal sprayed coatings is of interest for improving coating characteristics, mainly wear resistance. Understanding the behavior of sprayed coatings during nitriding in comparison to bulk materials will help us to understand generally the behavior of such coatings in gas atmospheres at increased temperatures. The objectives of the project are the investigation of the interaction between thermal spraying and nitriding, and the optimization of both processes to achieve improved bonding, wear, and corrosion characteristics, respectively, to get nitriding of the substrate through the coating without spalling or cracking. Furthermore the behavior and structural changes of different coatings at increased temperatures are determined. The metallographic, x-ray, wear, and corrosion results of the resulting compound coatings and parts are presented. Possible new applications are discussed. Substrates include ferrous alloy 16MnCr5 with composition Fe-1Mn-1Cr, and coatings include alumina, carbon steel and stainless steel, and nickel alloy.

M.C. Nestler, K. Herrmann, and H.-J. Spies. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 369-375 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1253.

Continuous Detonation Spray

Thick Coatings of Co-Base Alloys by CDS Process. The continuous detonation spray (CDS) is one of the most recent coating processes producing thick coatings. Examined was the correlation between the process parameters and the properties of the WC-17% Co coating deposited on an austenitic stainless steel (304) substrate. Among the parameters that were considered the most important appeared to be the oxygen and propane flow rates and their ratio, and the distance between the torch nozzle and the surface to be coated. The first affect the amount of heat generated in the process, while the second affects the interaction between the flame and the sprayed powders, determining their heating rate and the final temperature. The properties of the coatings were evaluated in terms of porosity, surface roughness, hardness, and wear resistance.

E. Ramous, M. Bianco, B. Badan, M. Magrini, and A. Zambon. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 280-291 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-58-0763.

Directed Light Fabrication (DLF)

Directed Light Fabrication of Rhenium Components. Directed light fabrication (DLF) is a direct metal deposition process that fuses gas-delivered powder, in the focal zone of a high-powered laser beam to form fully dense near-net-shaped components. The rapid fabrication is accomplished in one step without the use of molds, dies, forming, pressing, sintering, or forging equipment. Moreover, DLF is performed in a high-purity inert environment minimizing the contaminants associated with conventional processing such as oxygen and carbon pickup, lubricants, binding agents, and cooling or cleaning agents. Applications using rhenium have historically been limited in part by its high melting temperature, workability, and cost. The ability to fuse rhenium metal powder, using a DLF machine, into free-standing rods was considered and the associated parameter study was described. In addition, microstructural comparisons between DLF processed rhenium and commercial rhenium sheet product were performed. These results, combined with existing DLF technology, demonstrate a new methodology for fabricating complex near-net shapes and components using rhenium.

J.O. Milewski, G.K. Lewis, and D.J. Thoma. Cited: *Rhenium and Rhenium Alloys* (Proc. Conf.), Orlando, FL, 9-13 Feb 1997, Minerals, Metals and Materials Society/AIME, 1997, p 283-290 [in English]. ISBN 0-87339-365-1. PHOTOCOPY ORDER NUMBER: 199809-54-1278.

Electromagnetic Powder Deposition

The Diagnostic History of a New Electromagnetic Powder Deposition System. This paper describes the diagnostic tools used in the development of a new electromagnetic powder deposition system. The instrumentation, interpretation of data, and subsequent decisions regarding the direction of system development are discussed. Important system parameters, their impact on system performance, and techniques to measure them are presented. The electromagnetic powder deposition system is based on railgun technology developed by the Department of Defense. The system drives an ionized plasma sheet down the length of a railgun, reaching a final plasma velocity of 4 km/s. The high-velocity plasma, in turn, snowplows a shock compressed gas column in front of it. This gas column sweeps through a powder cloud and accelerates it by viscous drag to a final velocity of 2 km/s. Important system parameters include particle velocity, gas velocity, gas column pressure, and plasma propagation and velocity. Diagnostic tools include pressure transducers, a high-speed digital framing camera, fiber optics, and magnetic probes.

J.L. Bacon, D.G. Davis, R.J. Polizzi, R.L. Sledge, J.R. Uglum, and R.C. Zowarka. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 399-406 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1255.

Electromagnetic Powder Deposition System

A New Electromagnetic Powder Deposition System. Existing state-of-the-art thermal spray processes (HVOF, D-gun, plasma spraying) are limited to powder velocities of about 1 km/s because they rely on the thermodynamic expansion of gases. A new thermal spray process using electromagnetic forces can accelerate powder particles to a final velocity of up to 2 km/s. At this velocity, powder particles have sufficient kinetic energy to melt their own mass and an equivalent substrate mass on impact. The process is based on railgun technology developed by the Department of Defense. A railgun is filled with argon gas and a high energy electrical pulse, provided by a capacitor bank, drives the gas down the railgun to a final velocity of up to 4 km/s. This gas passes over a powder cloud and accelerates the powder through drag forces. The electrical and powder discharge frequency can be adjusted so that the deposition rate and thermal input to the substrate can be controlled. Examples: deposition of Inconel 718 on same, chromium on a nickel alloy, and titanium on titanium.

J.L. Bacon, D.G. Davis, R.J. Polizzi, R.L. Sledge, J.R. Uglum, and R.C. Zowarka. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 393-397 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0872.

HVOF

High-Velocity Oxyfuel Thermal Sprayed Coatings: Processing, Characterization, and Performance. The Department of Materials Engineering and Materials Design at Nottingham University has developed a thermal spraying capability using the high-velocity oxyfuel (HVOF) process. Over the past three years, focused research has been conducted using a gas fueled system. Recently, a state-of-the art liquid fueled system has been installed that will open up many new avenues for research. Particular strengths of the department are its capabilities for undertaking detailed microstructural characterization studies of coatings using advanced x-ray and electron optical techniques, combined with expertise in evaluating coating performance through numerous types of wear and corrosion test procedures.

D.G. McCartney. Cited: *Surf. Eng.*, Vol 14 (No. 2), 1998, p 104-106 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-58-0938.

Influence on Properties

HVOF Sprayed Alloy IN718—The Influence of Process Parameters on the Microstructure and Mechanical Properties. The construction effort and hence the costs and weight of combustion chambers for hypersonic propulsion systems are to be reduced through direct thermal spraying of the load-bearing metallic pressure jacket onto the tubular cooling system. As a semifinished product, the selected Inconel 718 alloy exhibits good mechanical properties in the cryogenic temperature range as well as under higher thermal loads and is commercially available in powder form. Aging serves to increase the strength up to the range of 1200 N/mm^2. For the sprayed IN718 version, coating thicknesses in the centimeter range, a porosity <1% and mechanical properties comparable with those of the cast version are required. The objective of the research work is to optimize spray-process control so that the resultant structural thick layers meet the design as well as the material requirements with respect to combustion-chamber technology. This necessitates elaborating the dominant microstructural parameters influencing the mechanical properties and the effect on them of the spraying process, and correlating them with the particle-condition parameters and the process parameters.

H.F. Voggenreiter, H. Huber, H. Baum, and H.-J. Spies. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 895-900 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-54-1234.

