Selected Abstracts of Thermal Spray Literature

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Applications

Bioactive Glasses

Thermal Spraying of Bioactive Glass Ceramics. This paper reveals the aspects for the formation of biocompatible coatings on implants such as artificial hips. Various techniques to improve bonding between the natural bone and the implant to extend lifetime have been developed in the past. Recent and successful processes to fabricate functional biocompatible coatings are atmospherical plasma spraying (APS) and high velocity oxygen fuel spraying (HVOF). Beneath hydroxyapatite, glass ceramics are other suitable examples for bioactive materials. In this case, the used glass ceramic consists of SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, F^- and P_2O_5. During fabrication of the powder, different apatite-phases (hydroxyapatite and fluorapatite) and other phases like phlogopit are formed, which improve the bioactive and mechanical behavior.

E Lugscheider, A. Nyland, P Remer, and R Sicking (Technische Universitat Aachen). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 583-587 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1554.

Biomedical

High-Velocity Oxyfuel Thermal Spray Coatings for Biomedical Applications. Plasma spraying is used to produce most commercially available bioceramic coatings for dental implants, however, these coatings still contain some inadequacies Two types of coatings produced by the high-velocity oxyfuel (HVOF) combustion spray process using commercially available hydroxyapatite (HA) and fluorapatite (FA) powders sprayed onto titanium were characterized to determine whether this relatively new coating process can be applied to bioceramic coatings. Diffuse reflectance Fourier transform infrared (FTIR) spectroscopy, x-ray diffraction (XRD), and scanning electron microscopy (SEM) were used to characterize the composition, microstructure, and morphology of the coatings The XRD and FTIR techniques revealed an apatitic structure for both HA and FA coatings However, XRD patterns indicated some loss in crystallinity of the coatings due to the spraying process Results from FTIR showed a loss in the intensity of the OH^- and F^- groups due to HVOF spraying; the phosphate groups, however, were still present. Analysis by SEM showed a coating morphology similar to that obtained with plasma spraying, with complete coverage of the titanium substrate. Interfacial SEM studies revealed an excellent coating-to-substrate apposition. These results indicate that with further optimization the HVOF thermal spray process may offer another method for producing bioceramic coatings.

J.D. Haman (University of Alabama); D.E. Crawmer (Miller Thermal); A A. Boulware and L C. Lucas (University of Alabama) Cited: *J. Therm. Spray Technol.,* Vol 4 (No 2), June 1995, p 179-184 [in English] ISSN 1059-9630 PHOTOCOPY ORDER NUMBER: 199510-57-1210.

Corrosion of Steel

Application of Electric Arc Spraying Technique to Enhance Corrosion Resistance of Steel Structures on Ships. Steel structures on ships operate in hostile environments and can be subject to severe corrosion Composite coatings consisting of aluminum arc sprayed and organic layers can effectively increase the corrosion lifetime of such structures The composite layer developed consists of an electric arc sprayed Al layer followed by a layer of organic paint to seal the Al coating, followed by a layer of a conventional ship's paint.

B. Xu, M. Shining, and J. Wang (China Mechanical Engineering Society). Cited: *Surf. Eng.,* Vol 11 (No. 1), 1995, p 38-40 [in English] ISSN 0267-0844 PHOTOCOPY ORDER NUMBER: 199511-57-1378

Drill Strings

Electric Arc Sprayed Self-Lubricating Coatings for the Protection of Drill String Tool Joints. When drilling for oil or gas, the torque due to frictional forces between the drill string tool joints and the hole casing limits the length of extended reach wells. This paper describes electric arc spray coatings that can significantly reduce the friction between the tool joint and the casing. In addition, both casing and tool joint wear can be reduced by using these coatings. By injecting powder into the spray, composite coatings of graphite in mild steel have been laid down onto rotating tubes. These coatings have been wear tested using the pin-on-disk technique with mud lubricated conditions. Coatings containing graphite have a coefficient of friction of ~80% less, with much reduced wear to both pin and disk, when compared with coatings without graphite. The effect of graphite powder size, coating graphite content, and wear test stresses are discussed with reference to wear and friction properties

A P. Newbery, R M. Jordan, A D. Roche, and A R E. Singer (Sprayforming Developments). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 683-688 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-58-1425.

Extraction Ball Valves

High Performance, Severe Service Critical Extraction Ball Valves. Securaseal high performance, severe service, critical extraction metal seated ball valves are required to resist extremes of wear, corrosion, and erosion at extreme Cv flow values, pressure and temperature. The valves' wetted surfaces are often in contact with acids, bases (caustics), slurries, and high-velocity solids. The metal-seated ball valves must maintain very low or no leakage rates and not fail between routine maintenance periods as the valves endure all of these extreme operating conditions. These metal seated ball valves incorporate numerous design features to offer superior performance in these environments. Among these features are customized HVOF and plasma sprayed coatings applied exclusively by Engelhard Surface Technologies Securacoat coatings have been developed to provide repeatable, highly reliable coatings which are often customized for a client's particular application/environment. Securamax utilizes the repeatable properties of the coatings by incorporating these properties into their valve design using extensive FEA including operating simulations to ensure validated stress levels and that the coating contact stresses are within the coating's performance specifications. Numerous examples of valve/coating performance in severe service environments such as chemical plants, gold mining and synthesis and others are discussed.

E J Barrette (Securamax International). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 699-704 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-57-1560.

Gate Valves

Advances in the Metallurgical Design of Gate Valves. Reliability and cost factors represent the two controlling forces for gate valves that contain state-of-the-art metallurgical improvements Better and less-expensive gate valves are always in demand for the oil and gas or petrochemically related industries. In this very specialized marketplace, environmental conditions are always the primary design challenge because service requirements typically involve high temperature, elevated pressure, extreme corrosion, or erosion A proper design selection for extended life under such harsh service will always involve the surface integrity for all effluent-wetted gate valve components This paper gives a brief survey of gate valves in terms of the different design approaches that are used for oil field and refinery applications. However, the main interest of this paper is devoted to modern surface treatment methods that enhance a cost attractive substrate to achieve a competitive and duplex or composite structure. For example, innovative processes are discussed relative to plating, hardfacing, thermal spray, conversion coatings, spray-fusion, weld-clad and HIC-ing

C Hays (Hays Metallurgical Engineering) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 595-598 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-58-1420.

General Overview

Thermal Spraying and Its Application. Thermal spraying as a method of providing surface coatings is discussed It is reported that the strength and adhesion of properly applied coatings is sufficient to withstand abrasion, fretting erosion, or adhesive wear. It is also noted that thermal spraying is not suitable for heavy impact loading. For successful implementation, quality control and operator training combined with selection of the appropriate method and material for the application is required Specific application examples are also given to help better understand thermal spraying

I.H Hoff (The Thermal Spraying Association). Cited *Weld. Met. Fabr.,* Vol 63 (No 7), July 1995, p 266, 268-269 [in English] ISSN 0043-2245 PHOTOCOPY ORDER NUMBER 199512-57-1500

Hardfacing Review

Hardfacing: Not Merely a Reclamation Process. Billions of pounds are lost every year in industry as a result of worn parts and wastage of materials In view of the need for energy and materials conservation, the hardfacing of parts or components must be considered as a production process from the design stage, rather than merely a reclamation process. By applying hardfaced coatings to parts or components subjected to breakdown through wear, their working lifetime can be extended by up to 5 times. The present paper outlines the types of wear and choice of hardfacing alloy, as well as spraying and welding deposition processes.

D Womersley (Loughborough University of Technology). Cited *Surf. Eng*, Vol 11 (No. 1), 1995, p 43-46 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER· 199511-58-1239.

HVOF at Elevated Temperatures

The Elevated Temperature Erosion Behavior of HVOF Tungsten Carbide Cermet Coatings. A series of elevated temperature erosion tests was carried out on HVOF WC-17Co cermet coating specimens at 300 and 450 °C at particle velocities of 30 and 60 m/s and at impact angle of 30 and 90°, using bed ashes and fly ashes retrieved from operating CFBC boilers. The elevated temperature erosion behavior of HVOF WC-17Co coatings was compared with those of AISI 1018 steel and other thermal sprayed coatings including an HVOF 75% Cr_3C_2-25% NiCr cermet coating, an arc-sprayed FeCrSiB metallic coating, and a flame sprayed Cr_2O_3-6SiO_2-4Al_2O_3 ceramic coating. The morphologies of specimens were examined by light microscopy and scanning electron microscopy (SEM) The microhardness of the surface of the specimens was measured It was found that the hardness of the coating had no direct relationship with erosion-corrosion wastage and the erosion behavior of coatings is closely related to their microstructure and composition. In general, the coatings with large splat size, coarse and heterogeneous structure, higher porosity and the presence of craze cracks or inclusions have the higher erosion wastage. However, the effect of microstructure of coatings on the erosion behavior varied with erosion test conditions

B Q Wang (Metalspray USA) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 711-715 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1562

Infrastructure and Automation

Field Evaluation and Economic Impact of an Automated Thermal Spray System (ATSS) for Infrastructure Rehabilitation. The integration of automation into infrastructure rehabilitation projects was investigated using a three-axis linear motion platform as a positioning system for a vacuum blasting unit, a visual inspection camera and a two-wire electric arc thermal spray gun The maintenance cycle of a steel structure was divided into three independent tests, each performed by the tools described above The linear motion system performed repetitive motion sequences, allowing the maintenance tools to move along a predetermined path and clean, inspect and coat the substrate, thus performing a complete maintenance cycle. The economic viability of this automated system was evaluated by performing a field test that included removing existing layers of rust, lead-based paint and dirt from a bridge section, followed by an inspection of the cleaning process and a thermal sprayed coating of zinc as a protective top coat. The field test was carried out on an overpass near Riverhead, New York, with the participation of the New York State Department of Transportation and the Regional Bridge Maintenance division

R. Benary, C C. Berndt, R V Gansert, H. Herman, and S. Sampath (State University of New York, Stony Brook); V. Hock (U.S Army Construction Engineering Research Laboratory). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 621-626 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1421.

Machinery Components

Thermal Spray Manual for Machinery Components. The "Thermal Spray Manual for Machinery Components" is a National Shipbuilding Research (SP-7) Project. This manual is being developed by Puget Sound Naval Shipyard with the help of other government thermal spray facilities and SP-7 panel members. The purpose of the manual is to provide marine repair facilities with a user friendly "how-to" document known to be technically sound through production experience. The manual's intent is to give these facilities guidelines on how to become qualified to requirements of Military Standard 1687A.

R Travis, C. Ginther, J. Herbstritt, and M Herbstritt (Puget Sound Naval Shipyard). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 89-92 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1387.

Petrochemical Ta Coatings

Tantalum Coatings for the Petrochemical Industry. Tantalum coatings have never been a cost-attractive item for the petrochemical industry but corrosion-resistant tantalum coatings have been and continue to be a very cost-effective solution for many complex metallurgical applications There are certain environments where thermally sprayed Ta has little or no competition from all other corrosion resistant alloy coatings (CRAC) This paper reviews Ta technology in terms of the relevant petrochemical needs and priorities. Selected properties of both Ta and Ta_2O_5 are given along with a brief history of Ta and Ta coatings. Some important discussion is also given about the very difficult development path that Ta has been forced to overcome. This characterization study involves two different applicators and two competitive processes: plasma and high-velocity oxygen flame (HVOF) spraying. Test coupons are evaluated in terms of structure, properties, and composition. Electron and optical metallography are both used with microhardness and associated methods of characterization for thermal spray coatings.

C. Hays (Hays Metallurgical Engineering); J P. Walker, Jr (F W. Gartner Thermal Spraying), J L Watson, Sr (Watson Grinding & Manufacturing). Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 589-593 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1419.

Reciprocating Wear

Reciprocating Wear of WC-17Co Coatings in Aqueous Environments. Surface engineering is briefly reviewed and the deposition of hard coatings by a high-velocity oxygen fuel process is described. Features of the deposit microstructure are discussed in terms of production parameters and their effect on both strength and wear behavior. An experimental program to create controlled reciprocating wear of the coatings in the presence of air, aqueous, and aqueous abrasive media is described. The resulting wear is assessed quantitatively in terms of volume loss and change in surface roughness. Introduction of seawater to the wearing interface reduces wear by a factor of four, and the introduction of alumina slurries results in wear rates and scar roughness values intermediate between those in seawater and air. The reduced wear rates in aqueous media are attributed to the cushioning effects of the liquid and the relatively benign effects of the abrasive to the replacement of early adhesive wear (in air) by abrasive wear The fine (0.1 μm) abrasive is more damaging than the coarse (7 μm) one, which is thought to be due to the easy embedding of the 0 1 μm alumina in the soft phase, which has a typical microstructural mean free path of about 0 5 μm. Coatings were sprayed onto tubular mild steel substrates.

W. Coulson, E.R. Leheup, and M G Marsh (University of Nottingham). Cited: *Trans. Inst. Met. Finish.,* Vol 73 (No. 1), Feb 1995, p 7-11 [in English]. ISSN 0020-2967. PHOTOCOPY ORDER NUMBER 199511-58-1191.

Rolling Contact Fatigue

Rolling Contact Fatigue Characteristics of Thermal Sprayed Tungsten Carbide Coatings. The rolling contact fatigue (RCF) behavior of tungsten carbide (WC) based cermet coatings (WC-12% Co) deposited by plasma and HVOF spraying was studied. The studied coatings were sprayed on quenched-and-tempered 42CrMo4 (DIN 17200) steel rolls while counter rolls were made of carburized-and-quenched 17CrNiMo6 (DIN 17210) steel having 1.5 mm carburized (60 HRC) case depth. The RCF testing was carried out with a two-roll configuration testing machine under unlubricated rolling conditions without sliding. Loads applied in the tests resulted to Hertzian contact pressures of 420 to 600 MPa. The influence of spraying method on the RCF behavior of the coatings was studied as a function of Hertzian contact stress. Plasma sprayed coating showed severe surface roughening and subsurface cracking of the coating under all studied load levels HVOF sprayed coating behavior was clearly different from the plasma coating with smaller structural changes HVOF coating retained its original surface roughness, but vertical cracks penetrating the coating appeared in this coating.

