Selected Abstracts of Thermal Spray Literature

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Applications

Adhesive Bond

The Thermal Spraying of Aluminum as an Adhesive-Bond Pretreatment. Adhesive bonding is commonly used for the joining of aluminum in the aerospace industry and is increasingly used in the automotive and construction industries. Aluminum's low density and reduced corrosion susceptibility are key drivers for its use in the replacement and refurbishing of bridges. Before adhesively bonded aluminum can play a significant role in this application, however, a surface treatment for aluminum adherents must be developed that is environmentally acceptable, suitable for field or on-site application, stable under moist conditions, and cost effective. One such promising technology involves the use of thermal spray treatments.

G.D. Davis. Cited: *JOM*, Vol 49 (No. 5), May 1997, p 25-27 [in English]. ISSN 1047-4838. PHOTOCOPY ORDER NUMBER: 199803-55-0861.

Aircraft Hookpoints

HVOF Coatings for Heavy-Wear, High-Impact Applications. The hookpoint used on A-4 aircraft for arrested landing is exposed to various forms of heavy wear and impact. Nowhere is this more true than training field landings, where the hookpoint is subjected to drag along a concrete runway for possibly thousands of feet while flying at high speeds and heavy downloads. After extensive screening, a series of materials were subjected to special impact tests and concrete wear tests. Ten coatings, applied by thermal spray, were selected for future arrestment testing on the basis of these results. Test samples were made of 3340V alloy steel, the material used for hookpoint manufacture. Coating systems used were cemented carbides (Co-WC and 25NiCr-CrC), fusible alloys (Metco 15, Colmonoy 88, Fused Metco 12C), cobalt alloys (Stellite 6, Stellite 21, Stellite 25), molybdenum alloys (Tribaloy T-400, Tribaloy T-800), and amorphous ferrochromes (Armacor M, Ducor). Deposition methods were HVOF, PTA, and wire arc.

L. Moskowitz and K. Trelewicz. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 294-299 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-58-0022.

Biomaterials

Post-Spray Hot Isostatic Pressing of Plasma Sprayed Ti-6Al-4V/Hydroxyapatite Composite Coatings. A series of Ti-6Al-4V/hydroxyapatite (HA) composite coatings was produced by plasma spraying. Several compositions (20, 33, and 80 wt% HA) were prepared. Subsequent examination of the coatings showed them to have a high level of porosity. However, some amount of porosity, within a specified size range, may be desirable in biomedical applications to enhance bony tissue in-growth, although interlamella pores in the size range 10 to 300 nm (100 to 3000 Å) in the plasma sprayed coatings are detrimental to their mechanical properties, and these small pores should be reduced drastically in order for the coatings to have sound mechanical strength. Hot isostatic pressing (HIP) is applied in this study to reduce the amount of micropores in the plasma sprayed coatings. The influence of HIP temperature on the pore size distribution, microstructure, and other physical properties of the composite coatings is investigated. Scanning electron microscopy revealed that the lamellae in the HIP samples appeared "compressed" because of the plastic deformation of the Ti-6Al-4V phase. A mercury intrusion porosimeter measured the pore size distribution of the HIP samples, the results indicating that the majority of the micropores, most likely interlamella pores, are reduced drastically after HIP. A dynamic mechanical analyzer is employed to measure the storage modulus of the composites by a three-point bend fixture, the results showing that the storage modulus of the 20 and 33 wt% HA coatings improved with HIP and that there is a corresponding increase with the HIP temperature employed. Other physical properties such as density and microhardness also improved with HIP. Overall, the results demonstrate that HIP can effectively enhance the mechanical properties of the Ti-6Al-4V/HA composite coatings. Tensile adhesive bond tests show that interface between the coating and the substrate to be improved. The mode of failure apparently transferred from adhesive failure in the as-sprayed coatings to a predominantly cohesive mode of failure in the HIP samples and suggests that the influence of HIP is greater in the enhancement of the coating/substrate interface than in interlamellae strengthening.

K.A. Khor, P. Cheang, and C.S. Yip. Cited: *J. Mater. Process. Technol.*, Vol 71 (No. 2), 15 Nov 1997, p 280-287 [in English]. ISSN 0924-0136. PHOTOCOPY ORDER NUMBER: 199802-58-0229.

Ultrastructural Features of the Bone Response to a Plasma Sprayed Hydroxyapatite Coating in Sheep. The intentions of this study were to characterize the macroscopic, microscopic, and structural aspects of a plasma sprayed implant and to thoroughly investigate bone tissue response after its implantation in sheep. Therefore, we used scanning electron microscopy, transmission electron microscopy (TEM), high-resolution TEM, x-ray diffraction, and energy-dispersive x-ray analyses. Assessment of the biomaterial prior to implantation showed a coating with irregular outlines and varying thickness, mainly consisting of hydroxyapatite (HA) covering a rough metallic implant core. Six months after insertion of the HA-coated Ti-6Al-4V implant, neither mechanical failure of the coating-substrate interface nor a significant loss of coating thickness was evident. However, an occasional lack of HA coating and phagocytosis of HA particles were noted. More generally, the implant was surrounded by well-mineralized bone investing the smallest cavities of the plasma sprayed layer. Newly formed microcrystals with size, shape, and structure similar to those of bone apatite crystals were growing directly at the coating surface. These results suggest that the bone-bonding behavior of the considered grooved implant should provide satisfactory osseointegration and be suitable for fixed prostheses.