Laser-Assisted Plasma Spray

Tribological Properties of Several Coating Films Synthesized by Laser-Assisted Plasma Spray Method. This paper reports a new surface modification technique that couples high-power CO_2 laser processing with low-pressure plasma spray coating. In order to clarify the laser beam irradiation effect on tribological properties, synthesized were several metal and ceramic films using a laser and plasma hybrid spraying (LPHS) system. The tribological characterization of the coated films was evaluated by a sliding tester under lubrication with oil. Results of experiments show that it is possible to produce a high-performance tribomaterial possessing better adhesiveness and little microporosity. Analytical results by XRD suggest that a metastable state is formed by laser irradiation during the spraying process, which is closely, related to the antiwear and low friction mechanisms of LPHS films (TiNi, Triballoy and Mo/Cu).

S. Sasaki. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 1-12 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-58-0756.

Laser-Melted Plasma Coatings

Microstructures of Laser-Melted Plasma Coating on Aluminum Alloy. A plasma coating (Ni-Cr-B-Si) on the Al-Si alloy (ZL111) was melted by a 5 kW CO_2 laser. Using SEM, TEM, and x-ray diffractometer, the microstructures in the laser alloy zone were investigated. Experimental results showed that the Al-Ni intermetallic compounds (Al_3Ni, Al_3Ni_2, AlNi, and $AlNi_3$) were dominant in the laser alloy zone. Some Al-rich AlNi, Al + Al_3Ni eutectics exist in the surface of laser alloy zone, and some Ni-rich in the inner region of laser alloy zone. Some amorphous structures are in the subsurface of laser alloy zone, which makes this region have higher average hardness (YV 952). This hardness is twice as high as that of the plasma coating and 11 times higher than that of the Al substrate.

G. Liang, J. Gu, X. Tao, T. Wang, Q. Zheng, C. Li, J. Su. Cited: *Chin. J. Nonferrous Met.*, Vol 8 (No. 1), March 1998, p 28-32 [in Chinese]. ISSN 1004-0609. PHOTOCOPY ORDER NUMBER: 199809-58-0849.

Liquid-Stabilized Plasma Gun

Plasma-Generated Oxide Ceramic Components. A technique using a liquid-stabilized plasma gun is described for the manufacturing of rotation-symmetrical free-standing shapes with dimensions not attained so far. The components are generated by spraying pure ceramic powder onto a rotating metal mandrel. Surface pretreatment and temperature control of the mandrel during the process are important factors. Essential properties of the free-standing shapes are presented as well as examples of applications.

S. Schindler and W. Schultze. Cited: *Int. J. Mater. Prod. Technol.*,Vol 10 (No. 3-6), 1995, p 498-509 [in English]. ISSN 0268-1900. PHOTOCOPY ORDER NUMBER: 199807-E4-C-0279.

Sintering Behavior

Sintering Behavior of Plasma Sprayed Yttria-Stabilized Zirconia Coating. Behavior of plasma sprayed yttria-stabilized zirconia coating at high temperature was investigated. The coating shrinks owing to the sintering by the heat treatment >1300 K. Its density increases rapidly within initial 10 h and then shrinkage rate decreases. After heating for 100 h, the density becomes higher when the coating is heated at higher temperature. The density of as-sprayed coating strongly affects the density after heating. The shrinkage rate of the coating is compared with that of the powder compact to study sintering mechanism. In the initial stage, the coating shrinks faster than the powder compact, but the rate slows down asymptotically to that explained as volume diffusion. Substrate was mild steel SS400.

S. Sodeoka, T. Inoue, M. Suzuki, and K. Ueno. Cited: *J. High Temp. Soc. Jpn.*, Vol 23 (Suppl.), Nov 1997, p 235-239 [in English]. ISSN 0387-1096. PHOTOCOPY ORDER NUMBER: 199808-57-1144.

Processes

HVOF and HVAF

Comparative Study of WC-Cermet Coatings Sprayed via the HVOF and the HVAF Process. The high-velocity air-fuel (HVAF) system is a high-velocity combustion process that uses compressed air and kerosene for combustion. Two WC-cermet powders were sprayed by the HVAF and the high-velocity oxyfuel (HVOF) processes, using an AeroSpray gun and a CDS-100 gun, respectively. Several techniques, including x-ray diffraction, scanning electron microscopy, and energy dispersive spectroscopy, were used to characterize the microstructures and phase distribution of the powders and coatings. In addition, mechanical properties such as hardness and wear resistance (pin-on-disk) were investigated. A substantial amount of W_2C was found in the HVOF coatings, and a high concentration of tungsten in the binder phase, indicating that oxidation and dissolution processes change the composition and microstructure from powder to coating during spraying. This was in contrast to the HVAF coatings in which composition and microstructure were unchanged from that of the powder. Additionally, the wear resistance of the HVAF coatings was superior to that of the HVOF coatings.

L. Jacobs, M. De Bonte, and M.M. Hyland. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 213-218 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-58-0952.

HVOF and VPS of Iron-Base Alloys

HVOF and VPS Coatings Using Nanostructured Iron-Base Alloys. In thermal spraying, Fe-base alloys are often applied for relatively thick and inexpensive coatings. The main advantage of the Fe-base alloy coatings is their high ductility as compared to ceramic and hardmetal coatings. Other advantages such as high toughness, easy machinability, and satisfactory corrosion resistance are characteristic of Fe-base alloys. The wear resistance is not outstanding, but nevertheless acceptable for a large number of applications. A further improvement of the wear resistance can be achieved by reinforcing the Fe-base alloy coatings, e.g., by addition of nitrogen to the spraying powder. Materials: Ni-stabilized austenitic (4% V) alloy and martensitic (9% V) alloy stainless steel powders.

O.C. Brandt, S. Slegmann, and H.-P. Isch. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 875-876 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-58-0881.

HVOF of WC-Co Coatings

High-Velocity Oxyfuel Thermal Sprayed Coatings as Alternates to WC-12Co Coatings and Chromium Plating. Tungsten carbide-12 wt% cobalt (WC-12Co) coatings and chromium plating are used to provide wear-resistant surfaces in gas turbine applications. These treatments provide surfaces with hardnesses greater than 60 HRC. In addition, a surface finish better than 8 μin. RMS is required for optimum performance. To achieve this surface finish, diamond grinding is required. The diamond grinding step adds considerable cost to the product, and economical benefits could be achieved if more conventional grinding techniques were incorporated. A program was initiated to develop an alternative thermal spray coating, with a target hardness lower than 60 HRC, but high enough to provide the wear resistance required. Spray development was conducted on five commercially available materials using the Diamond Jet 2600 high-velocity oxyfuel process. Laboratory evaluation included coating microstructure, macro- and microhardness, bond strength, salt-spray corrosion, and cyclic compression tests. Substrate: 4340 steel; coatings evaluated: powders Diamalloy 2001, 3001, and 3006 (self-fluxing Ni-Cr alloy, cobalt alloy, and cermet, respectively), AE7439 (cemented carbide), Stellite 6 (a cobalt base alloy), and JK 112 (cemented carbide).

Z. Mutasim, V. Bankar, and C. Rimlinger. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 901-908 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1286.

Processing

Aluminum Powder

Particle Morphology and Size Distribution of Plasma Processed Aluminum Powder. Commercially available aluminum powder has been processed in a thermal plasma jet. The processed powder has been characterized by scanning electron microscopy (SEM) for particle size and morphology. Particle size distribution has been determined by laser scattering technique. Results show that, in contrast to the irregular shapes of the particles of the raw material, majority of the processed powder particles bear spherical or near-spherical morphology. The spherical morphology without sharp edges and corners and particle size distribution in a narrow range ensures free flow of the powder through the powder feed lines and better spray efficiency, making it ideal for thermal spray applications.