R. Nieminen, T. Mantyla, K. Niemi, and P. Vuoristo (Tampere University of Technology). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 651-657 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-57-1559

Steering Rams

HVOF Repair of Steering Rams for the USS *Saipan*. The carbon steel rams aboard the USS *Saipan* (LHA-2) were badly corroded after 18 years of service. These rams are hydraulically operated and change the angle of the ship's rudder This corrosion allowed excessive leaking of hydraulic fluid into the machinery space Permanent repairs were required as the ship has more than 20 years of service life remaining Two methods of repair were considered, chrome plating and a HVOF-applied WC-Co coating. The size, 13 in. in diameter and 15 ft in length, posed a significant problem for either process. The cost of the repair was similar, but the time for completion was better with the HVOF process since chrome plating would have to be accomplished

off-yard. The HVOF process was not available within the shipyard at the time and the process and material to be used had not been approved. Extensive testing was required to get approval to proceed, a facility to accomplish the work had to be built, and the operators and HVOF procedure had to be qualified After completion of spraying, single point machining and honing was used to obtain the required surface finish. This was the largest single HVOF coating applied by the Navy.

A.L. Dwyer (Norfolk Naval Shipyard, Portsmouth); R. Hays and B. McCaw (CDNSWC); S.A. Jones and R J. Wykle (Norfolk Naval Shipyard, Portsmouth) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 615-619 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-57-1557.

TBC Review

Ceramic Thermal Barrier Coatings. This article reviews the current status and future trends in the application of thermal barrier coatings (TBCs) to commercial airline engine turbine components. Plasma sprayed ceramic has demonstrated acceptable life in commercial engines due to several system enhancements As turbine inlet temperatures increase, the durability and the performance of TBCs must improve. The further improvements in coating life required to withstand these higher temperatures can be achieved with the highly columnar ceramic structure produced by the electron beam physical vapor (EBPVD) process.

S. Durham (Pratt and Whitney Canada); D K. Gupta, S.M Meier, and K.D Sheffler (Pratt and Whitney). *Advances in High Temperature Structural Materials and Protective Coatings,* National Research Council of Canada, 1994, p 226-236 [in English] ISBN 0-660-15140-5. PHOTOCOPY ORDER NUMBER: 199511-57-1344.

TBCs

Failure of PVD/Plasma Sprayed Thermal Barrier Coatings during Thermal Cycling. ZrO_2-$7Y_2O_3$ plasma sprayed coatings (PS top coating) were applied on high-temperature nickel-base alloys precoated by physical vapor deposition with a thin, dense, stabilized zirconia coating (PVD bond coat). The PS coatings were applied by atmospheric plasma spraying (APS) and inert gas plasma spraying (IPS at 2 bar) for different substrate temperatures. The thermal barrier coatings (TBCs) were tested by furnace isothermal cycling and flame thermal cycling at maximum temperatures between 1000 to 1150 °C The temperature gradients within the duplex PVD/PS thermal barrier coatings during the thermal cycling process were modeled using an unsteady heat-transfer program. This modeling enables one to calculate the transient thermal strains and stresses that contribute to a better understanding of the failure mechanisms of the TBC during thermal cycling. We have also studied experimentally the adherence and failure modes of these coating systems during this high-temperature testing The TBC failure mechanism during thermal cycling is discussed in the light of coating transient stresses and substrate oxidation.

V. Teixeira (Universidade do Minho); H Buchkremer, H Gruhn, W Mallener, and D. Stover (Forschungszentrum Julich); M Andritschky (Universidade do Minho). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 515-520 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1547

Thermonuclear Reactors

Protective Coatings for Plasma Facing Components in Thermonuclear Reactors. The plasma facing components in future thermonuclear confinement experiments have to withstand high stationary heat loads during normal operation and severe thermal shocks during off-normal conditions (so-called disruptions) In these transient events on the first wall, energy depositions up to 2 MJ m^{-2} can occur with pulse durations of the order of 1 ms. To improve the performance of the plasma and to protect it against high-Z impurities from metallic structures, boron carbide coatings have been used successfully in different fusion experiments. Thick coatings of this material have been prepared by plasma spraying, a technique that also offers potential for in situ repair of damaged coatings inside the torus. Coatings with thicknesses of several hundred micrometers on different substrates (graphites, carbon fiber composites, stainless steel, and refractory metals) have been tested in high heat flux test facilities at heat loads simulating the normal operation and disruption conditions. In addition, a limited number of coated tiles have been installed in fusion relevant tokamak experiments such as TEXTOR, JET, or JT-60U.

J. Linke, S. Deschka, and E. Wallura (Forschungszentrum Julich); M Akiba and T. Ando (Japan Atomic Energy Research Institute); J.P Coad (JET Joint Undertaking) Cited: *Int. J. Refract. Met. Hard Mater.,* Vol 11 (No 6), 1992, p 357-365 [in English]. ISSN 0263-4368 PHOTOCOPY ORDER NUMBER: 199511-E7-Z-0245.

TTBCs

Investigation of Damage Behavior of Thermally Sprayed Coatings on Coating Thickness. To increase the lifetime of components used for diesel engines or gas turbines, surfaces are coated by ceramics. In recent years, the authors succeeded in spraying thermal barrier coatings based on zirconia up to a thickness of a few millimeters. A comparison of the damage behavior between yttria partially stabilized zirconia coatings with different thicknesses on gray iron or IN 617 substrates is presented. The coatings are produced by atmospheric plasma spraying. The thickness is varied from 0 5 up to 2 mm In order to characterize the mechanical as well as the damage processes, different methods of destructive testing (tensile, bending, and loading test) are applied. Additionally, nondestructive testing methods were used to investigate the damage processes on microstructural level The results are discussed according to the microstructure

H -A. Crostack and U Beller (Universitat Dortmund). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 433-438 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-57-1540

Valve Seats

The Microstructure and Wear Mechanisms of Wire Arc Sprayed Inconel 625 Coatings on 319 Aluminum. The direct formation of valve seats on aluminum cylinder heads provides enhanced conductive cooling of the valves and the opportunity to redesign the head for larger valves and improved engine performance. A two-wire arc spray process was used to deposit coatings from Inconel 625 feedstock wire onto 319 cast aluminum test pieces, simulating the situation in an engine head The microstructure and apparent wear mechanisms in dry sliding against a 4620 steel counterpiece were investigated using scanning electron microscopy (SEM), transmission electron microscopy (TEM), and x-ray energy dispersive microanalysis. Wear tests were conducted using the ASTM G66-77 block-on-ring test with wear volume measured using 3D laser probe profilometer. The wear mechanisms of this tribosystem are principally adhesive and delamination wear.

X. Wang (University of Minnesota), R.C. McCune and O. Popoola (Ford Motor) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 633-638 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-58-1423

Composites

Ceramic Fibers in MMCs

Application of Ceramic Fibers to the Manufacture of Reinforced Metal-Matrix Composites. The application of the thermal spraying process is a new way to produce carbon fiber or Tyranno SiC fiber reinforced aluminum matrix composites. Spread fiber rovings are enveloped in the matrix material with wire flame spraying. The advantage of the thermal spraying process is the low times for contacting between the fibers and the liquid matrix material. Chemical reactions on the interface fiber/matrix, which decrease fiber tensile strength, can be excluded The thermal sprayed prepregs can be compressed to MMC by hot pressing process The long fiber reinforced composites are used to produce cast components of motors. The aim of this research is the estimation of possibilities to apply the wire flame spray process for prepreg manufacturing

B. Wielage, J. Rahm, and S. Steinhauser (Institute of Composites Technical University, Chemnitz). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 555-560 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-62-1538.

Control

Particle Sensor

A Particle Temperature Sensor for Monitoring and Control of the Thermal Spray Process. The temperature and velocity of thermally sprayed particles prior to their impact on the substrate are two of the predominant determinants of coating quality and characteristics This paper describes an instrument developed for real-time monitoring of in-flight particle temperature in an industrial environment The instrument is designed to operate as a stand-alone device for verifying that a desired particle temperature is attained or for developing process settings to yield a particular temperature. The device is also suitable for incorporation into a closed loop process controller. Data showing the relationship between torch parameters and average alumina or NiAl particle temperature are presented There is good agreement between previous measurements using laboratory instrumentation and the simpler industrially hardened technique described here The assumption of gray body behavior is evaluated and for known emissivities corrections are developed

W.D Swank, J.R. Fincke, and D.C. Haggard (Idaho National Engineering Laboratory) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 111-116 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-57-1517.

Plasma Process

Feedback Control of the Subsonic Plasma Spray Process: System Model. In the development of real-time closed-loop control of the plasma spray process a system model that accurately represents system characteristics is required. The system model is developed by randomly varying the process input parameters and observing the outputs. In the thermal plasma spray process, the primary parameters to be controlled are the particle temperature, the particle molten state or fraction, and the particle velocity The process inputs are current, primary and secondary gas flow, and powder feed rate and inspection velocity. The system model represents the system transfer function and is the first step in the design and assessment of a process controller. Subsonic spray deposition of NiAl powder is discussed

J R. Fincke, D.C. Haggard, and W.D. Swank (Idaho National Engineering Laboratory), T M. Demeny, A R Kashani, and S.M. Pandit (Michigan Technological University). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 117-122 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1390

Processing

On-Line Control of Plasma Sprayed Particles in the Aerospace Industry. The standards of quality in the aerospace industry require a precise control of the thermal spray process to ensure a good reproducibility of the coating characteristics. Even if the existing process control based on the control of the input parameters of the torch is sufficient to meet the aerospace standards, it is expected that future applications will require a better control of the process. For that purpose, the Industrial Materials Institute has developed an optical system dedicated to the on-line measurement of temperature, velocity, and trajectory of the sprayed particles in an industrial environment This system has been used in the installations of Pratt and Whitney Canada during the production of coatings by plasma spraying. For yttria-zirconia particles can vary significantly even if the input spraying conditions are kept constant. Furthermore, measurements on fine metallic powders have shown that the time necessary to reach the process stability can exceed 4 min after the spraying start-up.

P. Gougeon and C. Moreau (National Research Council of Canada); F. Richard (Pratt and Whitney Canada) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 149-155 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1519

Diagnostics

Laser Methods

A Comparison of Two Laser-Based Diagnostics for Analysis of Particles in Thermal Spray Streams. This paper discusses two commercially available laser diagnostics that have been used in thermal spray research (1) a Phase Doppler Particle Analyzer (PDPA) and (2) a Laser Two-Focus (L2F) velocimeter The PDPA provides simultaneous, correlated measurements of particle velocity and particle size distributions; however, particle sizing does not work well with nonspherical particles or particles with rough surfaces The L2F is used to collect particle velocity and number density distributions, and it can readily distinguish and separately measure particles with off-axis velocity vectors. PDPA and L2F principles of operation are presented along with potential advantages and limitations for thermal spray research. Four experiments were conducted to validate and compare measurement results with the PDPA and L2F instruments (1) spinning wire, (2) powder in a high-velocity oxyfuel (HVOF) jet, (3) powder in a cold jet, and (4) droplets in a wire-fed HVOF jet.

M F. Smith (Sandia National Laboratories); T.J. Roemer (KTECH); J.E. Brockmann, R.A. Neiser, and T J O'Hern (Sandia National Laboratories). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 105-110 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-58-1389

Spectral Analysis

Spectral Analysis of a Molybdenum Particle Laden Plasma Plume. In-flight measurement of the temperature of plasma-sprayed particles is important for the correlation of particle characteristics to coating structure and properties. In addition, particle temperature measurements are needed to better understand the plasma/particle interaction in the plume. However, the use of optical pyrometry for particle surface temperature measurement has inherent uncertainties due to nonthermal emission signals in the plasma/particle plume. This nonthermal signal is especially bothersome near the torch exit and in regions of the plume where there are few particles. This work presents measurements of the nonthermal signals present when making temperature measurements of plasma-sprayed molybdenum particles. The measurements help to define a method for subtracting the nonthermal signal from the raw data to improve the accuracy of particle temperature calculations. In addition, the particle number flux is measured from the spectra collected

K.-J. Hollis (University of Wisconsin); R A. Neiser (Sandia National Laboratories). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 129-134 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1392.

Environmental

Lead Removal

In situ Vitrification and Removal of Lead-Based Paint for Steel Structures. The feasibility of in situ vitrification of lead oxide contained in red lead based organic coatings was investigated. The removal of organic lead-based primers and paints has been achieved by a flame spray process that uses a glass/ceramic compound designed for high lead solubility and resistance to devitrification. The glass/ceramic compounds were prepared by fusing, fitting, and ball milling to produce the desired powder. The resulting powder was collected and used to flame spray previously prepared samples containing a commonly used red lead primer. Oxyacetylene flame spray technology was used to apply the glass compound to the steel substrate. The resulting glass waste was collected and analyzed for lead content using energy dispersive spectroscopy (EDS) and x-ray diffraction analysis. The lead cation leachability rates were determined by the U.S. Environmental Protection Agency (EPA) approved toxicity characteristic leaching procedure (TCLP). The designer glass waste form that exhibited the best results was a borosilicate glass with iron oxide additions. The iron silicate glass waste form leached ~1 ppm of lead during the TCLP, far below the current 5 ppm limit for hazardous waste.

S. Covey, A. Kumar, and L. Lattimore (U.S. Army Construction Engineering Research Laboratory) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 605-614 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-57-1556.

Experimental Design

Statistical Methods

An Experimental Study of the Air Plasma Spraying of Aluminum Powder. An experimental study has been performed to deposit aluminum powder on carbon steel for corrosion prevention using Ar-He working gases. Experiments were conducted using a box statistical design of experiment (SDE) approach A substantial range of plasma processing conditions and their effect on the resultant coating is presented. The coatings were characterized by hardness tests and optical metallography. Coating qualities are discussed with respect to hardness, porosity, surface roughness, deposition efficiency, and microstructure. Attributes of the coatings are correlated with the changes in operating parameters An optimized coating design predicted by the SDE analysis is presented for the particular application.

D.J. Varacalle, Jr. and L.B. Lundberg (Idaho National Engineering Laboratory); D.E Crawmer and P.A. Didier (Miller Thermal) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 381-386 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1413

An SDE Study of Twin-Wire Electric Arc Sprayed Nickel-Aluminum Coatings. An analytical and experimental study of the twin-wire electric arc spraying of nickel-aluminum coatings has been performed to demonstrate the suitability of the wire system as a bond coat material for ceramic overcoats in thermal barrier applications, and for spraying a single coat for part refurbishment. Experiments were conducted on 6061 Al alloy substrates using a Box-type full-factorial design parametric study. Operating parameters were varied around the typical process parameters (i.e., current, primary and secondary pressure, spray distance) in a systematic design of experiments (SDE) in order to display the range of processing conditions and their effect on the resultant coating The coatings were characterized by hardness tests and optical metallography. Coating properties were quantified for hardness, porosity, deposition efficiency, and microstructure The features of the coatings are correlated with the changes in operating parameters. Analytical calculations of the gas and droplet dynamics are presented, which includes molten metal entrainment and droplet breakup models.