J. Hemmerlé, S. Ertürk, and A. Önçag. Cited: *J. Biomed. Mater. Res.*, Vol 36 (No. 3), 5 Sept 1997, p 418-425 [in English]. ISSN 0021-9304. PHOTOCOPY ORDER NUMBER: 199802-12-0272.

Corrosion

Thermal Spray Coatings for Corrosion Protection: An Overview. The use of protective coatings for corrosion prevention has grown rapidly during the past decade, and thermal spray coatings represent a significant portion of this growth. An overview of the process, including materials, equipment, specific applications, and trends, is discussed. A wide range of materials is implied in the discussion, including structural steels and nonferrous alloys.

E.R. Sampson. Cited: *Mater. Perform.*, Vol 36 (No. 12), Dec 1997, p 27-30 [in English]. ISSN 0094-1492. PHOTOCOPY ORDER NUMBER: 199803-35-0466.

Corrosion Resistance

Improving the Marine Water Corrosion Resistance of Steels HVOF Coated with WC + 12% Co or WC + 10% Co + 4% Cr. The present work has been carried out in order to study the corrosion phenomena that take place when a commercial steel (34CrMo4 UNS G41350), coated with two different powders (WC + 12% Co or WC + 10% Co + 4% Cr), is submerged in marine water. Corrosion potential, potentiodynamic, and impedance spectroscopy techniques have been used. Structural evolution of the coatings during corrosion has been studied by scanning electron microscopy. The results show that corrosion takes place only at the interface between the coating metal matrix and the tungsten carbides. The coated steels have higher values of corrosion potential (E_{cor}) than the uncoated steel. The samples coated with the WC-Co-Cr powder exhibit better corrosion resistance than those coated with WC-Co. The impedance diagram in the Hyquist format indicates that corrosion takes place in localized sites, as has been confirmed by SEM techniques.

J.M. Guilemany, P.L. Cabot, J.M. de Paco, J. Fernández, and J. Sánchez. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 1, *Metals and Composites* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 771-774 [in English]. ISBN 90-803513-1-8. PHOTOCOPY ORDER NUMBER: 199802-35-0278.

Thermal Barrier Coatings

Development in Heat Barrier Coatings for Aeroengine. The thermal barrier coating (TBC) comprising ceramic materials with excellent heat-insulating functions has found wide applications to hot-end components of aeroengines. It is able to increase the efficiency of engines, decrease fuel consumption, and lengthen component life. The technological principle and equipment of plasma spraying are described as well as development in optimizing stabilizers, reducing substrate temperature, improving binding bottom layers, modifying by laser remelting, and fabricating function graded materials. A chemically bonded TBC by electron beam-physical vapor deposition exhibits seven times higher life than plasma sprayed one. The spalling mechanism and life prediction of coatings are discussed.

U.L. Cheng. Cited: *Mater. Prot. (China)*, Vol 30 (No. 2), Feb 1997, p 19-21 [in Chinese]. ISSN 1001-1560. PHOTOCOPY ORDER NUMBER: 199801-57-0105.

Thermoelectric Materials

Processing of Thermoelectric Material by Thermal Spraying. Thermoelectric generators are well known as reliable converters of thermal into electric energy. For that reason they are established in astronautics since the early 1960s. Newer research activities try to broaden the employment of thermoelectric generators to terrestrial applications. Currently, the main problem is not so much the low efficiency of conversion, but the lack of economic production methods. The work in this paper shows that the thermal spray technology can become a useful and economic process to generate thermoelectric modules compared to the classical methods of hot isostatic and hot uniaxial pressing. Aluminum and cobalt doped $FeSi_2$ powder has been consolidated by atmospheric, shrouded, and vacuum plasma spraying (APS, SPS, VPS). The microstructure, phase composition, and oxygen input have been investigated. Moreover, first attempts have been carried out to generate graded structures.

G. Langer, J. Schilz, H. Jungklaus, E. Lugscheider, and R. Mathesius. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 411-415 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0125.

Diagnostics

HVOF Processing

Acceleration Behavior of Particles in High-Velocity Oxygen-Fuel Flame Spraying of WC-Co. The representative factors that have been studied in the development of thermal spraying processes are the heating and the acceleration techniques of spray particles. As the simultaneous promotion of heating and acceleration of particles in thermal spraying, which is performed in an extremely short time, is contrary to each other, there is a limit for the attainment of both. In this study, from the point of acceleration of spraying particles, the velocity of WC cermet spraying particles in two types of high-velocity oxygen-fuel flame spraying process was measured by using a CCD video camera system with a high-speed electrical shutter. It is apparent that the particle velocity in the high-velocity oxygen-fuel flame spraying process was much higher than that in the plasma spraying process. These results were consistent with those reported previously. The driving force for higher acceleration in the high-velocity oxygen-fuel flame spraying process was discussed. As the result of the estimation of the drag force for particles in spraying fluid, it was derived that the main factors which dominated the higher acceleration were large in density and high in velocity of the combustion gas mixture gas mixture as compared with Ar-He plasma jet.