P.V. Ananthapadmanabhan, R. Kameswaran, K.P. Sreekljmar, N. Venkatramani, C.C. Dias, and S.C. Mishra. Cited: *Bull. Mater. Sci. (India),* Vol 19 (No. 3), June 1996, p 559-564 [in English]. ISSN 0250-4707. PHOTOCOPY ORDER NUMBER: 199808-58-0774.

DC Plasma Jet Parameters

Parameters Controlling the Generation and Properties of Plasma Sprayed Zirconia Coatings. D.C. plasma jets temperature and velocity distributions as well as the arc root fluctuations at the anode were studied for Ar-H_2 (25 vol%) plasma-forming gases. The parameters were the arc current up to 700 A, the total gas flow rate up to 100 slm, and the nozzle diameter which was varied from 6 to 10 mm. The trajectories of partially stabilized zirconia particles into the jet were studied by a two-dimensional laser imaging technique and two fast (100 ns) two-color pyrometers. The results have revealed the difficulty to inject small particles into the plasma flow since most were found to bypass the jet rather than penetrate it. The results also show the broad trajectory distribution within the jet and the influence of the arc root fluctuations on the mean particle trajectory distribution within the jet. Beside the measurements of the particle surface temperature and velocity distributions in flight, the particle flattening and the cooling of the resulting splats were studied statistically for single particles all over the spray cone. Such studies have emphasized the drastic influence of the substrates or previously deposited layers temperature on the contact between them and the splats. At 200 to 300 °C this contact is excellent (cooling rates of the order of 100 K/μs for 1 μm thick splats), and it results in a columnar growth within the splats and the layered splats of a bead (up to 500 layered splats). This growth can be observed through passes provided the bead surface temperature has not cooled too much (a few tens of K) before the next bead covers it. A/C values up to 60 MPa were achieved with PSZ coatings. The effect of impact velocity of the particles, of substrate preheating temperature, of relative movements torch to substrate, of substrate oxidation on A/C values and splat formation were also studied. Substrates: 304L and PSZ.

P. Fauchais, L. Bianchi, A.C. Léger, A. Vardelle, and M. Vardelle. Cited: *Plasma Chem. Plasma Process.,* Vol 16 (No. 1), March 1996, p 99S-125S [in English]. ISSN 0272-4324. PHOTOCOPY ORDER NUMBER: 199809-57-1353.

Flame-Assisted Ultrasonic Spray Pyrolysis

Preparation of Zirconia and Yttria-Stabilized Zirconia (YSZ) Fine Powders by Flame-Assisted Ultrasonic Spray Pyrolysis (FAUSP). Flame-assisted ultrasonic spray pyrolysis (FAUSP) has been developed to prepare ceramic powders. FAUSP comprises simple and inexpensive equipment and can be operated easily under ambient conditions to form fine particles with a narrow particle-size distribution. The technique allows the use of a wide range of precursors and has been used to prepare zirconia and yttria-stabilized zirconia powders. The powder particles are spherical and dense with a narrow particle-size distribution in the micron or submicron range, depending on the concentration of the precursor solution.

C.H. Chen, E.M. Kelder, J. Schoonman, and F.L. Yuan. Cited: *Solid State Ionics,* Vol 109 (No. 1-2), June 1998, p 119-123 [in English]. ISSN 0167-2738. PHOTOCOPY ORDER NUMBER: 199809-E4-C-0466.

Graphite Substrate

Thermal Spraying on Graphite. In order to expand the fields of application and to improve the performance of graphite (Cg), it is necessary to reduce its permeability and to limit its reactivity and especially its oxidation. It is, therefore, essential to protect it from the environment through the use of ceramic coatings. Adhesion between ceramic coatings and graphite is controlled by the mechanical stresses in the coatings and the thermodynamic work of adhesion. Different metal-graphite systems were examined that showed that the adhesion particularly depended on the thermal expansion coefficient mismatch between the two materials and on metal carbide stability. Thus, the role of the addition on the graphite surface of elements such as Cr, Mo, Al, Si, and O on the adhesion of metals or ceramics to graphite has been identified. Coatings: zirconia, alumina, yttria, molybdenum, and two nickel alloys.

N. Mesrati, H. Ajhrourh, N. Du, and D. Treheux. Cited: 15th International Thermal Spray Conference (Proc. Conf.), Nice, France, 25-29 May 1998, *Thermal Spray: Meeting the Challenges of the 21st Century,* Vol 2, ASM International, 1998, p 1507-1511 [in English]. PHOTOCOPY ORDER NUMBER: 199809-E7-C-0123.

Gun Parameters

The Influence of Gun Parameters on Coinjected Particles in the Spraying of Metal-Ceramic Functionally Graded Materials. Functionally graded materials (FGMs) having either continuously or stepwise varying compositions and/or microstructures offer solutions to a variety of engineering problems involving coatings. A classic example is thermal barrier coatings (TBCs) where large differences in the coefficient of thermal expansion between the substrate and coating can lead to failure during thermal cycling. One of the major objectives in the fabrication of FGMs is that the final structure should vary in a regular and consistent manner. Most of the deviations in the compositional gradient can be traced back to nonoptimized spray parameters, resulting in lower than anticipated deposition efficiency. Therefore, it is important that the interrelationship between the gun operating parameters and the resulting particle trajectories and temperatures, etc., are well understood. To this end, this study examines the behavior of single particle types and ensembles of dissimilar coinjected particles over a range of spray conditions. Materials: NiCrAlY metallic particle and ceramic particle zirconia.

W.D. Swank, J.R. Fincke, D.C. Haggard, S. Sampath, and W. Smith. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 451-458 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1332.

Nanocrystalline Inconel

Thermal Spraying of Nanocrystalline Inconel 718. Nanocrystalline Inconel 718 was thermal sprayed utilizing a HVOF (high-velocity oxygen fuel) thermal spraying facility. First, nanocrystalline powder was produced by high-energy ball milling of Inconel 718 (average particle size, 10 μm) under methanol and gaseous nitrogen. The ball-milled powder was then processed by HVOF to produce a coating 250 μm thick. The nanocrystalline Inconel 718 coating exhibited a significant increase in hardness (approximately 60%) over that of the Inconel 718 control sample after the thermal spray process. The grain sizes of the as-received, as-ball milled, and HVOF processed materials were 10 μm, 25 nm, and 32 nm, respectively, as determined by x-ray diffraction. A scanning electron microscopy (SEM) analysis of the powders and coating exhibited typical morphologies of as-received and as-ball-milled materials. After HVOF spraying, some of the particles appear to have gone through the processing without complete melting.

V.L. Tellkamp, A. Fabel, M.L. Lau, and E.J. Lavernia. Cited: Third International Conference on Nanostructured Materials (Proc. Conf.), Kona, HI, 8-12 July 1996, *Nanostructured Mater.,* Vol 9 (No. 1-8), 1997, p 489-492 [in English]. ISSN 0965-9773. PHOTOCOPY ORDER NUMBER: 199807-54-1087.