D.J. Varacalle, Jr (Vartech); D.L Hale, and L.B. Lundberg (Idaho National Engineering Laboratory), G Irons, W Kratochvil, and V. Zanchuk (Tafa); G.C. Wilson (Vartech). Cited: *1995 Advances in Thermal Spray Science and Tech-*

nology, Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 373-380 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1412.

Feedstock

Carbides and Borides by HVOF

Improved Carbides and New Borides for HVOF and Their Coating Properties. Investigations on HVOF coatings produced from a new family of powders are discussed The influence of microstructure, composition, and production methods is discussed in view of powder properties and resulting coating properties. New boride powders and coatings are compared with regard to their properties (deposition efficiency, hardness, surface roughness, bond strength, and wear) against commercial WC-Co and Cr_3C_2-NiCr coatings. Additionally, improved WC- and CrC-based powders and coatings are compared with regard to oxidation and erosion resistance

M.J Froning and H. Keller (H.C. Starck) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 549-553 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-57-1551.

Polymers

Plasma Spraying of High-Performance Thermoplastics. High-performance thermoplastics like the polymers polyphenylene sulfide (PPS) or polyaryletherketone (PAEK) find increasing interest because of their extraordinary properties, i.e., strength and chemical stability, low creep, and good electrical insulating even at relatively high temperatures of >200 °C. At present, such materials are mainly processed by injection molding to solid bodies. To produce coatings, which would have numerous applications, no reliable and efficient method exists at present. The high material viscosity and surface tension represent the main obstacles High-velocity plasma and flame spraying with adapted torch nozzles seem to have the potential for the production of dense and well-bonded coatings on steel substrates But special precautions have to be observed and methods applied to get reliable coatings and to overcome the problem of layer shrinking due to recrystallization of the material after spraying which can cause detrimental cracks. These precautions and the adapted process procedure are described together with the state of polymer coating of CFRP.

R.H. Henne and C Schitter (DLR Institute of Technical Thermodynamics) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 527-531 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-57-1549

Powder Wires

Nickel-Free Powder Wires for Electric Arc Spraying of Restoring and Wear-Proof Coatings. Though electrode wires, which include nickel and aluminum, provide high adhesion of thermal gas coatings, they are expensive, a reason for their limited application. On the basis of thermal dynamic and calorimetry analysis, the selection of different charge materials for powder wires for electric arc spraying has been carried out. Wires of diameter from 1.6 to 2 6 mm have been in the form of a shell from low carbon strip 0.4 mm thick 17 to 30%, respectively. The charge of the following contents has been under consideration: (Fe-Cr-B), (Fe-Cr-B) + Al, (Fe-Cr-B) + Al + CuO, (Fe-Cr-B) + Al + Mg, (Fe-Cr-B) + CaF_2, Cr + B_4C + SiC + Al, Al + TiO_2, etc. Some mixtures have provided exothermic reactions, which have been the reason for retardation of a sharp drop in its flight toward a surface under spraying from electric arc; thus coating adhesion has been increased. Interrelation between the initial content of powder wires, and the structure and properties of a coating has been established. Comparatively inexpensive wires have been developed providing coating adhesion up to 25 to 45 MPa with high wear resistance, which are being widely used for restoring wear-proof coating of crank shafts of all typical dimensions, compressors, etc.

V I Pokhmursky and M.M Student (Academy of Sciences of Ukraine). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 695-697 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1426.

Size Analysis

Size Distribution Analysis of Powders used for Thermal Spraying. The particle size distribution of powders can be obtained by several methods. A comparison of different measurement methods, laser scattering and microscopic image analysis in particular, for T800 powders used in thermal spraying is presented. The conversion of intersect data to true spatial sizes for spherical particles was necessary Fair agreement between the size distributions shows not only that the conversion works reliably for the gas atomized powders encountered, but also that the different methods reveal comparable results.

M H. Poesch, S Isfahani, and H Opielka Cited *Powder Metall. Int*, Vol 5, Oct 1993, p 233-237 [in English] ISSN 0048-5012 PHOTOCOPY ORDER NUMBER 199512-58-1279

HVOF

Oxidation of Molybdenum

HVOF and Plasma Sprayed Molybdenum Coatings—Microstructure and Properties. High-velocity oxyfuel (HVOF) and plasma spray experiments were carried out to investigate the oxidation mechanism of molybdenum in the spray process and to determine how the various process parameters affect the microstructure and properties of the coatings on mild steel substrates. HVOF coatings exhibit their highest hardness and wear resistance at an oxygen content of 6 to 8 wt%. Such an O level can be achieved with Mo and Mo-MoO_2 composite powders as well In the plasma spray process, oxidation of Mo is less pronounced and Mo-MoO_2 composite powders containing 6 to 8% O have to be used to obtain similar properties as compared to HVOF coatings. When Mo-Mo_2C composite powders are used, oxidation of Mo becomes greatly reduced and highly wear resistant coatings are obtained at a low hardness level in both spray processes

S. Zimmermann and H Kreye (Universitat der Bundeswehr). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 297-301 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-58-1408

Infrastructure

Adhesion of Zinc

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

J.-G Legoux and S. Dallaire (National Research Council of Canada). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 345-350 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1411.

Mechanical Properties

Elastic Measurements

In Situ Evaluations of Young's Modulus and Poisson's Ratio Using a Cantilever Beam Specimen. Young's modulus and Poisson's ratio for thermal spray coatings are needed to evaluate properties and characteristics of thermal spray coatings such as residual stresses, bond strength, fracture toughness, and fatigue crack growth rates. Because coatings are used while bonded to a substrate, it is desirable to have a procedure to evaluate Young's modulus and Poisson's ratio in situ A cantilever beam method to evaluate the Young's modulus and Poisson's ratio of thermal spray coatings is presented. The method requires only inexpensive materials and instruments and makes use of laminated plate theory to compute Young's modulus and Poisson's ratio from data on deformations of the cantilever beam under static loads A sensitivity analysis of the method has shown the method to be accurate over a wide range of coatings and substrate materials. The method is verified by comparing predicted values of Young's modulus and Poisson's ratio with reference values from a three-dimensional finite element analysis of the thermal spray coated cantilever beam. The method was applied to evaluate the Young's modulus and Poisson's ratio of four thermal spray coatings of industrial importance (Ni-5Al on 6061 aluminum alloy, austenitic stainless steel on low carbon steel, WC-Co on low carbon steel, and yttria-stabilized zirconia on 6061 Al alloy).

E.F Rybicki, D.J. Greving, J R. Shadley, and Y. Xiong (University of Tulsa). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM Interna-

tional, 1995, p 409-414 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-22-1355.

Fatigue Resistance

Hard Coatings Deposited by Various Thermal Processes: Effect on Fatigue Resistance of Typical Alloys for Helicopter Components. Different tungsten-carbide-base nickel and chromium oxide coatings were applied by plasma spray, detonation gun, super detonation gun, jet coat, CDS, and HVOF on specimens made from the following materials: AISI 9310 and 4340 alloy steels and Ti-6Al-4V titanium alloy The rotating bending ($R = -1$) fatigue life of the coated specimens was evaluated and compared with that of the uncoated specimens Except for the Super D-Gun process, a general reduction in fatigue life is noted on coated steel specimens, varying from 9 to 47% lower. On coated titanium specimens, the reduction in fatigue life is more sensitive, from 15 to 63% lower, and the beneficial effect of shot peening is demonstrated

A. Buffoli and M. Pesetti (Agusta) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 671-676 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-31-4326

Influence of HVOF Sprayed WC/Co Coatings on the High-Cycle Fatigue Strength of Mild Steel. HVOF thermally sprayed WC/Co coatings are applied onto components that are exposed to wear caused by abrasion, erosion, fretting, and sliding. Besides wear attacks and static stresses, in many cases alternating mechanical stresses caused by dynamic loads occur additionally Therefore, the fatigue resistance of WC/Co-88/12- and WC/Co-83/17-coated specimens was investigated by high-cycle fatigue tests (HCF) The results of the fatigue tests were documented in statistically ascertained Woehler-diagrams (*S-N* curves). Furthermore, the mechanisms of failure are discussed

H.-D Steffens, S. Mobus, K Nassenstein, and J. Wilden (Universitat Dortmund) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 469-474 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-31-4325

The Effect of HVOF Sprayed Coatings on the Elevated Temperature High Cycle Fatigue Behavior of a Martensitic Stainless Steel. This study reports the influence of three high-velocity oxyfuel (HVOF) applied coatings on the high-cycle fatigue resistance of a martensitic stainless steel substrate at room and elevated temperatures. It was found that chromium carbide and tungsten carbide coated specimens exhibited significantly lower fatigue capability compared to the substrate material at elevated temperatures, while IN625 coated specimens exhibited a small beneficial effect An attempt is made to explain the observed behavior in terms of elastic modulus mismatch, thermal expansion mismatch, residual stress, and coating/substrate properties. It is concluded that coated metallic components must be analyzed as composite structures and that data generated for design properties must be applied to specimens which represent the geometry and characteristics of intended component.

A.A Tipton (Dresser-Rand). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 463-468 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-31-4324

HVOF Coatings

Influence of Particle Velocity and Molten Phase on the Chemical and Mechanical Properties of HVOF-Sprayed Structural Coatings of Alloy 316L. The HP/HVOF spraying process allows the production of oxide-low, thick coatings with low porosity This fact implies the feasibility of load-bearing HP/HVOF-sprayed iron base alloy 316L. Process-parameter-dependent particle properties like temperature and velocity strongly influence the microstructure and the chemical and mechanical properties of HP/HVOF-sprayed alloy 316L. Results of metallographical and chemical analysis and laser-optic-aided particle velocity measurement lead to a new understanding of particle oxidation based on a high volume fraction of liquid phase and high particle impact velocity. The volume fraction of oxides greatly affects the mechanical properties of homogenized HP/HVOF-316L. Optimum process parameters result in reduced oxide content less than 0.9% and consequently in strength and elongation comparable to that of wrought alloy 316L In addition to these excellent mechanical properties, a low porosity level of ~0 1 to 0 2% is achieved. These fundamental results were transferred successfully to a new type of combustion chamber for hypersonic aircraft with reduced complexity and weight.

H. Voggenreiter (Daimler-Benz); H.-J Spies (Bergakademie Freiberg); H Huber (Daimler-Benz); S. Beyer (Higher Technical College, Germany). Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 303-308 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1409.

Mechanical Properties of HVOF Coatings. High-velocity oxygen fuel (HVOF) thermal sprayed carbide coatings are distinguished by high hardness, low porosity, and good wear resistance compared to other thermal spray technologies. However, for many engineering applications the ductility and fatigue resistance are the most important material properties. In the use of HVOF systems, these properties are influenced by many boundary conditions. The paper presents the effects of different spraying parameters on the fatigue resistance of samples coated by the HVOF process. Substrates coated were $AlMg_3$ aluminum alloy and steel St37.

O.C. Brandt (Universitat der Bundeswehr). Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 2), June 1995, p 147-152 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER. 199510-58-1110

Quenching Stresses

Evolution of Quenching Stress during Ceramic Thermal Spraying with Respect to Plasma Parameters. The aim of the paper is to study the quenching stress evolution within deposits with respect to particle parameters at impact and substrate temperature The use of two alumina particle size distributions and two dc plasma torches makes it possible to vary the particle velocity at impact from 90 to 250 m/s. Usual setups gave information on the final average stress within deposits sometimes with distributions through the coating thickness. Here, in situ measurement of the substrate deformation during spraying made it possible to calculate the quenching stress and to follow the substrate curvature with respect to coating thickness Three different torch velocities, leading to different pass thicknesses, were tested The mild steel substrates were smoothly sand blasted in order to minimize the stress generated by this treatment and deposits (made of layered beads) were built for substrate temperatures ranging from 150 to 350 °C.

L Bianchi and P. Lucchese (CEA); S. Kuroda (National Research Institute for Metals, Japan); A. Denoirjean and P Fauchais (Universite de Limoges). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 267-271 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER· 199512-57-1526

Residual Stresses

Measuring of Residual Stresses in Thermal Sprayed Coatings. The Modified Almen Method (MAM) uses the deformation of test aluminum and steel substrate samples for measuring the residual stress and with small mathematical expenditure it yields the distribution in the coating. This paper presents the basic theory of MAM and the boundary conditions for using this method for the classification of thermal sprayed coatings with respect to the residual stress. The residual stress distribution of different HVOF coatings are shown in this work. Typical spray parameters are compared. The results are also compared with the ones calculated with other methods for the determination of the residual stress in thermal sprayed coatings.

O.C. Brandt (Universitat der Bundeswehr) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 451-455 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1543

Measurement of Residual Stresses within Alumina Coatings Plasma Sprayed on XC38 Steel. Sand blasting, preheating, and plasma spraying induce residual stresses within coatings and substrates. To better understand their evolution during the different steps of spraying, a method based on radius of curvature of coated test beams ($\sim 100 \times 10 \times 1$ mm^3) was used It was quite easy to set up the experiments to determine the strains, and the Young's moduli of coatings and substrate were determined to compute the corresponding stresses (the values of the Poisson's coefficient being usually low) The residual stresses of alumina coatings on XC38 steel were studied for different R_a of substrate surface and different preheating and spraying temperatures and coating thicknesses.

M. Mellali, P. Fauchais, A Grimaud, A.C Leger, and M Vardelle (Universite de Limoges) Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 439-444 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1541.