Nanocrystalline Structure via D-Gun

WC-Co Detonation Coatings Having a Hybrid Amorphous-Nanocrystalline Structure Display Improved Properties. X-ray diffraction and transmission electron microscopy studies and measurements of hardness and void content were carried out for WC-20% Co coatings produced by detonation flame spraying at various oxygen/acetylene ratios in the detonating gas mixture. It was demonstrated that successive transition from (WC + Co) to ($W_2C + Co_3W_3C$) to ($W + Co_7W_6$) occurs as the oxygen content in the mixture is increased, and that amorphous-nanocrystalline structures form in the coating. Two types of these hybrid structures were revealed, one including an amorphous metallic matrix containing precipitates of intermetallic nanocrystals, the other having an amorphous oxide matrix and nanocrystalline precipitates of Co_3O_4 and WO_3. The hybrid structures were shown to improve coating density and hardness. Substrate: carbon steel.

T. Shmyreva and V. Britun. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 925-928 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1288.

Substrate Preheating Condition

Optimization of Substrate Preheating Condition on Adhesive Strength of Thermal Sprayed Coating. Several kinds of metallic powder materials were HVOF sprayed on flat substrate, and dependence of splat pattern of each material on substrate temperature was fundamentally investigated. Splats of almost all materials observed, for example Ni and NiAl, changed to the pattern without splash from the one with splash while increasing the substrate temperature. Adhesive strength of the coatings produced by spraying of these materials on blasted substrate was also evaluated. From the fact that the dependent tendency of both splat pattern and adhesive strength on substrate temperature increase corresponded quite well, it was confirmed that optimum conditions of substrate preheating could be estimated by investigating the changing tendency of the splat patterns of powder materials on flat substrate. Substrate material was SUS304 stainless steel.

M. Fukumoto, K. Oku, Y. Tanaka, and T. Yokoyama. Cited: *J. High Temp. Soc. Jpn.,* Vol 23 (Suppl.), Nov 1997, p 240-246 [in Japanese]. ISSN 0387-1096. PHOTOCOPY ORDER NUMBER: 199808-58-0816.

Surface Roughness

Surface Roughness of Thermal Spray Coatings Made with Off-Normal Spray Angles. The formation of a thermal spray coating using an off-normal direction angle for the spray has been analyzed to identify the causes of the large surface roughness of the coating. In the analysis, the string method was used for modeling the formation of the coating. The method uses a string of equally spaced node points to define the shape of the coating surface and to track the change in this shape as the thermal spray mass is deposited. The method allows for the calculation of arbitrary shapes for the coating surface that may be very complex. The model simulates the stochastic deposition of a large number of thermal spray droplets. Experiments were carried out to obtain the data used in the model for the mass flux distribution on the target surface. The data show that when the thermal spray mass impinges on the target surface a large fraction of it, called overspray, splashes off the target and is redeposited with a small direction angle. This component of the deposited mass results in a large coating roughness. Application is to HVOF spraying of wear-resistant coatings onto the surfaces of aluminum engine cylinder bores.

M.P. Kanouff, R.A. Neiser, Jr., and T.J. Roemer. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 219-228 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-57-1391.

Suspension Plasma Spraying

Suspension Plasma Spraying for Coating and Powder Preparation: The Case of Hydroxyapatite. Suspension plasma spraying (SPS) is a single-step, powderless process dedicated to the preparation of thick coatings or for powder production using a radio frequency inductively coupled thermal plasma technique. SPS is based on a liquid suspension of very fine (<10 μm) or even ultrafine (<100 nm) powders, axially fed into the r.f. plasma flame through an atomization probe. Results of characterization of the HA coatings and atomized powders are reported, involving the use of a HA colloidal suspension. Process variables are studied as a function of phases, structure, and crystallinity of the coating. The applied plasma power was kept relatively low, in the range of 35 to 40 kW, while the chamber pressure was varied between 20 kPa and values close to atmospheric pressure, the plasma gas being a mixture of Ar/H_2 and Ar/O_2. Coatings produced by SPS at high deposition (on 316L) rates (>150 μm/min) are well crystallized and show crystallographic textures according to the (002) Miller's planes. Under SPS conditions HA is partially decomposed into the high-temperature equilibrium phases of tricalcium phosphate and lime. SPS HA particulates are quite dense and well spheroidized, with an average diameter of 18 μm.

E. Bouyer, M.I. Boulos, and F. Gitzhofer. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 292-305 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-57-1011.

Suspension Plasma Spraying (SPS) of Cobalt Spinel. Fine (median size 6 and 0.3 μm) cobalt spinel (Co_3O_4) powders were processed suspended in a suitable liquid phase. Suspensions exceeding 50 wt% solid phase content were successfully injected into an inductively coupled plasma. Spheroidized powders with large particle size (−80+30 μm) were prepared, and cobalt oxide coatings were produced by this novel RF-SPS method. The microstructural features of the coatings can be controlled by parameter optimization similarly to plasma spraying of dry powders. Numerous variations of the physical and chemical conditions of the process were performed in an attempt to overcome the main disadvantage of the process, i.e. the decomposition of the spinel phase to CoO. So far, the spinel phase could be reestablished only by a posttreatment of the deposited coatings with atomic oxygen in the r.f. plasma. Cobalt oxide powders were processed and collected, then sprayed onto steel and nickel substrates.

G. Schiller, M. Müller, R.B. Helmann, M.I. Boulos, and F. Gitzhofer. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 343-347 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1330.

Properties

Cavitation Resistance

Cavitation Resistance of Thermal Spray Coatings. Cavitation and erosion damage to hydroelectric turbines and pumps can be a major problem. The effectiveness of thermal sprayed cavitation-erosion resistant coatings for hydroelectric turbine and pumps was evaluated. The coatings evaluated were applied using high-velocity oxyfuel (HVOF) and plasma spray systems. Hardfacing cobalt-base alloys were evaluated on coupons in the laboratory. Testing was performed using a cavitating jet-erosion apparatus utilizing an operating pressure of 27.6 MPa. The results were compared to welded 308 stainless steel. Cavitation-resistant austenitic stainless steel weld alloys were also evaluated. The results showed that the cavitation rate of the austenitic stainless steel weld alloys were as low as one-third of the rate of the 308 stainless steel. The cavitation rate of the thermally sprayed hardfacing coatings were more than three times higher than the rate of the 308 stainless steel. CERHAB glass enamel coatings containing 7 wt% wollastonite fibers were successful applied by using two combustion spray processes. The applied CERHAB coatings were successfully annealed using field portable heaters and may have application as a seal coat for thermal spray coatings applied in the field.

A. Kumar, P. March, J. Boy, and R. Zatorski. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 83-90 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1230.

Corrosion of WC-Co

Effect of Corrosive Environment on the Delamination Strength of WC-Co Coating Deposited by High-Velocity Flame Spraying. WC-Co cermet was coated on the smooth tensile specimens of annealed tool steel (JIS:SKD5) by high-velocity flame spraying. For some specimens, the pores in the coating were sealed by Zn plating. After the specimens were immersed into tap water or 3% NaCl water, the tensile tests, where the load was applied parallel to the coating, were carried out in air to examine the change of interfacial energy by corrosive environments. With increasing tensile load, the coating is divided by several cracks and the interval of cracks is decreased by the repeating process of division, and the delamination of coating occurs after the crack division has finished. The interfacial energy decreases with an increase in immersion time, and the degree of decrease is larger in the specimen immersed in 3% NaCl water than in tap water. The interfacial energy of the Zn-plated specimen is almost the same as the unimmersed specimen up to the immersion time of about 1000 ks in 3% NaCl water, but it quickly decreases to reach the same value as the unplated specimen when the immersion time exceeds 1500 ks. The interfacial energy is almost inversely proportional to the crack interval.

K. Nakasa, F. Egawa, M. Kato, and D. Zhang. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 47 (No. 2), Feb 1998, p 204-207 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199808-57-1046.

Creep Failure of TBC Systems

Creep Failure Analysis of Advanced Plasma Spray Coating Systems in Hot Corrosive Environment. Creep rupture properties and failure mechanism in hot corrosive environment were investigated of the plasma spray coated Ni-base superalloy systems (Inconel 751) with different spraying parameters, including thermal barrier coating system with ceramic top coat. Characteristic modes of the coating failure were revealed in different coating systems, with the most significant property degradation in the air plasma sprayed (APS) CoCrAlY coating system, while minimal degradation occurred in the thermal barrier coating (TBC) system in spite of inducing the extremely localized damage that is associated with the open defect in the ceramic top coat. Possible failure mechanism for each coating system was discussed mainly from the viewpoint of stress-corrosion interaction.

M. Yoshiba and K. Wada. Cited: *Creep and Fatigue: Design and Life Assessment at High Temperature* (Proc. Conf.), 15-17 April 1996, Mechanical Engineering Publications Ltd., 1996, p 51-59 [in English]. ISBN 0-85298-990-3. PHOTOCOPY ORDER NUMBER: 199808-31-3809.

Erosion Resistance

Erosion Resistance of Arc Sprayed Coatings to Iron Ore at 25 and 330 °C. Iron ore pellets are sintered and reduced in continuous large industrial oil-fired furnaces. From the furnace, large volumes of hot gas are sucked by powerful fans. Being exposed to gas-borne iron particles and temperatures ranging between 125 and 328 °C, fan components are rapidly deteriorated. Extensive part repair or replacement are required for maintaining a profitable operation. The arc spraying technique has been suggested for repair provided it could produce erosion-resistant coatings. Commercial wires were arc sprayed using various spray parameters to produce thick coatings. Arc sprayed coatings and reference specimens were erosion tested at 25 and 330 °C and impact angles of 25 and 90° in a laboratory gas-blast erosion rig. This device was designed to impact materials with coarse (32 to 300 μm) iron ore particles at a speed of 100 m/s. The volume loss was accurately measured with a laser profilometer. Few arc sprayed coatings exhibited erosion resistance comparable with structural steel at low impact angles. Erosion of arc sprayed coatings and reference specimens dramatically increases at 330 °C for both 25 and 90° impact angles. Erosion-enhanced oxidation was found responsible for the increase in wastage above room temperature. Though arc spraying can be appropriate for on-site repair, the development of erosion-resistant coatings is required for intermediate temperatures.

S. Dallaire and H. Levert. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 65-72 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1228.

Erosion-Corrosion Behavior of WC

Effect of Metallic-Matrix Composition on the Erosion-Corrosion Behavior of WC Coatings. In corrosive media the wear resistance of ceramic-metallic coatings is dependent on the corrosion resistance of the metal matrix. Other factors that will affect the coating deterioration are the corrosivity of the medium and any galvanic interaction from the surrounding material. This paper presents results from a study where different types of WC(Co/Cr/Mo/Ni) powders have been sprayed by HVOF, Diamond Jet 2600 Hybrid equipment. The properties of the sprayed coatings have been verified by metallographic studies and by erosion-corrosion testing both under corrosive and noncorrosive conditions. The results clearly demonstrate the importance of having a metal matrix at least as corrosion resistant as the surrounding materials. When wear exposed components in pipe systems, pumps, or valves are coated with a WC-type coating, the corrosion resistance of the metal matrix should be compatible to the material of the rest of the system. This is especially important when the surrounding materials are corrosion-resistant alloys such as stainless steels, where the coatings otherwise will act as an anode.

T. Rogne, J. Berget, and T. Solem. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 113-119 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1233.

Fatigue Life of WC

Fatigue Life in Bending and Coatings Residual Stress in Tungsten Carbide Thermal Spray Coatings. Tungsten carbide (WC) thermal spray coatings are being used for wear protection on selected components of aircraft, such as aircraft flap tracks and fan and compressor blade midspan dampers. However, a larger use of tungsten carbide coatings is being considered for other commercial aircraft applications where it would be used as a replacement for chrome plating. For instance, WC coatings are currently being tested on aircraft landing gear parts. One factor that affects the suitability of WC coatings for these applications is the fatigue life of the coated part. Coatings, whether chrome plating or thermal spray coating, can reduce the fatigue life of the part compared to an uncoated part. This study compares the fatigue life of uncoated 6061 aluminum specimens to the fatigue life of WC thermal sprayed coated 6061 aluminum specimens. The relation between the residual stress level in the coating and the fatigue life of the specimens is also investigated. Fatigue tests were run on cantilever flat beam specimens that were coated on one side. Specimens were cycled in bending so that the coatings experienced tensile fatigue stresses. Residual stress levels for each type of coating were determined using the modified layer removal method on specimens processed along with the cantilever flat beam specimens. Test results show that the fatigue life of the WC coated specimens is directly related to the level of compressive residual stress in the coating.

R.T.R. McGrann, B.E. Bodger, W.A. Emery, D.A. Somerville, D.J. Greving, E.F. Rybicki, and J.R. Shadley. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 737-742 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-31-4392.

Fatigue Behavior and Deformation of Aluminum and Steel HVOF Sprayed with WC-Co Coatings. The effect of WC-Co coating on the high-cycle fatigue (HCF) behavior of SAE 12L14 steel and 2024-T4 aluminum was investigated. The fatigue tests were performed at room temperature and 370 °C. The fatigue life distributions of specimens in the polished, grit-blasted, peened, and coated conditions are presented as a function of the probability of failure. HVOF sprayed WC-Co coating has influenced the fatigue life of aluminum and steel. Factors contributing to this influence, which include grit blasting, elastic modulus, and residual stress, are discussed. A three-dimensional finite-element model (FEM) of the coated specimen was used to calculate the stress distribution across the coating and the substrate. The results of the analytical model are in good agreement with fatigue lives observed experimentally. Substrate materials: 12L14 low-carbon steel and aluminum alloy 2024-T4.

A. Ibrahim and C.C. Berndt. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 731-736 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-31-4391.

Fatigue Strengths of WC Cermet

Evaluation of Fatigue Strengths of WC Cermet and 13Cr Steel Sprayed Materials. Rotating bending fatigue tests have been conducted at a room temperature in laboratory air using specimens of medium-carbon steel (S45C), low-alloy steel (SCM435), and titanium alloy (Ti-6Al-4V) with high-velocity oxyfuel (HVOF) sprayed coating of a cermet (WC-12%Co) and S45C with wire flame spraying (WFS) sprayed coating of a 13Cr steel (SUS420J2), and the fatigue strength and fracture mechanisms were studied. The fatigue strength evaluated by nominal stress was strongly influenced by substrate materials and the thickness of sprayed coatings. Detailed observation of crack initiation on the coating surface and fracture surface revealed that in the WC cermet-sprayed materials, small defects initiated at WC grain boundaries coalesced and then the crack grew rapidly in the coating, while in the 13Cr steel-sprayed material, many microcracks were initiated from defects on the coating and coalesced to be a main crack. Cracks were initiated in the substrate due to the stress concentration of the crack in the coating, which was modeled by finite element analysis. The fatigue strength of the sprayed materials was dominated by that of the sprayed coating. Thus the fatigue strength could be evaluated uniquely in terms of the true stress on the coating surface.