Initiation and Propagation of Interfacial Cracks during Spontaneous Debonding of Thermally Sprayed Coatings. Spontaneous debonding of alumina coatings sprayed onto mild steel substrates has been investigated experimentally and theoretically. Residual stress states generated during spraying and subsequent cooling have been predicted using a numerical model and validated experimentally For any given residual stress state, the strain energy release rate, G_r, can be calculated for interfacial debonding by evaluating the associated change in stored elastic strain energy. The magnitude of G_r at which specimens were observed to bond spontaneously have been taken as critical strain energy release rate, G_{ic}, i.e., interfacial fracture energy, values. For a variety of coating thicknesses and substrate temperatures, values of G_{ic} obtained in this way all fell in the range of 400 to 500 J/m^2 Corresponding values of the phase angle, ψ, (characterizing the mode mixity)

were all in the range of 70 to 90°. The consistency of these G_{ic} values is encouraging, but this method of evaluation is based on analysis of the propagation, rather than initiation, of the interfacial crack. Similar experiments were therefore performed on specimens with interfacial precracks of various lengths. The value of G_{ic} was found to decrease somewhat with increasing length of precrack, indicating that debonding was initiation controlled. These results are considered in the light of theoretical models for initiation of substrate/coating interfacial cracks.

A. Itoh and T.W. Clyne (University of Cambridge) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 425-431 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-57-1539.

Spray Angle Effect

Influence of Heat Treatment and Spraying Angle on Cohesion Strength of Plasma Sprayed Deposits. The influence of heat treatment and spraying angle on the cohesion strength of plasma sprayed deposits has been studied. Three coatings were selected. NiCr + Cr_2O_3, ZrO_2-Y_2O_3 (8 wt%), and Mo. The substrate used was a ferritic chromium steel. Heat treatments of 4 h were conducted after spraying in the temperature range 600 to 900 °C, and the spraying angle varied from 45 to 90° to the surface of the sample The cohesion strength of the deposit was measured using tensile tests. For the Cr_2O_3 deposit, the cohesion tensile strength was found to increase strongly with the temperature of the heat treatment, but was not influenced by spraying angle. For the ZrO_2-$8Y_2O_3$ coating neither the heat treatment nor the spraying angle affected the cohesion strength, whereas for the Mo coating, the cohesion strength increased with decreasing spraying angle and heat treatment had no effect.

J. Hennaut, J. Charlier, and J. Othmezouri (Universite Libre de Bruxelles). Cited: *Mater. Sci. Technol.,* Vol 11 (No. 2), Feb 1995, p 174-179 [in English]. ISSN 0267-0836. PHOTOCOPY ORDER NUMBER: 199511-57-1401.

TBC Elastic Properties

A Method for Measuring Non-Linear Elastic Properties of Thermal Barrier Coatings. Accurate characterization of the elastic properties of thermal barrier coatings (TBCs) is important for failure prediction. Thermally sprayed coatings often exhibit anisotropic and nonlinear elastic properties due to the coating microstructure that results from the thermal spray process. A method was developed for determining the elastic behavior of TBCs on substrates by measuring the in-plane modulus as a function of residual coating stress. The TBC substrate system used in this study was APS 8 wt% Y_2O_3-ZrO_2 topcoat on a 0.25 mm thick APS NiCrAlY bondcoat on a 3 2 mm thick Inconel 718. The in-plane modulus was determined by resonant frequency measurement, and the residual stress was measured from the substrate curvature. The residual stress was varied both by increasing the temperature of the TBC and substrate and by applying compressive plastic strain to the metal substrate. The stress-strain behavior of the TBC was derived from the data for modulus versus residual stress, and significant nonlinear elastic behavior was observed.

C.A Johnson, H G. deLorenzi, A.C. Kaya, and J.A. Ruud (General Electric Corporate Research and Development) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 415-420 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-22-1356.

TiC and Wear

Plasma Spray Processing of TiC-Reinforced Coatings for Wear Protection. TiC-reinforced coatings promise to be an excellent replacement for WC/Co and Cr_2C_2/NiCr carbide reinforced thermally sprayed coatings. TiC-containing coatings (up top 90 vol%) are lighter, less expensive, and offer lower friction coefficients than these two standard industrial thermal spray coatings. TiC reinforcing phases, however, may be less stable during plasma spraying and may react or decompose during processing or in operation. Investigations into the compatibility of TiC in titanium, TiNiCrAl, and FeCr matrices have been conducted and the results of plasma spray processing are presented. Powders that have been evaluated were produced via mechanical mixing and by self-propagating high-temperature synthesis (SHS). Resultant coating structures, properties, and comparative sliding wear resistance are reported

M. Mohanty and R.W. Smith (Drexel University) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 561-566 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-57-1552.

Wear Characteristics

Wear Characteristics of Oxide Coatings Deposited by Plasma Spraying, High Power Plasma Spraying and Detonation Gun Spraying. Various oxide coatings deposited by atmospheric plasma spraying (APS), high-power plasma spraying (HPPS), and detonation gun spraying (DGS) methods were evaluated. The aim of the work was to compare the characteristics of the coatings deposited by HPPS method with most commonly used PS method and with DGS method, which has been shown to be able to produce oxide coatings of very high quality. The advantage of the HPPS is its high spray rate together with high particle velocity making it a most promising deposition method for oxide coatings. Coatings studied in this work were alumina, alumina-titania, and chromia. Wear characteristics of these coatings were evaluated by rubber-wheel abrasion test, abrasive pin-on-disk test, particle erosion test, and block-on-ring adhesive wear test. In addition, coatings were evaluated by optical microscopy (microstructure and porosity), microhardness, x-ray diffraction (phase structures), and tensile bond strength measurements The results showed that coatings deposited by spray methods utilizing higher particle velocities; i.e HPPS and DGS, have lower porosity and improved wear characteristics over corresponding coatings deposited by conventional APS method. However, also with APS method it was possible to produce coatings of high quality as shown in the case of chromia coatings.

K. Niemi, T Mantyla, and P. Vuoristo (Tampere University of Technology), H. Jungklaus, J. Knuuttila, and E. Lugscheider (Technische Universitat Aachen). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 645-650 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-57-1558

Characteristics of Aluminum Phosphate Sealed Chromium Oxide Coatings. Atmospheric plasma sprayed (APS) chromium oxide coatings were scaled with aluminum phosphate at different temperatures Wear resistance was evaluated by rubber wheel abrasion tests and particle erosion tests Corrosion resistance of the coatings was measured by anodic potentiodynamic polarization technique and constant potential tests. Aluminum phosphate sealed coatings showed significantly better corrosion resistance than the unsealed ones. It was found that phosphate seems to act as a binder and thus improved mechanical properties were measured for sealed chromium oxide; higher hardness and higher wear resistance as compared with the corresponding unsealed coatings. The resistance against abrasion and erosion wear was found to be almost equal to those of Si_3N_4, SiC, Al_2O_3, and ZTA bulk ceramics.

E. Kumpulainen, T. Mantyla, K. Niemi, P. Sorsa, M. Vippola, and P. Vuoristo (Tampere University of Technology). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 579-582 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1553.

Wear of Composites

High Temperature Tribological Properties of Plasma-Sprayed Metallic Coatings Containing Ceramic Particles. This work is concerned with an investigation of plasma sprayed metallic coatings containing ceramic particles that can be used to seal a heated silica-base ceramic part in contact with a steel or copper rotating drum for the containment of molten steel. For sealing a moving metal component with a dense silica-base ceramic preheated at 800 °C, coatings with a low coefficient of friction and moderate wear loss are required. As reported previously, plasma sprayed coatings containing solid lubricants could reduce sliding wear in high-temperature applications. Plasma sprayed metal-base coatings containing ceramic particles have been considered for high-temperature sealing Selected metal powders (NiCoCrAlY, CuNi, CuNiIn, Ag, and Cu) and ceramic particles (boron nitride, Zeta-B ceramic) were agglomerated to form suitable spray powders Plasma sprayed composite coatings and reference materials were tested in a modified pin-on-disk apparatus in which the stationary disk consisted of a dense silica-base ceramic piece initially heated at 800 °C and allowed to cool down during tests. The influence of single exposure and repeated contacts with a dense silica-base ceramic materials preheated to 800 °C on the coefficient of friction, wear loss, and damage to the ceramic piece was evaluated. Being submitted to a single exposure at high temperature, coatings containing malleable metals such as indium, silver, and copper performed well. The NiCoCrAlY coating possesses a low coefficient of friction and wear loss, though it severely damaged the ceramic counter piece After three exposures to 800 °C, the NiCoCrAlY coatings containing BN presented valuable tribological properties, though they deteriorated with exposure time. The copper-Zeta-B ceramic coating experienced the lowest coefficient of friction (<0.05) of materials tested and a reduced wear loss for repeated contacts at 800 °C The outstanding tribological characteristics of the copper-Zeta-B ceramic coating were attributed to the formation of a glazed layer on the surface of this coating, which lasted over exposures to high temperatures This glazed layer, composed of fine oxidation products, provided a smooth and polished surface and helped in keeping the coefficient of friction low.

S. Dallaire and J.-G. Legoux (National Research Council of Canada). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 665-670 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-51-1604.

Wear of Quasicrystals

Microstructure and Wear Behavior of Quasicrystalline Thermal Sprayed Coatings. An Al-Cu-Fe alloy coating that forms a quasicrystalline phase is a potential candidate for replacing electrodeposited chromium on various components in the Space Shuttle main engine. Coatings were deposited by air and vacuum plasma spraying and by high-velocity oxygen fuel spraying Finer starting powders tended to lose aluminum during spraying, which affected the phase equilibrium of the coatings. Coatings that retained the starting powder composition were richer in the desired quasicrystalline phase Ball-on-disk wear tests between 440C stainless steel ball and the Al-Cu-Fe coatings were performed. Coefficients of friction ranged from 0.60 to 1.2 for the different coatings.

D.J Sordelet (Ames National Laboratory); R.L. Daniel, Jr. and P.D. Krotz (Rockwell Aerospace), M F Smith (Sandia National Laboratories). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 627-632 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-58-1422.

Wear Performance

Effect of Thermal Spray Process Selection on Tribological Performance of WC-Co and Al_2O_3-TiO_2 Coatings. High-velocity oxyfuel (HVOF), air plasma spraying (APS), and low pressure plasma spraying (LPPS) techniques were used to deposit WC-Co and APS was used to deposit Al_2O_3-TiO_2 coatings on ASTM 4130 steel in a study of the effect of process selection on the friction and wear of the coatings under dry sliding conditions in air The LPPS WC-Co, which had a cobalt matrix with few brittle η-carbides (Co_3W_3C and Co_6W_6C), small and evenly dispersed WC, and high residual compressive stress, was most abrasive to Al_2O_3-TiO_2.

Y Naerheim (Rockwell International Science Center); C Coddet and P Droit (Institut Polytechnique de Sevenans) Cited: *Surf. Eng.,* Vol 11 (No. 1), 1995, p 66-70 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199511-57-1380.

Abrasion Wear Resistance of Arc-Sprayed Stainless Steel and Composite Stainless Steel Coatings. The abrasion wear resistance of stainless steel (304) and composite stainless steel/titanium boride coatings arc sprayed with air and argon was evaluated. Stainless steel coatings arc sprayed with air were found to be slightly more resistant than bulk stainless steel, whereas those sprayed with argon were slightly less resistant. The wear resistance of composite stainless steel/titanium diboride coatings was from two to four times greater than that of bulk stainless steel, depending on the cored wire constitution and the type of gas used for spraying Microstructural analysis, microhardness measurements, and optical profilometry were used to characterize the coatings and wear damage. By considering both the wire constitution and the spraying conditions, it was possible to fabricate composite stainless steel coatings that showed a 400% increase in wear resistance over bulk stainless steel.

S. Dallaire, J.-G. Legoux, and H Levert (U.S National Research Council). Cited. *J. Therm. Spray Technol*, Vol 4 (No 2), June 1995, p 163-168 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199510-58-1111.

Wear Properties

Low Friction Coatings for Lubricant-Free Use in Rail Points. The development of different concepts for low friction coatings, e.g , self-lubricating coatings, lubricant-sealed coatings, or materials consisting of low friction matrices reinforced with wear-resistant particles, has increased. Various experimental investigations concerning the wear and corrosion resistance of different coatings gives a good insight into the different concepts Twenty-two coating materials sprayed by using atmospheric plasma (APS) or high-velocity oxyfuel (HVOF) techniques were compared A special testing facility was designed to investigate the wear resistance of the coatings to dry friction as well as to water lubrication and sand on the treated surface The properties of the best coatings can be transferred into practice

H.-D. Steffens (Universitat Dortmund); M Wewel (Klockner-Wilhelmsburger); M. Hohle (Sulzer-Metco); M. Gramlich, D Haumann, M.C. Nestler, and J Wilden (Universitat Dortmund). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 677-681 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-31-4327.

Wear Resistance

Wear-Resistant Coatings. The goal of this technical program is to develop wear-resistant coatings for piston ring and cylinder liner components for low heat-loss diesel engines. Friction and wear screening in Phase I identified plasma sprayed high-carbon iron-molybdenum and chromia-silica coatings as candidate piston ring wear coatings. Plasma sprayed chromia-silica and high carbon Fe-Mo coatings and a low-temperature arc vapor deposited (LTAVD) chrome nitride coating were identified as candidate cylinder liner wear coatings. The cast iron porcelain enamel coatings exhibited unsatisfactory wear rates because of porosity in the coating. The three main technical tasks for Phase II are further optimization of the LTAVD chrome nitride and of the cast iron porcelain enamel wear coatings and the process scale-up of wear-resistant plasma coatings for cylinder liners. The optimization of the LTAVD chrome nitride coating involves the development of an adherent 15 μm thick coating, which meets the friction and wear goals of this program. The cast iron porcelain enamel process optimization centers on developing a CIPE composition with a minimum of porosity. The process scale-up of the plasma coatings will first develop ID plasma spray parameters for coating cylinder liners Next, simulated cylinder liner specimens will be coated and the friction and wear properties of these coatings will be determined using reciprocating friction and wear testing using both new and "used" engine oil.

M.H Haselkorn (Caterpillar). Cited: "Ceramic Technology Project Semiannual Progress Report for April 1993 through September 1993," ORNL/TM-12674, Oak Ridge National Laboratory, 1994, p 123-125 [in English]. PHOTOCOPY ORDER NUMBER: 199512-31-4308

Microstructural

Phase Composition

Effect of Spraying Parameters on Phase Composition of Deposits Prepared by the WSP Process. The water-stabilized plasma gun PAL 160 was used for spraying of alumina-chromia composite powders (0 to 20 wt% of chromia) on low-carbon steel substrates. The resulting phase composition (PC) was determined by XRD in dependency on the feeding distance FD (e.g., the position where the powder was injected to the plasma jet) and on the spraying distance SD (gun-to-substrate distance). Both these parameters (FD, SD) significantly affect the phase composition since they control the dwell time and trajectories of particles in the plasma jet. 3-D diagrams (PC by FD by SD) were constructed as well as spatial distribution of PC particles on the cross section of the jet. It has been proven that for small SD, the feedstock phases and compositions are often preserved in deposits in partially melted particles. The longer the dwell time, the more likely are the phase composition changes. Similarly, the longer the dwell time, the better the chemical homogeneity of deposits. Diagrams of the spatial distribution prove that there are different fractions of unmelted, partially melted, and fully melted particles in various parts of the jet.