T. Ogawa, T. Ejima, K. Tokaji, Y. Harada, and Y. Kobayashi. Cited: *Mater. Sci. Res. Int.*, Vol 4 (No. 1), March 1998, p 12-18 [in English]. ISSN 1341-1683. PHOTOCOPY ORDER NUMBER: 199808-57-1059.

Residual Stresses

In Situ Measurements of Residual Stress within Coatings Plasma Sprayed under Industrial Conditions. In order to determine residual stresses in industrial plasma sprayed coatings, a rather simple apparatus, which monitors the curvature of a beam substrate during the deposition process, has been developed. The experimental setup consists of a water-cooled rotating cylinder, holding an initially plane substrate, whose curvature is continuously measured using a contacting displacement sensor disposed into the cylinder. The combination of the plasma gun translation and the cylinder rotation allows it to reach industrial spraying velocities. Liquid argon cryogenic system is used to control the substrate temperature from about 50 °C to more than 300 °C independently from the process velocity. A typical recording is analyzed thoroughly, and a theoretical approach to residual stress calculation discussed. This method is applied to partially stabilized zirconia coatings performed onto stainless steel substrates for spraying temperatures between 80 and 210 °C. Also studied: zirconia splats on polished plasma sprayed PSZ substrate.

L. Bianchi, N. Baradel, F. Blein, and M. Jeandin. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 831-838 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1346.

Scratch Test

A Novel Ball-on-Inclined Plane Scratch Test for the Evaluation of Ceramic Coatings. A ball-on-inclined plane scratch test method has been developed to determine the materials responses to stresses on thermally sprayed ceramic coatings. Material properties such as the critical damage load, damage patterns of the scratched surface and subsurface crack patterns are evaluated. Results show that when the applied load is below the critical value, there is no subsurface damage, but plastic deformation occurs locally on the surface. Beyond the critical load, high-velocity oxygen flame (HVOF) sprayed Al_2O_3 coatings exhibit severe plastic deformation on the scratched surface and subsurface cracks propagating in the directions parallel to and at an angle to the sliding surface. In the case of a plasma-sprayed ZrO_2 coating, beyond the critical load, cracks initiate at the surface and propagate into the subsurface at an angle about 30° to the sliding surface. (Article notes use of ceramic coatings on engine components, aircraft, as thermal barriers and wear-resistant coatings.)

Y. Wang and S.M. Hsu. Cited: *Advances in Coatings Technologies for Surface Engineering* (Proc. Conf.), Orlando, FL, 9-13 Feb 1997, Minerals, Metals and Materials Society/AIME, 1997, p 213-224 [in English]. ISBN 0-87339-371-6. PHOTOCOPY ORDER NUMBER: 199807-57-0917.

Slurry Erosion of Arc Sprayed Coatings

Slurry Erosion of Arc Sprayed Metal and Composite Coatings. Two grades of stainless steel, 316 and 440-C, in the form of solid wire, and two cored wires, Duocor and 95-MXC, were used. Coatings were made using the Miller BP-400 and TAFA 9000 systems. Slurry jet erosion tests were conducted using a 10% w/w alumina particle/water slurry. Two alumina particle sizes, 320 and 80 grit (nominal grain diameters 35 μm and 200 μm, respectively) were used at impinging angles of 90 and 20°. The nominal impact velocity of the slurry was 15 m/s and the nozzle-specimen distance 100 mm. The volume loss of material under various slurry erosion conditions was related to the coating properties and microstructure. Results indicate that the wear behavior of arc sprayed materials is dependent on the erodent particle size; for large erodent particle size, the relative erosion is almost independent of the impinging angle, while for the smaller particle size the angle effect is the dominant factor. This behavior can be related to the lamella structure and the relative toughness of the different phases of the coatings.

B. Arsenault, H. Hawthorne, and J.-G. Legoux. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 107-112 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1232.

Slurry Erosion of HVOF Coatings

Slurry Erosion of High-Velocity Oxyfuel Thermal Sprayed Coatings. Improvement of the high-velocity oxyfuel deposition (HVOF) process in the last decade has enhanced the microstructure of coatings in order to better perform against wear and corrosion. Indeed cermet and metal HVOF coatings are reliable and have excellent performance under slurry erosion and provide therefore an alternative to the use of high-priced material. This paper presents the results of a study undertaken within the core research program of the National Research Council of Canada technology group in surface engineering, "SURFTEC," in which the performance of ten HVOF erosion-resistant coatings was evaluated. Ten different types of HVOF coatings were studied including: six grades of WC with either Co or a Ni-base matrix, one grade of Cr_3C_2 in a Ni-Cr matrix, and three grade of metallic alloy: Ni alloy, Co alloy, and a SS 316-L. The performance of coatings was evaluated with respect to: the volume ratio and composition of metallic binder in carbide coatings, type of carbide, coating microstructure, impinging angle, and the size of the erodent particles. All coatings were produced using the HVOF JP-5000 system controlled by the Hawcs-II controller. Slurry erosion tests were conducted with a jet impingement rig with a 10% w/w alumina particle/water slurry. The volume loss of material under various slurry erosion conditions was related to the coating properties and microstructure. Results indicate that the behavior of HVOF sprayed materials is dependent on the erodent particle size, to the erosion impinging angle to some extent and to the corrosion resistance of the cermet matrix. Substrate: carbon steel.

B. Arsenault, H. Hawthorne, and J.-G. Legoux. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 97-106 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1231.

Solid Particle Erosion

Damage Mechanisms in Solid Particle Erosion of FeAl-Al_2O_3 Thermal Spray Coatings. The effect of microstructure and splat cohesion on the erosion rate and subsequent damage mechanisms of FeAl-Al_2O_3 plasma and high-velocity oxyfuel (HVOF) coatings was studied. The Al_2O_3 content in the cermet presprayed powder was varied from 0 to 80%. Microstructural evaluation revealed a good correlation between the Al_2O_3 content of the presprayed powders and the final as-deposited plasma coatings. In addition, increased porosity was measured as the Al_2O_3 content of the coatings increased. It was found that plasma sprayed coatings tend to fail via splat delamination due to poor cohesion and high porosity, providing accelerated weight loss compared to HVOF sprayed materials. The addition of Al_2O_3 to the plasma FeAl coatings increased their erosion rates. Examination of the eroded surfaces revealed cracking of the Al_2O_3, which led to undercutting of the FeAl matrix and hence the higher erosion rates. In contrast the HVOF coatings tended to fail by gouging of the individual splats, which led to lower overall erosion rates. Substrate: mild steel.

B. Schorr, D. Sordelet, A.R. Marder. Cited: *Advances in Coatings Technologies for Surface Engineering* (Proc. Conf.), Orlando, FL, 9-13 Feb 1997, Minerals, Metals and Materials Society/AIME, 1997, p 225-238 [in English]. ISBN 0-87339-371-6. PHOTOCOPY ORDER NUMBER: 199807-57-0945.

Standards for Surface Technology

Important Norms and Technical Rules in the Area of Surface Technology. This paper is simply a listing of the norms covering surface technology and considered important by the author. The listing is in three columns: (1) the number of the norm or regulation, (2) the date of issue, and (3) the title and brief description. The two categories of uncoated and coated surfaces are given, subdivided into DIN, DIN-EN, DIN-ISO, ASTM, and ISO. Covered among the uncoated surface treatment are electrolytic coatings and cleaning solvents and procedures, as are metal preparation for thermal spraying of powders as well as galvanizing. Testing procedures, both destructive and nondestructive, are covered also. Mechanical bonding elements, galvanizing and anodizing as well as painting cover the coated materials. Included here are norms for gold-plated jewelry. Parts to be used in aerospace are given separate norms.

T.W. Jelinek. Cited: *Galvanotechnik*, Vol 88 (No. 7), July 1997, p 2236-2238 [in German]. ISSN 0016-4232. PHOTOCOPY ORDER NUMBER: 199808-57-1008.

Temperature-Variant Hardness

Temperature-Variant Hardness Behavior of Plasma Sprayed Ceramic Coatings. The temperature-variant hardness response of a few plasma sprayed duplex ceramic coatings (on cast iron) is reported. Coating materials investigated are 99% alumina and partially stabilized zirconia with yttria and MgO. The Vickers microhardness of all four coatings studied decreases as the temperature increases from room temperature to 800 °C. However, while the hardness of ZrO_2-8%Y_2O_3 coatings does not recover to room temperature hardness on cooling, the hardness of ZrO_2-24%MgO and alumina coatings is almost completely recovered to their room temperature hardness on cooling. This different hardness response that shows the reversible or the irreversible changes during the temperature-variant indentation experiments can be explained in terms of the relaxation of residual compressive stress during the first heating cycle and thus coating microstructures. An activation energy approach for the temperature dependence of hardness is also discussed.

H.-J. Kim and Y.-G. Kweon. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 359-368 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-57-1013.

Thermal Residual Stresses

Investigation of Thermal Residual Stresses in a Layered 2024 Al/SiC Composite Using Finite Element Method and X-Ray Diffraction. A SiC particulate-reinforced 2024 Al matrix composite was fabricated using a spray atomization and codeposition process to produce a layered macrostructure. The thermal residual stresses that develop in the fabricated layered 2024 Al/SiC composite during cooling from the codeposition temperature to ambient temperature were studied using thermoelastoplastic finite element analysis. The numerically calculated residual stresses were compared with those obtained experimentally from x-ray diffraction analysis. Based on the present study, it was found that the residual stress distribution is very distinct for the aluminum and the SiC rich layers. The radial stress was tensile in the aluminum layers and compressive in the SiC-rich layers. The axial stress was found to be compressive in the vicinity of the center region of the spray deposited material and to have mostly a continuous distribution in the aluminum and the SiC rich layers. The magnitude of the axial stress was noted to decrease with increasing deposition thickness from the bottom. In addition, the spray deposited material exhibited the highest von Mises' stress around the outer edge of the deposited material. It was also found that the numerically calculated values from finite element method are in good agreement with those obtained from x-ray diffraction.

S. Ho and E.J. Lavernia. Cited: *Processing and Fabrication of Advanced Materials V* (Proc. Conf.), Cincinnati, OH, 6-10 Oct 1996, Minerals, Metals and Materials Society/AIME, 1996, p 265-277 [in English]. ISBN 0-87339-349-X. PHOTOCOPY ORDER NUMBER: 199807-62-1318.

Wear Resistance

The Powder High-Temperature Materials on the Base of Nickel Alloys for Hardening the Parts of Hot Zones in the Metallurgical Units. A problem of wear resistance rise of the rapidly wearing metallurgical unit parts, operating under severe conditions of affecting heating, stresses, aggressive media, and another unfavorable factors, is considered. Creation of a protective layer of nickel-base materials, containing up to 50 mass% Co, Cr, Mo, W, Ti, Nb, Al, and up to 10 mass% refractory compounds (oxides, carbides, nitrides, carbonitrides), is one of possible methods for solving this problem. The protective coatings are prepared by two surface hardening methods, namely plasma surfacing and plasma spraying. It is shown that the use of heat-resistant powder materials as the protective coatings at carbon steel parts of machines for continuous casting increases their service life by four times.

M.A. Surikova. Cited: *Metalloved. Term. Obrab. Met.*, Vol 1, Jan 1998, p 34-38 [in Russian]. ISSN 0026-0819. PHOTOCOPY ORDER NUMBER: 199809-54-1239.

Al-Rich Hard Coatings on Al Alloy by Low-Pressure Plasma Spraying. In order to improve the wear resistance of an Al alloy surface, a low-pressure plasma spray coating has been carried out on an A6063 Al alloy substrate plate by using rapidly solidified Al alloy powders of Al-50 wt% Si, Al-17 wt% Si-15 wt% Fe, and Al-50 wt% Fe alloys. A dense layer with high hardness of 200 to 240 HV and 450 to 530 HV was obtained at Al-50Si and Al-17Si-15Fe powders, respectively. The abrasive wear resistance of these coatings was improved by two and three times compared to that of A6063. Much higher hardness, 700 to 850 HV in the coatings, was obtained with Al-50Fe powder, but porosity and cracking occurred in the layer. These defects prevented an improvement of the abrasive wear resistance of the coatings compared to those of Al-50Si and Al-17Si-15Fe powders.

K. Nakata and M. Ushiroda. Cited: *Surface Modification Technologies X* (Proc. Conf.), Singapore, 2-4 Sept 1997, Book. No. 668, Institute of Materials, 1997, p 334-348 [in English]. ISBN 1-86125-022-3. PHOTOCOPY ORDER NUMBER: 199808-58-0764.

Review

Thermal Spray Industry

Thermal Spray: New Technology Is Its Lifeblood. The thermal spray industry is reviewed from market and technology perspectives. The high-velocity oxygen-fuel (HVOF) process is gaining in applications, and manufacturers of thermal spray equipment have competed to reduce operating costs and efficiencies of the process. Sulzer Metco Inc. of Westbury, NY, Praxair Surface Technologies, Inc. of Indianapolis, IN, and Eutectic Corp. of Charlotte, NC, are the three main vendors of thermal spray equipment and consumables. Worldwide, the thermal spray industry has annual sales of $4 to 5 billion, with the United States representing about $500 million per year. Independent research on thermal spray technology is conducted at the Center for Thermal Spray Research (CTSR) at the State University of New York at Stony Brook. CTSR is a consortium of scientific institutions that works with a wide range of companies. Technology is the key to expanding markets, and thermal spray technology is being applied in the oil industry as cathodic protection of weld joints used to connect offshore pipelines, sucker rod couplines, and wear-resistant coatings in oilfield equipment. In Europe, Sulzer and Sprayform Developments Ltd. have been pioneering the use of thermal spray for rapid prototyping. Metal-cored tubular wires are making it possible to extend the range of thermal spray coating metallurgy. Reduction of operating expenses is the key force behind HVOF growth. Recently, Eutectic + Castolin has introduced the first system to make use of high-velocity, impact fusion technology (HVIF). In transportation, plasma spraying is used to coat piston rings, cylinder bores, and exhaust gas sensors, while a major potential application still in development involves the plasma and arc spraying of the surface of a cast aluminum engine block.