J. Dubsky, P.J Chraska, and B.J. Kolman (Institute of Plasma Physics, Prague). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 421-424 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-57-1538.

Structural Changes on Post-Sintered Flame-Sprayed Alumina and Alumina-Titania. Substrate-free coatings of alumina and alumina-titania produced by oxyacetylene flame spraying were postsintered between 1300 and 1700 °C The porosity and specific surface area of both coatings initially increased during the sintering, then decreased for higher temperatures. These changes were associated with the solid-state transformations followed by postsintering and thermal stress relaxation. The present phases and microstructure for as-sprayed and postsintered coatings were examined by x-ray diffraction and scanning electron microscopy.

R.S. Lima and C.P. Bergmann (DEMAT-EE-UFRGS). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 327-332 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1531.

Microstructure

Amorphous Layers by D-Gun

Structures and Properties of Amorphous Layers Formed by Gas Detonation and Other Powder Spraying Methods. The following powder spraying methods: gas detonation, plasma-spraying, and gas-flame spraying on the properties of construction steel C 1043 is characterized. Ni-Cr-Si-B powder was used. Results of x-ray testing show that the layers had amorphous and fine-grain structures. Investigations of fatigue strength, wear, fractography of fatigue fractures, residual stresses, and structural testing using optical and transmission microscopy TEM (with replica method) is presented. Linear and surface distributions of elements and microhardness have been measured.

T. Babul (Institute of Precision Mechanics) Cited: *Mater. Manuf. Process.*, Vol 10 (No 4), July 1995, p 611-623 [in English] ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199510-58-1130.

Splat Characteristics

Zirconia Splat Formation and Resulting Coating Properties. The aim of this paper is to show the influence of particle parameters at impact and substrate temperature on splat formation During plasma spraying, the flattening of the particles on the substrate was studied using either a setup derived from the line-scan test or a system integrating two fast (100 ns) two-color

pyrometers. These devices allowed us to determine the distributions of diameters and shape factors of the collected lamellae as well as their cooling rates on polished steel substrates at different temperatures, with various oxidation rates. Results on zirconia powders are presented for two particle size distributions: −45+22 μm and −90+45 μm. Two dc plasma torches and a rf plasma torch were used in order to get different particle velocities at impact, i.e., in the range 20 to 200 m/s. During spraying, the substrate temperature was held either at 75 or 300 °C, and the substrates were plasma jet preheated during various times ranging from 30 to 900 s in order to modify the oxide layer thickness Plasma sprayed zirconia coatings ~300 μm thick, realized with the three plasma torches, were compared with a special emphasis on their adhesion-cohesion. Such results, in good correlation with those obtained for the splats, depend strongly on particle velocity at impact, substrate temperature and oxide layer thickness.

L. Bianchi and P Lucchese (CEA); A. Denoirjean and P. Fauchais (Universite de Limoges). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 261-266 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-57-1525.

Microstructural Investigation of Plasma-Sprayed Alumina Splats. Alumina splat formation on smooth (R_s ~ 0.2 μm) substrates preheated to 300 °C was studied because in this case very regular disk shaped splats quite adherent to the substrate were obtained Thermal contact resistance evaluations suggested that the true contact area between the lamella and the substrate was less than the apparent area covered by the splat because of entrapped gas, surface contamination or oxide film. This resulted in good contact area through which the heat flux was released during crystal growth and poor ones for which the heat flux had to flow through the already solidified parts. This means that, emphasized by the low thickness of the splats (of the order of 1 μm), the heat flux directions within the splats may be both perpendicular and/or parallel to the interface. Furthermore, very good contacts with the substrate produced very high cooling rates (up to 10^9 K/s as measured for zirconia at least at the beginning of the cooling), theoretically in favor of homogeneous nucleation whereas bad contacts linked to lower cooling rates (10^6 to 10^7 K/s) should induce columnar growth. In this paper, atomic force microscopy of the splats enabled one to show different types of crystallization fields linked to the true splat contacts with the substrate. Different substrates' nature (steel 304L, Pyrex, and polished γ alumina coatings) and spraying angles have shown the difficulty of dissociating the spreading stage from the solidification stage and differences in crystalline structures.

L. Bianchi and P. Lucchese (CEA); A. Denoirjean and P. Fauchais (Universite de Limoges) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 255-260 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1524.

Generation of the First Layers of a Zirconia Plasma Sprayed Coating: Correlation between Splat Layering and Spraying Parameters. Fused and crushed partially stabilized zirconia particles (8 wt% Y_2O_3) were plasma sprayed with an Ar-H_2 plasma jet (45 r, 15 slm H_2, 600 A, nozzle ID 7 mm, internal injection) The study was devoted to the splat, beads, and passes (maximum eight passes) formation. The particles were sprayed on cast iron or stainless steel substrates while temperature was kept as constant as possible either at 75 or at 350 °C with the help of air jets either blown orthogonally to the plasma jet or to the substrate surface The splat shape and morphology was examined by OM and image analysis, the beads and passes cross sections as well as fractured sections were examined by SEM and their phases determined by XRD. These examinations have shown the drastic influence of the substrate temperature on the splat shapes and contacts with underlying layers, columnar structure growth within one bead or one pass and macrocracks network within the beads and passes.

A. Haddadi, P. Fauchais, A Grimaud, and F. Nardou (Universite de Limoges) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 249-254 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-57-1523.

Splat Formation: Ceramic Particles on Ceramic Substrate. The flattening and cooling processes of zirconia particles plasma sprayed onto zirconia substrates were monitored from the thermal radiation emitted by particles in flight and upon impact The measurement device consisted of a laser sheet and a high-speed two-color pyrometer focused on the substrate surface. Information about the flattening degree and cooling rate was obtained and compared with that obtained on stainless steel substrates In both cases, the substrate temperature was kept at 350 to 400 °C, and different preparations for substrate surface were investigated The results showed the influence of surface roughness on particle impact and cooling.

A.C. Leger, B. Dussoubs, P Fauchais, A. Vardelle, and M. Vardelle (Universite de Limoges). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 169-174 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-57-1521

Splat Diagnostics

A Method of Simultaneous Measurement of Temperature, Size, and Vector of Single Particles in Plasma Flows. New method of simultaneous measurement of two components of the velocity, size, and temperature of emitting particles in a dusted high temperature flow is described. Most attention is paid to the methodical side of the measuring method In this connection, alumina particles are used as an example for obtaining estimates of the error of measuring their color, temperature, size, and two components of the velocity. And, finally a brief description is given of the diagnostic apparatus realizing the above-mentioned method.

A.A. Mihalchenko, S.M. Gusel'nikov, and O P. Solonenko (Academy of Sciences of Russia). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 163-168 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1520

TBCs

Microstructure, Phase Composition, and Interface Phenomena in ZrO_2-7Y_2O_3 Plasma-Sprayed Thermal Barrier Coatings. Investigations were conducted on a duplex thermal barrier coating (TBC) system consisting of a ZrO_2-7Y_2O_3 ceramic layer and a NiCrAlY bond coat layer The coatings were deposited by atmospheric plasma spraying on nickel-base superalloy substrates ($Ni_{55.43}Cr_{22}Co_{12.5}Mo_9Al_1C_{0.07}$) kept at different temperatures. The microstructure, composition, and interface phenomena were studied by applying x-ray diffraction (XRD), transmission electron microscopy (TEM), and scanning electron microscopy (SEM), both of the latter combined with energy-dispersive x-ray spectroscopy (EDS). It was found that the bond coat is composed mainly of the Ni-solid solution with a small amount of the $AlNi_3$ intermetallic. In the ceramic layer the presence of the metastable tetragonal t'-ZrO_2 phase with traces of the monoclinic m-ZrO_2 and the cubic c-ZrO_2 phases was revealed. Both bond and ceramic layers have a characteristic lamellar structure. The bond lamellae consist of an outer amorphous and nanocrystalline film, an intermediate thin layer of fine columnar grains of oxides, and an inner polycrystalline region of big columnar and equiaxed grains of intermetallics. The ceramic lamella in the vicinity of the ceramic-bond interface is composed of an outer amorphous and nanocrystalline film and an inner region of columnar and equiaxed grains of mainly the metastable tetragonal t'-ZrO_2 phase; the lamellae within the ceramic coat exhibit the columnar and equiaxed morphology An increase in the substrate temperature from 75 to 500 °C has no influence on the microstructure of TBCs. A model was used for predicting the temperatures of the ceramic and metallic powder particles in the plasma jet. The calculated data showed a good agreement with experimental results

M. Levit, S. Berger, I. Grimberg, and B.-Z. Weiss (Technion). Cited: *J. Mater Synth Process.,* Vol 2 (No 1), Jan 1994, p 11-27 [in English]. ISSN 1064-7562. PHOTOCOPY ORDER NUMBER: 199511-57-1339

WC-Ni by HVOF

Microstructure Characterization of WC-Ni Coatings Obtained by HVOF Thermal Spraying. The microstructure of WC-Ni coatings on 34CrMo4 (G41350) obtained by HVOF thermal spraying was characterized by light optical microscopy, SEM, TEM-STEM, EDS, HRTEM, EPMA, XRD, image analysis, and elemental analysis. Commercial WC-17%Ni powder was used to make the coating by HVOF spraying. A layered structure was observed in the coating. 20 vol% of WC was found to be dispersed in the layers The metallic binder of the coating consisted of layers with two basic structural types: Ni-rich material and a fcc crystal, which had lattice parameter larger than that of the Ni-W-rich nanocrystalline material.

Z Dong, J.M. Guilemany, J R. Miguel, and J. Nutting (Universitat de Barcelona) Cited. *Scr Metall Mater.,* Vol 33 (No. 1), 1 July 1995, p 55-61 [in English] ISSN 0956-716X PHOTOCOPY ORDER NUMBER: 199512-58-1280.

Wear Relationships

Relationship between Structure and Wear Resistance of Chromium-Based Gas Thermal Coatings. The coatings were produced by the methods of plasma, gas-flame, and explosive spraying with the use of granulated chromium powder containing to 20% of alloying iron nickel, aluminum additives. The coating structure on cast iron specimens was studied by scanning and transmission microscopy methods. Friction tests under the action of VK-8 solid alloy indenter showed that the wear degree is in direct proportion to adhesive strength of particle to one another.

V F. Gorban' and V.V. Sychev (Academy of Sciences of Ukraine) Cited: *Trenie Iznos,* Vol 15 (No 6), Nov-Dec 1994, p 1014-1021 [in Russian]. ISSN 0202-4977 PHOTOCOPY ORDER NUMBER: 199511-58-1229

Modeling

Residual Stress

Modeling of Residual Stresses in Plasma Sprayed Multilayer Systems. The simulation program to calculate residual stresses in plasma sprayed single-layer-systems is extended for multilayers in order to study the influence of metallic bond coatings The stress model is based on the two-dimensional form of Hooke's law. Stress relaxation is implemented To get information about the reliability of this model, boron carbide was sprayed on stainless steel 316L substrate with and without copper interlayer. Residual stresses were measured by x-ray diffraction and compared with simulated results. For single-layer-systems, the verification of the developed model is reached. For multilayer systems, the stress reduction function of the copper interlayer demonstrated by the measurement is not delivered by the simulation It is expedient to introduce time-dependent behavior like stress relaxation or creep in the stress model for the simulation of residual stresses in plasma-sprayed metallic coatings like the copper interlayer.

H Gruhn, W. Mallener, and D. Stover (Forschungszentrum Julich). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 231-236 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-57-1522

Splat Geometries

3-D Profilometries of Vacuum Plasma Sprayed Nickel-Based Alloy Splats using Scanning Mechanical Microscopy. The relationships between processing parameters and deposit microstructures are not well understood due to the numerous parameters managing the thermal spray process and to the random deposition mode of the material. These interactions are directly related to the impact and spreading of the material droplets onto the substrate or previously deposited layers Thicknesses of splats of a vacuum plasma sprayed (VPS) nickel-base alloy (e.g., Astroloy) were determined by experimental measurements using a scanning mechanical microscope (SMM) Three-dimensional profiles of splats sprayed with different processing parameters were collected and showed that splats produced with a 90° spray angle exhibit a near constant thickness along a random cross section, while splats produced with an off-normal spray angle exhibit a thickness evolution following the impact direction. In the case of a normal spray angle, the splat thickness is a function of the initial particle diameter and the spray parameter set

G. Montavon and C. Coddet (LERMPS) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 285-289 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1407

Heuristic Modeling of Thermally Sprayed Powder Splat Characteristics. A simple heuristic model was implemented to calculate, *a posteriori,* several splat geometrical characteristics, as well as to estimate some plasma-sprayed Astroloy particle behaviors before the impact on a flat substrate. This model is based on statistical transfer functions, which permit one to establish relationships between observed splats and the initial sprayed powder particles (in terms of fraction of powder used to build the deposit, of velocity before the impact, etc) Using Taguchi experimental designs, the effects of the processing spray parameters on the aforementioned characteristics and behaviors were determined and are discussed in this paper. Such a low-cost and little-time-consuming approach could be easily implemented on an industrial basis and could permit one to define, for example, required characteristics for the sprayed powder (i.e., particle size distribution), in view of increasing the deposition efficiency and the deposit quality

G. Montavon and C. Coddet (LERMPS). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 225-230 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-58-1403

Thermal Conductivity

Pore Phase Mapping and Finite-Element Modeling of Plasma Sprayed Tungsten Coatings. The effect of pores on the thermal conductivity of plasma sprayed tungsten coatings was investigated Finite element models of the actual pore structure observed in the coatings gave estimates of the coating thermal conductivity The calculated values were compared to measured values for the same coatings Vacuum plasma sprayed (VPS) tungsten pore structures were found to be well represented by the cross-sectional micrography image thus leading to an accurate simulation of the conduction phenomena with a 2-D model. Atmospheric plasma sprayed (APS) cross-sectional pore structures required modification for proper phenomenological representation In addition to thermal conductivity values, values of the maximum effective pore length in the 3-D pore structure were estimated for the APS coatings Comparison of the calculated thermal properties to measured thermal properties of the same coatings shows that the pore structure is the major factor decreasing the thermal conductivity of plasma sprayed tungsten coatings.

K -J Hollis (University of Wisconsin). Cited· *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 403-408 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER· 199512-58-1415.

Numerical Simulation

HVOF "CFD" Analysis

Computational Analysis of a Three-Dimensional High Velocity Oxygen Fuel (HVOF) Thermal Spray Torch. An analysis of a high velocity oxygen fuel thermal spray torch is presented using computational fluid dynamics (CFD). Three-dimensional CFD results are presented for a curved aircap used for coating interior surfaces such as engine cylinder bores The device analyzed is similar to the Metco Diamond Jet Rotating Wire torch, but wire feed is not simulated. These are the first published (to the best of the author's knowledge) 3-D results of a thermal spray device. The feed gases are injected through an axisymmetric nozzle into the curved aircap. Argon is injected through the center of the nozzle. Premixed propylene and oxygen are introduced from an annulus in the nozzle, while cooling air is injected between the nozzle and the interior wall of the aircap The combustion process is modeled assuming instantaneous chemistry. A standard, two-equation, k-ε turbulence model is employed for the turbulent flow field. An implicit, iterative, finite volume numerical technique is used to solve the coupled conservation of mass, momentum, and energy equations for the gas in a sequential manner Flow fields inside and outside the aircap are presented and discussed.

B Hassan, A R. Lopez, and W L Oberkampf (Sandia National Laboratories). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 193-198 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-58-1398

HVOF Oxygen Content

Oxygen Partial Pressure Measurement in the HVOF Gun Tail Flume. An important aspect of the HVOF thermal spray process is the turbulent mixing of the spray jet with the surrounding air. The air mixing into the jet causes undesirable oxidation of the sprayed coating. In this paper a low cost and accurate method to determine the degree of air mixing is presented This method was used to measure for the first time the partial pressure of oxygen in the thermal spray flame. The measuring method is based on electrochemical determination of oxygen potential in the tail flame using a solid electrolyte cell The oxygen partial pressure in the HVOF-gun tail flame was measured with fuel-to-oxygen ratio, the fuel flow rate and the stand-off distance as variables. The oxygen content of the tail flame was measured and found to vary between 4 to 17% depending on fuel-to-oxygen ratios and stand-off distances. Such high oxygen contents are several magnitudes too high if serious oxidation in the coating is to be avoided.

K. Korpiola (VTT Manufacturing Technology), H. Jalkanen (Helsinki University of Technology); L. Laas and F Rossi (Joint Research Centre, Netherlands); J.-P. Hirvonen (VTT Manufacturing Technology) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 181-185 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-58-1396.

HVOF Particles

Simulation of Gas Particle Flow in an HVOF Torch. A transient two-dimensional numerical simulation of Inconel spraying in an HVOF torch barrel has been performed. The gas flow is treated as a continuum multicomponent chemically reacting flow, while particles are modeled using a stochastic particle spray model, fully coupled to the gas flow. The calculated results agree well with experimental data and show important statistical aspects of particle flow in the torch

C.H. Chang and R.L. Moore (Idaho National Engineering Laboratory). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 207-212 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1400

HVOF Process

Numerical Simulation of Thermal Spray Processing. The rapid, multiphase, multicomponent, and reactive flow processes occurring on different time and spatial scales complicate both numerical and experimental analysis of HVOF thermal spray (TS) systems. In addition, practical applications call for consideration of geometric details of the jet spray/three-dimensional substrate or powder collector interaction. In this paper, a newly developed system of numerical tools for analysis of TS processes is applied These CFD tools are based on unstructured, adaptive gridding techniques implemented on triangles or tetrahedrals The unstructured grids allow consid-

eration of the complex geometric details of the gun or substrate. The unstructured grids were used with a structured, three-dimensional grid for simulation of the Metco DJ gun and TAFA JP-5000 gun. Numerical results were validated by comparison with the experimental data. The numerical and experimental results show less than 10% divergence for the velocity field data, both along the jet axis and in the jet cross-section at the gun exit The methodology has a potential to significantly improve TS gun performance through control of its parameters This approach also will be a key for process scalability and reliability improvement.

S. Eidelman, W. Grossmann, I. Lottati, and X. Yang (SAIC). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 219-224 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1402.

Numerical Simulation of Gas and Particle Flow Field Characteristics in HVOF Guns. The particle flow field characteristics in an HVOF gun are examined using numerical simulation techniques Considered are the particle injection, acceleration, convection heat transfer, and particle barrel interaction processes in a TAFA JP-5000 HVOF gun Details of particle trajectories and temperature history as a function of particle size and other parameters are simulated and analyzed. A parameter study is conducted for different particle size, particle injection direction, and particle velocity. The number of distinct particle injection regimes was predicted and analyzed Particle velocity and temperature at the exit of the barrel are listed. Using numerical simulation, the injection condition can be designed as a function of the set of flow parameters as well as particle properties, including particle size and material properties, to optimize the thermal spray process. A comparison paper by the same authors presents a comprehensive analysis of the gas flow conditions for the HVOF gun.

X. Yang, S. Eidelman, and I. Lottati (SAIC) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 213-219 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1401.

Thermal Interaction Coating-Substrate in High Velocity Oxyfuel (HVOF) Spraying of WC-Co Powder Particles. The mathematical simulation of the thermal interaction between a 34CrMo4 (UNS-G41350) steel substrate and a coating formed by the droplets of WC-12%Co powder particles during HVOF spraying is undertaken. Analysis of the heat transfer processes permitted the investigation of the temperature evolution, coating solidification, substrate fusion and solidification, particular features of the thermal interactions between the substrate and the coating as well as between the successive coating layers. The analysis has also permitted the estimation of optimal conditions of the substrate and the coating structure formation. The obtained results were used in subsequent articles to predict the structure parameters, which agree with the experimental data.

V.V. Sobolev, J.A. Calero, and J.M. Guilemany (Universitat de Barcelona). Cited: *Rev. Metal.,* Vol 31 (No 3), May-June 1995, p 156-165 [in Spanish]. ISSN 0034-8570 PHOTOCOPY ORDER NUMBER 199512-58-1331.

Patent

Feedstock of Composite Wire

Composite Metallizing Wire Containing Lubricant and/or Wear Resistant Particle Method for Producing Said Wire. A composite metallizing wire useful in thermal flame spraying has a conductive metallic solid core wire strand and a coating consisting of solid lubricant particles and/or wear resistant particles homogeneously suspended in a conductive metal complementary to the solid core wire strand The lubricant particles may be graphite, BN, MoS_2, or polytetrafluoroethylene; the wear resistant particles may be SiC, TiC, or Cr_3C_2; and the metal of the core nickel, iron, copper, molybdenum, or titanium. The plating metal may be the same metal as that of the core. An additional outer sheath of Cu may also be present. A method of making such composite metallizing wire comprises submersing a solid core wire mandrel of conductive metal in a plating bath to act as a cathode (the bath contains conductive metal salt and an electrolyte having a salt with a depositable metal and a dispersant of wear-resistant particles and solid lubricant particles) and energizing the electrolyte to codeposit metal from the electrolyte along with wear-resistant particles and/or solid lubricant particles onto the wire mandrel. Alternatively, an electroless deposition may be used. A method of thermal spraying to produce a metal-matrix composite coating uses the composite wire. An engine cylinder block formed by this spraying technique has a thermally sprayed coating consisting of silicon carbide particles and graphite particles suspended in a matrix of Ni-based metal

R.C McCune (Ford Motor) Patent No. GB2273109 (UK), 8 June 1994; Conv date, 29 Oct 1993 [in English] PHOTOCOPY ORDER NUMBER 199511-62-1351.

Feedstock of Powder

Spray Powder for Hardfacing and Part with Hardfacing. A spray powder for thermal spraying onto a substrate to provide a hardfacing, and a part with such hardfacing on the surface thereof, that is corrosion-resistant and abrasion-resistant. The spray powder comprises between ~75 and 90 wt% of tungsten carbide. The powder further comprises between ~10 and 25 wt% of a nickel-base alloy, which includes Mo, and optionally, includes one or more of Fe, C, Cr, Mn, Co, Si, and W.

C.J. Terry (Kennametal) Patent No. US5328763 (USA), 12 July 1994; Conv date, 3 Feb 1993 [in English]. PHOTOCOPY ORDER NUMBER 199511-58-1247.

Plasma

Oxidation of Metals

Oxidation of Metal Droplets in Plasma Sprays. Although in some applications, the oxide content of thermal spray metal coatings may improve certain properties, it is generally detrimental for corrosion applications. This study examines the rate-controlling phenomena in the oxidation of iron particles during flight and after impact with the substrate.

A Vardelle (Universite de Limoges); N.J. Themelis (Columbia University), P. Fauchais (Universite de Limoges) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 175-180 [in English].ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-58-1395.

Post-Processing

Laser

Laser Modification of Electrometallization Coatings. Coatings have been obtained by electric arc spraying of powder wire under following regimes: $U = 34$ V, $I = 140$ A The pressure of gas spray (air) was equal to 0 6 MPa. Powder wire mixture consists of refractory components Cr_2C_3, CrB_2, (Fe-Cr-B) + Al, B_4C, SiC; the latter ones are not completely melted in electric arc and almost do not come into reaction with shell material. Laser treatment has been carried out in such a regime in which the coating and a thin layer of a base are being alloyed. In this case, the structure of an overmelted layer consists of ferrite matrix and dendrites enriched with elements such as carbon and boron. The strength of a coating increases after laser treatment. Porosity after laser treatment decreases from 10 to 0%, making it possible to apply coatings. Corrosion resistance evaluation of samples with coatings carried out by analysis of polarization curves obtained in 3% NaCl solution shows that due to surface laser treatment corrosion current decrease from $2\,4 \times 10^{-2}$ to 1.3×10^{-3} mA/cm^2 is observed.

V I. Pokhmursky, O Y Bonchik, M.S. Homa, S.G. Kiyak, A V Pokhmurska, and G.V. Savitsky (Academy of Sciences of Ukraine). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 79-82 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1516.

Superfinishing of Coatings

Technology Update: Thermal Spray Coatings and Superfinishing. Thermal spray coatings are made by finely dispersing metallic or nonmetallic materials and spraying them onto a surface by plasma-arc, flame, or electric-arc. These are often used for decorative coatings, wear or corrosion resistance, or rebuilding worn surfaces Superfinishing is the application of a superfine finish by a cantilevered finishing stone that is oscillated and held in contact with the surface by pneumatic tension This process is ideal for finishing spray coatings because it does not cold work or heat the surface material and produces flat surfaces with finishes ranging from coarse to highly polished. These two surface treatments compliment each other, but the decision to superfinish usually depends upon the dimensional and finish requirements of the product specification

L Gilbert (Supfina Machine); C P Howes, Jr (Miller Thermal). Cited: *Tool. Prod.,* Vol 60 (No. 11), Feb 1995, p 17-18 [in English]. ISSN 0040-9243 PHOTOCOPY ORDER NUMBER 199510-57-1186.

Process

Combustion Fuel

Thermal Spraying of Coatings Using the Hydrogen-Oxygen Flame. Use of the oxyhydrogen flame generated when burning the mixture produced by the water-electrolysis generators for flame spraying of bronze powders and thermoreactive nickel-base powders permits production of coatings that are not inferior, as to their quality characteristics, to the coatings produced using the oxyacetylene flame. Here the transportation costs and the cost of using the gas cylinder facilities are significantly reduced, and the

ecological indices are improved because the combustion products are water vapors

V.N. Korzh, N.V Alexandrovskii, and Y.S. Pipil' (Kiev Polytechnical Institute). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 11-14 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-58-1378.

Deposition Efficiency of Plasma

Studies of the Air Plasma Spraying of Chromium Oxide Powder. Experimental and analytical studies of the air plasma spray process have been accomplished in order to increase the deposition efficiency of chromium oxide powder on aluminum plates Numerical models of the plasma dynamics and the plasma-particle interaction are presented The analytical studies were conducted to determine the parameter space for the empirical studies Experiments were then conducted using a Box statistical design of experiment (SDE) approach. A substantial range of plasma processing conditions and their effect on the resultant coating are presented. The coatings were characterized by hardness tests and optical metallography (i e., image analysis). Coating qualities are discussed with respect to hardness, porosity, surface roughness, deposition efficiency, and microstructure. Attributes of the coatings are correlated with the changes in operating parameters. An optimized coating design predicted by the SDE analysis is presented. The deposition efficiency of the powder was substantially increased to a maximum value of 65%. Several powder sieves were evaluated with the optimized process parameters.

D.J. Varacalle, Jr and G.C. Wilson (Idaho National Engineering Laboratory); D.E Crawmer (Miller Thermal) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 365-372 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1536.

HVOF Gas Parameters

The Effect of Gas Parameters on HVOF Coatings. The use of propane as fuel gas for HVOF has been investigated in a series of spray tests to determine the effect of gas-related parameters on the performance of WC-Co coatings The effects of total gas flow (oxygen plus fuel gas) and oxygen/fuel ratio have been related to coating microstructure, oxide content, microhardness, and abrasive wear resistance The use of alternative fuel gas supply options for propane (or propylene), i.e., vapor withdrawal and liquid withdrawal via a vaporizer unit, have demonstrated potential problems with the former system. Reduced pressures resulting from the temperature reduction caused during vaporization in the vapor withdrawal method would lead to inferior coating performance. Additionally, vapor withdrawal will result in a changing composition of the gas supply as the cylinder contents are used up This would be especially relevant to mixed fuel gas systems or fuels containing significant levels of other hydrocarbon impurities such as in the case of butane in propane. The liquid withdrawal supply option ensures adequate and consistent fuel gas pressure and flow rate and constant composition.