R. Irving. Cited: *Weld. J.*, Vol 77 (No. 3), March 1998, p 38-45 [in English]. ISSN 0043-2296. PHOTOCOPY ORDER NUMBER: 199809-57-1355.

Systems

Spray Booth Design

The Ultimate Spray Booth. Reproducibility is a current challenge for the thermal spray industry. Reproducibility-associated problems represent a large cost every year not only in terms of rejections and rework, but also in costs for destructive testing and decreased production flow. Thermal spray coatings are moving in the direction from being considered only as a "band-aid" to becoming a design element. One of the prerequisites for such a development is an increase in reproducibility for thermal spray coatings. The purpose of this paper is to outline a vision aiming in the direction of a future "ultimate spray booth," where thermal spraying is as reproducible and reliable as machining, grinding, or other production processes. A way to increase reproducibility and reliability in the future spray shop involves utilizing major parts of IT technology. This also includes active cooperation design-production in the prespray process. This paper will deal with areas such as: operation drawings and lists through multimedia techniques, education programs for operators and designers through multimedia techniques, CAD/CAM, off-line programming and simulation, on-line diagnostics of flame (particle diagnostics) and coating (temperature and acoustic emission measurements), on-line statistical process control, and knowledge-based system techniques.

L. Pejryd, N. Hanner, and J. Wigren. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 445-450 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1258.

Testing

Fatigue Testing on WC-Co

Damage in Thermal Sprayed WC-Co Coatings by Repeated Load. Two types of WC-12 wt% Co powders, each manufactured by a different process, were thermally sprayed on a medium carbon steel by HVOF, and repeated load tests (rolling contact fatigue test and high cycles fatigue test) were carried out. The surface damages for the two types of coatings were investigated. Coating damages depend on the types of powders. It has been found that in rolling contact fatigue, there are coatings in which damage is characterized by delamination, and by a mixture of delamination and cracks. In high-cycle fatigue, there are coatings in which damage is characterized by netlike fatigue cracks, and by linear fatigue cracks.

T. Tajiri, N. Sakoda, S. Watanabe, and S. Yamamoto. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 743-750 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1273.

Fractal Analysis of Roughness

Scale-Sensitive Fractal Analysis for Understanding the Influence of Substrate Roughness in Thermal Spraying. It is widely recognized that substrate surface roughness, or topography, plays an important role in droplet-substrate interaction and the adhesion of sprayed coatings. A key difficulty in understanding the role that topography plays during droplet impact, wetting, and solidification has been the availability of methods for appropriate characterization of the topography. The complex nature of the substrate topographies cannot be adequately characterized by conventional methods such as R_a. In this work, scale-sensitive fractal analyses are considered for advancing the understanding of roughness of grit-blasted surfaces in thermal spray applications. Area-scale analysis is performed on three-dimensional data sets acquired from different grit-blasted substrates. From fractal analysis it is known that the apparent area of a rough surface increases as the scale of observation decreases. The area-scale relations are used to guide experimental design for topographical data acquisition and analysis and to better understand the influence of grit blasting on substrates for thermal spray. The potential of these scale-sensitive analysis techniques to fulfill the above bases for supporting statistical correlations and clear physical interpretations is discussed. The objective of this paper is to investigate a scale-sensitive system for supporting experimental design for studying the topographic aspects of substrate preparation in thermal spray. Substrates: steels St 37-2, X5CrNi1810, 42CrMo4, and 100Cr6.

S.D. Slegmann and C.A. Brown. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18

Sept 1997, ASM International, 1998, p 665-670 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-57-1268.

Mechanical Property Standards

The Need for Standardization in Evaluating the Effect of Coatings on Substrate Mechanical Properties. As the application of thermal spray coatings is expanded to performance-critical applications, the need to ascertain how the coating affects mechanical properties of the substrate is very important. This is especially true for properties such as fatigue. A standard method for approaching this type of evaluation is necessary. Items such as test bar configuration, application of the coating, baseline comparison methods, and many other factors must be defined to formulate a consistent and repeatable system for evaluation.

J.P. Sauer. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 949-953 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-22-0757.

Metallographic Standards

The Use of Metallographic Standards in Calibration of the Polishing Process. The metallographic process for evaluating thermally sprayed coatings is sometimes viewed as a variable process in the scope of coating evaluation. There is always a question as to whether the failure of a coating is polishing related or an actual change in the spray production process. The use of metallographic standards similar to hardness calibration can be implemented to provide assurance of a repeatable metallographic polishing. Development and use of the standards are discussed and examples given of the standards principle.

J.P. Sauer. Cited: *Thermal Spray: A United Forum for Scientific and Technological Advances* (Proc. Conf.), Indianapolis, IN, 15-18 Sept 1997, ASM International, 1998, p 955-957 [in English]. ISBN 0-87170-618-0. PHOTOCOPY ORDER NUMBER: 199809-22-0758.

Microstructural Index

Microstructural Index to Quantify Thermal Spray Deposit Microstructures Using Image Analysis. The basic metallographic analysis leads to qualitative interpretation of the structural characteristics of a microstructure, for example the presence of phases, and the description of singularities such as inclusions. On the contrary, microstructural characterization that implements image analysis leads to a quantified analysis of structural characteristics. A method is described to assess thermal spray deposit microstructures using image analysis by means of a metallographic index. This index is based on the determination of several stereological and morphological parameters by primary reference to the size-shape distributions of the features, the fractal dimension of the deposit upper surface, and the Euclidean distance map of the bodies of interest. This work employs quantitative metallography on a much wider scale to provide better quality control of deposit microstructures. Experimental work was done using plasma sprayed Ti and Cu coatings.

G. Montavon, C. Coddet, S.-H. Leigh, and C.C. Berndt. Cited: *J. Therm. Spray Technol.*, Vol 7 (No. 2), June 1998, p 229-241 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199809-21-0300.

Thermal Shock

Effect of Local Thermal Shock Load on Plasma Sprayed Thermal Barrier Coatings. The number of cycles to failure of plasma sprayed thermal barrier coatings (TBCs) during thermal shock experiments gives an indication of their performance in a real environment. The authors have subjected 0.3 mm thick ZrO_2-$8Y_2O_3$ TBCs to a local thermal shock load with maximum surface temperature of 1300 and 1400 °C. The diameter of the flame was ~15 mm. During cycling, the temperature drop through the specimen thickness and the temperature profile of the back of the substrate were measured. The number of cycles to failure and the type of failure appeared to be dependent on the maximum surface temperature of the coating. After failure, a phase analysis was performed. In addition, the residual stress profile of the top coat was determined after 200 cycles with T_{surf} = 1300 °C. It is concluded that at 1300 °C bond coat oxidation is the main cause of failure, while at 1400 °C top coat degradation leads to failure. Substrates were Hastelloy X.

M.F.J. Koolloos, J.M. Houben, and G.G. van Liempd. Cited: *Surf. Eng., Vol 14 (No. 2), 1998, p 144-148 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199809-57-1384.*

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