G K. Creffield (BOC Gases Europe), G.R White (BOC Gases America), M.A. Cole (BOC Gases Europe). Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 291-296 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-57-1528

HVOF Nozzle Design

The Influence of Nozzle Design on HVOF Spray Particle Velocity and Temperature. This investigation examines the influence of HVOF nozzle gas dynamics on spray particle velocity and temperature, which are expected to influence coating microstructure and properties Gas dynamic control of particle velocity and temperature is possible by varying parameters such as nozzle contour, combustion chamber operating pressure, and powder injection location. In this study, the mechanisms of particle acceleration and heating in the HVOF nozzle are examined. The accelerating force on a particle is related to its drag coefficient and the dynamic pressure of the gas. Heating of the particle depends primarily on exposure time in the high-temperature region of the flow. Experiments were conducted to characterize the gas dynamic performance of a conical HVOF nozzle with several particle injection locations. Measurements of spray particle velocity, acquired using particle trace velocimetry, indicate increasing velocity with higher combustion chamber pressure. The measurements are presented for a range of operating conditions and for two particle injection locations. In addition, HVOF spray particle acceleration and heating are numerically modeled, and these results are compared with the experimental data.

C M. Hackett and G S Settles (Pennsylvania State University) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 135-140 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-58-1393.

HVOF Wire

Wire Melting and Droplet Atomization in an HVOF Jet. Coatings produced by feeding a 1025 steel wire into a high-velocity oxyfuel (HVOF) torch are being intensively studied by the automotive industry as a cost-effective alternative to the more expensive cast iron sleeves currently used in aluminum engine blocks The microstructure and properties of the sprayed coatings and the overall economics of the process depend critically on the melting and atomization occurring at the wire tip. This paper presents results characterizing several aspects of wire melting and droplet breakup in an HVOF device. Droplet stripping from the wire tip was examined using a gated CCD camera. Fluctuations in the incandescent emission of the plume 1 cm downstream from the wire tip were recorded using a fast photodiode A Fourier transform of the light traces provided a measure of the stripping rate of molten material from the wire tip. Simultaneous in-flight measurement of atomized particle size and velocity distributions were made using a Phase Doppler Particle Analyzer (PDPA). The recorded size distributions approximate a log-normal distribution. Small particles traveled faster than large particles, but the difference was considerably smaller than simple aerodynamic drag arguments would suggest A set of experiments was carried out to determine the effect that variations in torch gas flow rates have on wire melt rate, average particle size, and average particle velocity. The observed variation of particle size with spray condition is qualitatively consistent with a Weber breakup of the droplets coming off the wire. The measurements also showed that it was possible to significantly alter atomized particle size and velocity without appreciably changing the wire melt rate.

R.A. Neiser (Sandia National Laboratories); R E. Teets (General Motors); T.J. Roemer (KTECH), J.E. Brockmann, R C Dykhuizen, T.J. O'Hern, and M.F. Smith (Sandia National Laboratories). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 99-104 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1388.

A New HVOF Thermal Spray Concept. HVOF plays an important role in the commercial production of thermal spray coatings from powder. Initially, both the chamber and duct modes were used. Today, the best coatings are produced by high-pressure chamber guns with some manufacturers having switched their designs from the duct to the chamber mode. There has been little or no spraying of wire with HVOF equipment. A new HVOF process, the shock-stabilized mode, complements chamber powder spraying by offering the user a very simple device for wire use. Calculations show that the much higher jet velocities of the chamber mode make that design the better suited for use with powder. Conversely, the greatly increased jet temperatures offered by shock-stabilized combustion give extremely high wire melt-off rates.

J.A Browning (DRACO); H.J. Richter (Dartmouth College); R.J. Matus (Fluent). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 7-10 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1377.

Laminar Plasma

Application of DC Plasma Torch with a Quasi-Laminar Jet Outflow. The experimental results characterizing a heat exchange between plasma jet and a plane obstacle under laminar and transient regimes of flow are presented. Such parameters as shape of exit nozzle-anode (cylinder, diffuser, and step), distance between the nozzle exit and a flat barrier, and dc plasma torch regime parameters (arc current and flow rate of plasma-forming gas) were varied in the experiments. The plasma jets were generated by dc plasma torch with a sectional interelectrode inserts (IEI). The supply of the plasma-forming gas (nitrogen) with the flow rate of 0 4 to 1.4 g/s was tangential. Into the gap between the last section of the IEI and the anode argon with the flow rate of 0.2 g/s was fed. The use of the stepped exit nozzle allows one to decrease a mixing of the plasma jet with surrounding atmosphere and to increase the thermal efficiency of the heat exchange plasma jet surface The results under consideration were used for optimization of the technology of a coating plasma treatment

V I. Kuz'min, O.P Solonenko, and M F. Zhukov (Academy of Sciences of Russia). Cited· *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 83-88 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1386.

Laser Powder Method

Laser Technique: Improve Functional Surfaces with or without Additives. Laser-powered two-stage powder coating for improving performance of inner/outer boundary layers is described. A CO_2 laser used to melt the coating for powder spraying substrates of steel and Cu-Al-Ti alloys is the basic tool for altering the boundary layers as desired. Different coating materials mentioned are Co/Ni/Mo alloys, metal-bonded carbides or oxides etc.

Cited: *Ind.-Anz.,* Vol 12 (No 16.03.1992), 16 March 1992, p 66, 68, 70 [in German]. ISSN 0019-9036. PHOTOCOPY ORDER NUMBER· 199512-58-1366.

Nozzle Design

Bell-Contoured, Parallel Flow Nozzles for Reducing Overspray in Thermal Spray Processes. Thermal spray guns that exhaust supersonic plasmas currently employ anodes incorporating conical nozzles. These nozzles do not ideally expand the plasma flow and therefore produce disruptive shock waves and expansion fans in the plume. Shock waves and expansion fans turn the flow, allowing injected particles to escape and resolidify. Also, the divergent, linear walls produce tangential flow velocity components that are not parallel to the nozzle center axis. The divergent flow components, in turn, impart divergent trajectories to many injected powder particles, which facilitates their escape from the plasma flow. To solve this problem, bell-contoured nozzles were designed and fabricated to ideally expand the plasma and thus eliminate disruptive flow phenomena while exhausting a collimated flow As a result, injected powder particles remained in the plasma, and overspray was reduced substantially. Additionally, the flow exiting the bell nozzles did not impart divergent components to injected particles; therefore, the impact velocities of the particles were maximized Consequently, test results show that bell-contoured nozzles have reduced overspray by 50%

G.P Beason, Jr (Plasma Processes), F.R Zimmerman (NASA Marshall Space Flight Center); T N McKechnie (Plasma Processes). Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 61-65 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-58-1384

Nozzle Shields

Plasma Sprayed Alumina Coatings with Nozzle Shields: Injection Problems. Nozzle shields with conventional plasma torches allow to increase the dwell time of the particles in the plasma together with their impact velocity. In this paper, the influence of simple nozzle shield design on the plasma flow, alumina particles (−45+22 μm) molten state and velocity upon impact and coating properties is presented With simple conical water-cooled nozzle shields (NS) with cone angle <6° and length <6 cm, the mixing of the plasma gas with the surrounding air is delayed. In spite of the thermal losses within the NS, the temperature and velocity radial distributions of the plasma jet exiting the NS are higher than those measured at the same location without the NS and the heat transfer to a water-cooled substrate is improved with the NS. When injecting particles in the torch nozzle, at the NS exit their axial velocity is higher than that without the NS, but their radial velocity in the jet fringes is lower. The resulting coatings have confirmed the drastic influence of the particles impact velocity on the coatings adhesion/cohesion (A/C) values However, with NS efficient to improve the plasma jet velocity, the collisions of the particles with their walls tend to decrease the A/C values. For NS angles of 12° such problems are overcome, but the NS efficiency is poor.

A Betoule, J.F. Coudert, A. Denoirjean, P Fauchais, and M. Vardelle (Universite de Limoges). Cited. *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 15-19 [in English]. ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER: 199512-57-1514

Shrouded HVOF

Research on HVOF Gas Shrouding for Coating Oxidation Control. High-velocity oxyfuel (HVOF) spraying of metals in the atmosphere typically leads to the formation of embedded oxides within a coating In many service applications, the presence of oxides results in poor coating performance. This paper first summarizes the mechanisms by which oxides are formed during HVOF spraying. Then, gas dynamic principles are applied in experiments to produce an HVOF gas shroud that substantially reduces the oxide content of sprayed iron coatings Flow visualization of the shrouded HVOF jet mixing with the atmosphere indicates that the amount of atmosphere entrained into the HVOF jet can be controlled with the shroud gas mass flow rate. Further, oxide levels in sprayed iron coatings on copper substrates are reduced by up to 50%, the amount of this reduction being linearly proportional to the shroud gas flow rate.

C.M. Hackett and G.S. Settles (Pennsylvania State University). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 21-29 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1379.

Shrouded Plasma

Effect of Shrouded CO_2 Gas Atomization on Coating Properties in Wire Arc Spray. A shroud nozzle with secondary injection of shrouding gas has been developed for spraying with CO_2 gas to improve coating quality. Wire arc spraying of stainless steel on aluminum substrates using CO_2 gas atomization has been investigated with the objective of establishing correlations between voltage fluctuations, droplet sizes, and coating properties such as porosity (16%) of air sprayed coatings, further reduction of oxide content (6%) and porosity (4%) is achieved by using a shrouded nozzle with secondary gas from mixing with surrounding air, which results in less oxide content and less chromium loss in the coating. Also, secondary gas injection contributes to better atomization of the droplets, which leads to less porosity of the coating

X Wang, W. Gerberich, J Heberlein, and E. Pfender (University of Minnesota). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 31-37 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1380.

Small Diameter Plasma Arc

Surface Modification of Steel by a Small Diameter Plasma Arc. A plasma arc, which is produced through a small diameter nozzle, is applied to surface modification of steel. The nozzle diameters are 0 2 and 0.3 mm; the arc diameter is so small that the power density is of the order of 10^6 W/cm^2 This is applicable to small area surface modifications. In case of surface hardening due to self-quenching, Vickers hardness of 1000 is obtained for AISI 1045; melting does not occur In case of alloying with SiC particles, Vickers hardness of 1200 is obtained for AISI 1010; furthermore, the wear resistance is increased by a factor of several tens

N Kinoshita (Tokyo Denki University); T Miyazaki and S. Yoshioka (Chiba Institute of Technology), T. Kimura and A Komatsu (Origin Electric) Cited: *CIRP Ann. 1995,* Vol 44 (No 1), 1995, p 161-164 [in English]. ISBN 3-905-277-23-9 PHOTOCOPY ORDER NUMBER. 199512-16-0671

Processes

APS and D-Gun

Comparison of Different Hard, Metal-Like Coatings Sprayed on Plasma and Detonation Gun Processes. Structure and wear properties of atmospheric plasma sprayed and detonation gun sprayed coatings prepared from an experimental (Ti,Mo)C-28.4%NiCo powder were compared to coatings sprayed from commercially available WC-12%Co and Cr_3C_2-25%NiCr powders All powders had an agglomerated (spray dried) and sintered structure and nearly the same content of the metallic binder of ~20 vol%. The powders were characterized by SEM (morphology and cross section) and x-ray diffraction (phase composition). The coatings on low-carbon steel substrates were studied by optical microscope, microhardness measurements, x-ray diffraction analysis, and abrasion and erosion wear tests The x-ray diffraction patterns of the coatings show that the (Ti,Mo)C-28.4%NiCo powder is characterized by high phase stability in both spray processes, whereas the WC-12%Co powder is prone to significant phase transformations during spraying. The results clearly show the high potential of the experimental (Ti,Mo)C-28.4%NiCo coatings in substituting the conventional systems in wear applications. For example, it was found that plasma spraying of the (Ti,Mo)C-28.4%NiCo powder with an Ar-H_2 plasma gas resulted in coatings with wear resistance comparable to WC-12%Co coatings However, detonation-gun-sprayed WC-12%Co coatings showed somewhat better abrasion wear resistance.

P Vuoristo (Tampere University of Technology), L.-M Berger and M. Nebelung (Fraunhofer Institute of Ceramic Technologies and Sintered Materials); T. Mantyla and K. Niemi (Tampere University of Technology). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 309-315 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER 199512-57-1529.

APS and HVOF of Carbides

Investigation of APS and CDS Processes of Aluminum Carbide and AlSi Carbide Coatings. The paper presents technological concept of the formation coating containing selected carbides (TiC, SiC) These powders were produced by self-propagated method of synthesis Spraying parameters APS and CDS were determined Microstructure and wear resistance of the coatings obtained on 7075 Al substrates were determined The results obtained in this investigation were applied to a selection of optimal parameters of spraying, content of hard phase grains in accordance with its deposition rate, and wear resistance.

A. Ilyuschenko, V Okovity, A Verstak, and P Vityaz (Powder Metallurgy Institute, Minsk), E. Lugscheider and P. Remer (Technische Universitat Aachen). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 317-320 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-57-1530

Processing

"Sonarc" Gun

Properties of Sonarc Sprayed Coatings. The combination of electric arc and HVOF spraying offers a lot of opportunities to enlarge the field of application for thermal spray technology. If hard material powders are processed by HVOF and simultaneously metal wires by arc spraying, metal-matrix composites (MMCs) can be formed out NiCr 8020 and aluminum coatings

were reinforced by applying various contents of SiC and tested by a taber abrasion device. Beside the investigations of the microstructure and the determination of the volume percentage of the hard particle content, bond strength tests according to European Standard EN 582 were carried out Furthermore, the coatings were tested by corrosion tests The results are compared to other coating systems and discussed in relation to the obtained microstructure

H -D. Steffens, K Nassenstein, and J. Wilden (Universitat Dortmund). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 689-693 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER. 199512-62-1539

Cryogenic Cooling

Plasma Spraying at Controlled Temperature. Plasma spraying of relatively fragile substrates such as resins, polymer matrix composites, organic materials, and pieces with complicated geometry and thin sections can be accomplished by cryogenically cooling the substrate prior to spraying Use of liquefied argon, carbon monoxide, and nitrogen cryogenic gases is discussed The technique can be used also to plasma form thin ceramic shells by spraying aluminum alloy mandrels at room temperature and then separating the coating by cryogenic shrinking of the mandrel.

A. Freslon (CEA) Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 57-60 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER· 199601-57-0060

D-Gun

Detonation Gun and Plasma Spraying of Amorphous Metal Coatings with Improved Corrosion Resistance: Simulation and Experiment. Coating formation in detonation gun or plasma spraying involves direct contact of molten particles with cool metal of the substrate, which results in extra high cooling rates in the melt and enables synthesis of coatings with amorphous or metastable crystalline structure. Mathematical modeling of detonation gun and plasma spraying was carried out to determine the physical and engineering parameters for producing hard, corrosion-resistant coatings. For an iron-base (Fe-Cr-P-C) and a nickel-base (Ni-Cr-Si-B-C) eutectic alloy, spraying process parameters were determined theoretically Purely amorphous or amorphous-crystalline coatings can be produced by detonation gun and plasma spraying with the use of values of individual layer thickness, pulse separation, powder feed rate, etc., thus obtained The structure of these coatings whose hardness may be as high as 1100 HV was described in more detail in a previous paper. Amorphous coatings are shown to outperform 304 stainless steel in resistance to corrosion in hydrochloric acid by no less than an order of magnitude

T. Shmyreva, A. Mukhin, and L Mukhina (State Metallurgical Academy of Ukraine). Cited· *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 243-247 [in English] ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1405

Density Modification

Structural and Phase Transformations in Plasma Sprayed Coatings by Powerful Ultrasound Loading and Laser Melting. The application of the different methods of the influence on the spray coatings allows us to decrease the defect of the coatings and transform the structure leading to increase of protection qualities. High energy actions on the coatings by ultrasound loading and laser melting are very effective in improving the properties of spray coatings without thermal influence into the substrate. To pick out more effective method of treatment of the coatings and predict the development of changes in the coatings by intensive deformation and thermal heating, it is very important to know the peculiarities of these transformations in the coatings on the different structural levels Complex research on the structure and phase composition of the coatings sprayed by means of optic and electronic microscopy and x-ray structural analysis allows one to get more exact notions about processes taking place by forming coatings and transformations. The peculiarities of the structure and phase composition of the plasma sprayed coatings based on nickel were determined It was proven in practice that methods of action on the coatings lead to material changes of the structure and phase composition, which cause improvement of the strengthening and fast corrosion properties

V.A. Klimenov, V P. Bezborodov, V.E. Panin, and O B Perevalova. Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 321-325 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1410

Nanocomposites

Formation of Superparamagnetic Nanocomposites from Vapor Phase Condensation in a Flame. Recent work on the magnetic characteristics of nanometer scale materials has suggested that magnetically isolated nanometer magnetic particles would show magnetic behavior different than those found in the bulk. Such behavior could be explored if such materials could be synthesized in sufficient quantities where the magnetic particles could be isolated from each other via encapsulation within a nonmagnetic host The application of flame technology for the synthesis of this class of materials was investigated A premixed methane/oxygen flame diluted with nitrogen was used as the reacting environment in which iron pentacarbonyl and hexamethyldisiloxane were added as the magnetic and nonmagnetic precursor materials. The results, based on x-ray diffraction, electron microscopy. Mössbauer effect, and magnetization data have shown that: (1) nanometer composite particles are formed containing 5 to 10 nm Fe_2O_3, encased in a silica particle whose diameter ranged from 30 to 100 nm, depending on loading and flame temperature, and (2) the iron oxide clusters are magnetically isolated and in some cases show superparamagnetic behavior

M R. Zachariah, M.I Aquino, and E B. Steel (Chemical Science and Technology Laboratory), R D. Shull (U.S. National Institute of Standards and Technology). Cited. *Nanostructured Mater.,* Vol 5 (No. 4), 1995, p 383-392 [in English]. ISSN 0965-9773. PHOTOCOPY ORDER NUMBER: 199510-62-1198.

Parameterization

One-Dimensional Mathematical Model for Selecting Plasma Spray Process Parameters. A simple, unified, one-dimensional model has been developed to relate the effects of plasma spray parameters on the temperature and velocity of the plasma and particles and on the void content in the coating The torch, spray, and substrate regions in a plasma spray process were first modeled independently and then coupled so that the plasma and particle characteristics calculated in one region served as inputs for the subsequent region. Comparison of the model predictions with experimental data for spraying of zirconia or WC-12Co on titanium showed reasonable agreement. Deviations from the measured data were attributable to the simplifying assumptions used in modeling the different regions of the process. A parametric analysis of the unified one-dimensional models showed that, despite its simplicity, the model is well suited for optimizing process parameters in terms of particle type and size to obtain high-integrity coatings.

S. Das (University of Detroit), U Chandra, K. Sampath, and V.K. Suri (Concurrent Technologies). Cited. *J. Therm Spray Technol.,* Vol 4 (No. 2), June 1995, p 153-162 [in English]. ISSN 1059-9630 PHOTOCOPY ORDER NUMBER. 199510-57-1209.

Particle Trajectory

Particle Trajectory Control with the Use of Different Carrier Gases. The influence of various carrier gases on the plasma jet, particle behavior and Ni-5Al coating quality are investigated. Argon, helium, and nitrogen have been used for comparison. The coating characteristics that are considered include coating thickness distribution, porosity, and unmelted particle distribution. The particle trajectories and velocities, the luminous jet geometries, and the plasma jet fluctuations are also compared by using the LaserStrobe Vision system and computerized image analysis.

K Leung, J. Heberlein, and E. Pfender (University of Minnesota). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 39-43 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1381.

RF Spraying of Chromium

Manufacture of Thick Chromium Coatings by RF Plasma Spraying for PVD Sputter Targets. The purpose of this research is to compare the hard chromium plating with the coatings on aluminum substrate and carbon steel substrate by the plasma spray method. The coating materials to be used were ceramics and cermets The post-treatments (HIP and post heat treatment) were introduced to improve the physical properties of the coatings to be made by plasma spray process. The coating layers were examined by SEM, TEM, and XRD. The scratch test and wear test were used to evaluate the plasma spray coatings. The wear resistance of Al_2O_3 system is better by 150% than that of the hard chromium plating. The HIP process created the interdiffusion and the cell structure was observed by TEM according to the cooling rate of the molten particles.

M. Muller and R.B Heimann (Freiberg University of Mining and Technology); M.I. Boulos and F. Gitzhofer (Universite de Sherbrooke) Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 573-577 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-58-1418.

Self-Propagating High-Temperature Synthesis

Low Pressure Plasma Sprayed SHS $MoSi_2$/SiC Composite Coatings. Self-propagating high-temperature synthesis (SHS) is a novel, economical, method of producing intermetallic composite powders. These materials have potential applications in high-temperature engine components and burner nozzles, enabling higher operating temperatures and fuel efficiencies

to be achieved. SHS $MoSi_2$/SiC composites with up to 30 vol% of the SiC reinforcing phase have been produced and successfully consolidated by low pressure plasma spray. Microstructural characterization of the powders and sprayed coatings, and measurements of mechanical properties (fracture toughness) indicate that plasma sprayed SHS materials exhibit properties superior to those of conventionally produced $MoSi_2$ materials.

R Knight, M. Mohanty, and R.W. Smith (Drexel University), E.A. Shtessel (Exotherm). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 743-748 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER: 199512-62-1542.

Sol-Gel of TBCs

Sintering of Plasma-Sprayed Sol-Gel Zirconia-Yttria as a Function of Silica Content. Recent work has demonstrated that the thermal fatigue life of thermal barrier coatings (TBC) plasma sprayed with sol-gel processed zirconia 7 wt% yttria increased by a factor of five when the silica content was reduced from 1.0 to 0.1%. Because the increase in life did not appear to be related to any observable difference in microstructure as a function of silica content, it was speculated that the change in life was due to differences in sintering or time-dependent deformation of the coatings during thermal exposure. The sintering rates were examined for coatings containing 0.1 and 1.0% silica. The measurements indicate an increase in sintering with increasing silica content. Sintering of thermal barrier coatings has been related to increases in elastic modulus and strength in plasma sprayed zirconia. These properties will affect the stress levels in the ceramic layer of the TBC and are therefore expected to influence the thermal fatigue life of the coating. Preliminary deformation studies included in the current program suggest that the 0.1 and 1.0% silica coatings exhibit different dependence of deformation on the strain rate. However, the effect of the difference in deformation on TBC life is unclear since the failure mechanisms during thermal fatigue are not well understood.

J.G. Goedjen, W J. Brindley, and R A Miller (NASA Lewis Research Center). Cited: *1995 Advances in Thermal Spray Science and Technology,* Proc. 8th National Thermal Spray Conf (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 73-77 [in English]. ISBN 0-87170-541-9. PHOTOCOPY ORDER NUMBER. 199512-57-1515.

Surface Treatment

Effect of Surface Treatment for Metals by Transferred Arc. Low pressure plasma spraying is well suited for high-temperature corrosion-resistant coatings of gas turbine components In this coating process, coating adhesion is an important problem, and so surface roughness and cleaning achieved by the transferred arc treatment with negative substrate polarity have to be investigated in order to improve the adhesion. An experimental investigation was conducted to clarify the effect of the transferred arc treatment on the bonding strength of sprayed coatings of NiCoCrAlY alloy. As a result, it was verified by SEM observations that surface cleaning and surface roughening could be made by the transferred arc treatment in case of IN738LC, SUS304, tungsten, and copper It was also confirmed that grit blasting before the transferred arc treatment was effective for the uniformity of surface cleaning and roughening, which improves the adhesion of sprayed coating. It was confirmed that the surface roughness achieved by the transferred arc treatment could be evaluated by thermal conduction parameter $c \cdot \rho \cdot (T_m - T_0)$, c, specific heat; ρ, density, T_m, melting point; T_0, initial temperature.

Y. Itoh, K. Honda, M. Miyazaki, and M Saitoh (Toshiba) Cited. *J. Soc Mater. Sci., Jpn.,* Vol 44 (No 498), March 1995, p 303-308 [in Japanese] ISSN 0514-5163 PHOTOCOPY ORDER NUMBER: 199512-58-1449.

VPS of NiCrAlY

Vacuum Plasma Technique of Protective Coatings Production of Complex Alloys. The process of vacuum plasma deposition of Ni-Cr-Al-Y system alloys is under consideration. The energy of bombarding particles ranged within 10 to 10^3 eV. Plasma jets consisted of multicharge ions of alloy elements, microdrops of cathode material, and neutral vapor component Deposition of multiphase plasma resulted in coatings with heterogeneous structure with an amorphous phase. Annealing of coatings at 1000 to 1050 °C for 3 to 4 h promoted formation of pronounced microcrystalline structure of high plasticity and thermal stability Vacuum plasma deposited coatings have high adhesion to the substrate and low porosity. The only disadvantage of coatings is marked to be an increased surface roughness when their thickness exceeds 50 μm.

E.N. Kablov and S.A Muboyadzhyan (All-Russian Institute for Aviation Materials, Moscow). Cited. *Metalloved Term. Obrab Met*, No 2, Feb 1995, p 15-18 [in Russian]. ISSN 0026-0819. PHOTOCOPY ORDER NUMBER 199510-58-1137.

Properties

High-Temperature Corrosion

High-Temperature Corrosion Performance of Plasma Sprayed CrNiMoSiB Coatings. The effects of application parameters for plasma spraying and CO_2-laser glazing of two types of chromium-base coatings were examined Coatings were deposited by low-pressure and atmospheric plasma spraying. The high-temperature corrosion resistance of Cr-Ni-2.5Mo-1Si-0.5B (55 and 58% Cr) coatings was evaluated with respect to structural and compositional changes both in the as-sprayed condition and after CO_2-laser glazing Coatings that were deposited by atmospheric plasma spraying and subsequently laser glazed showed excellent resistance to oxidation and sulfate-vanadate attack at 900 °C due to the formation of a protective chromia film and a high silica concentration on the top layers of the oxide.

Y Longa-Nava and M. Takemoto (Aoyama Gakuin University); K. Hidaka (Fukuda Metal Foil and Powder Industrial). Cited: *J. Therm. Spray Technol.,* Vol 4 (No 2), June 1995, p 169-174 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER 199510-58-1112.

Review

PVD-Based Processes

Plasma-Based Surface Engineering Processes for Wear and Corrosion Protection. Vacuum plasma-based coating and treatment methods have considerable potential for reducing wear and corrosion However, they have not been widely applied to engineering components other than tools such as those used in metal cutting This is due to several factors, not least of which are cost and an unsuitability for cheaper substrate materials. Six plasma-based processing routes that can widen the applicability of these processes and ensure greater market penetration are discussed. The methods are: duplex plasma nitriding plus physical vapor deposition (PVD) coating, low-temperature plasma diffusion treatment, postcoat plasma nitriding, layered diamondlike carbon/metal carbide PVD/chemical vapor deposition coating, thick metal/metal nitride (PVD coating), and duplex electroless nickel plus PVD coating. The characteristics of these methods are discussed, especially with regard to their beneficial influence on wear or corrosion of 431 martensitic stainless steel and 316 stainless steel coatings on mild steel substrates.

A. Mathews, M Bin-Sudin, B. Dorn, A Leyland, C Rebholz, J. Schneider, P.R. Stevenson, and A. Voevodin (University of Hull). Cited· *J. Vac. Sci. Technol. A,* Vol 13 (No. 3, Part I), May-June 1995, p 1202-1207 [in English] ISSN 0734-2101. PHOTOCOPY ORDER NUMBER: 199511-57-1319

Testing

NDT Quality Control

Quality Control of Thermal Sprayed Coatings with an Optoelectric Sensor. This paper reports on the development of a fully optoelectronic optical sensor that has been used for investigations concerning quality control of the high-velocity oxygen fuel (HVOF) flame spraying process Focus was on the following parameters: WC with cobalt, CoCr, nickel at $T < 500$ °C, and Cr_3C_2 with Ni-Cr, Ni at $T < 900$ °C. Until recently, there was no nondestructive testing (NDT) approach for flame spraying available, which is a major drawback for many critical applications, such as in the aerospace industry. For example, while cooling down after spraying, cracks in the coating may occur caused by strain. Furthermore, edges may cause similar damage to the coating The idea was to provide the flame spraying industry with a measurement technology that is applicable in the workshop, has a contactless principle of operation, and is fast compared to the commonly used metallography or scanning electron microscopy. The approach is designed for use close to the process; i.e , coating morphology was not the focus of investigations On the contrary, quality-related information was extracted from surface microtopography, which can be obtained in a nondestructive and affordable manner Main points covered in this paper are theoretical considerations, the operational principle and construction of the sensor head, and quantitative metrology of surface damage such as variations in rms-roughness and cracks.

H. Rothe, O Brandt, and A Kasper (Universitat der Bundeswehr). Cited *1995 Advances in Thermal Spray Science and Technology,* Proc 8th National Thermal Spray Conf. (Houston, TX), 11-15 Sept 1995, ASM International, 1995, p 481-485 [in English] ISBN 0-87170-541-9 PHOTOCOPY ORDER NUMBER 199512-57-1544

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