K. Tani, T. Usui, Y. Kobayashi, and J. Takeuchi. Cited: *J. Jpn. Inst. Met.,* Vol 61 (No. 7), July 1997, p 629-635 [in Japanese]. ISSN 0021-4876. PHOTOCOPY ORDER NUMBER: 199802-57-0215.

Education

Training Methods

Thermal Spray Inspection Methods and Training Requirements. Corrosion-proofing techniques go well beyond traditional painting. Thermal spray is one method that can increase the life of protective coatings and allow more exotic anticorrosion chemistry to be used. In order to take advantage of these benefits, inspection and quality control training are necessary.

C.S. Baxter. Cited: *Mater. Perform.,* Vol 36 (No. 12), Dec 1997, p 31-32 [in English]. ISSN 0094-1492. PHOTOCOPY ORDER NUMBER: 199803-35-0467.

Equipment

2 kW Small Track Plasma

Small Track Plasma Spray Coatings. A special plasma spraying process using plasma laminar jets, formed by a 2 kW power plasmatron is developed. Divergence angle of the laminar jet in its discharge to the atmospheric pressure environment is 2 to 6°. The laminar jet has a small initial cross-sectional area. These factors provide possibility for a decrease in the spraying spot size down to 1 to 3 mm and even less. It possesses a deposition small track coating on narrow fins, thin-walled and small-sized components without their essential heating and with small losses of sprayed material. The purpose of the work is development of the technology of microplasma spraying of small track coatings of 2 ± 1 mm width with the thickness of 0.2 ± 0.05 mm. The bases used for their deposition were flat samples of stainless steel (Fe17Cr8Ni, ~150 HV) of 0.5 mm thickness and of aluminum alloy (Mg = 0.5 to 2%, Si = 0.5 to 1.5%, Mn-0.2-1.5%, 100 HV) of 1 mm thickness, and rods of the above aluminum alloy of 6 mm diameter, quenched tool steel (C = 1.55 to 1.75%, Cr = 11 to 12%; W = 0.4 to 0.6%, Mo = 0.5 to 0.7; Si = 0.25 to 0.4%, Mn = 0.2 to 0.4%, V = 0.07 to 0.12%, 62 HRC) of 2 mm diameter and annealed tool steel (C = 1.1 to 1.3%, Cr = 0.04 to 0.8%, V = 0.08 to 0.15%, 250 HV) of 3 mm diameter.

Yu. Borisov, H. Marijnissen, G. ta Raa, V. Bobric, V. Darmochval, J.M. Houben, and P.P.J. Ramaekers. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 231-236 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0115.

Axial Plasma

Potential of the APS Technology with Axial Powder Injection—Comparison of Layers and Economical Aspects. For many years, thermal spraying technology has been considered to be a proven technique for depositing functional coatings and compound materials because of the almost unlimited combinations of coating of base materials available. Especially, high-energetic plasma spraying enables us to process all kinds of materials from low-melting plastics to high-melting metals and ceramics. But still the main disadvantage of this technology is the high powder loss caused by radial powder injection. Now, newly developed plasma spray systems are available that allow deposition efficiencies (DE) up to 95%. This is achieved by a newly designed plasma torch with axial powder injection. In this paper, results will be presented that were obtained with an APS system with axial powder injection. To estimate the potential of such a system, the results will be compared to conventionally produced coatings. It will be shown that axial powder injection leads to DEs ranging from 70 to 95%, with good properties of the layers. Besides the quality of the layers, the costs of a coating play an important role, and the paper closes with some economic considerations concerning the process.

I. Rass and U. Morkramer. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 195 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0124.

Microplasma

Microplasma Spraying. Equipment for microplasma spraying using a 2 kW power plasmatron has been developed. The equipment allows deposition of coatings on narrow fins, thin-walled components and other pieces without essential heating of these parts. Experiments on microplasma spraying of metal coatings are described. Fields of practical application of microplasma spraying are defined.

Yu. Borisov, A. Borisova, Yu. Pereverzev, S. Voynarovitch, and P.P.J. Ramaekers. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 237-241 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0116.

Feedstock

Alumina

Alumina-Base Plasma-Sprayed Materials. I. Phase Stability of Alumina and Alumina-Chromia. Aluminum oxide is a relatively inexpensive, abundant material that is widely used for plasma spray applications. This material, however, exists in many crystallographic modifications with different properties. In addition, most of these modifications are metastable and cannot be used in applications employed at elevated temperatures. Usually, γ, δ, or other phases form after spraying, while α phase (corundum) is often the most desirable phase due to high corrosion resistance and hardness. This paper first reviews the method of α stabilization in the as-sprayed materials offered in literature. Then, as an example, it summarizes the results of an extensive study of chromia additions to alumina. Chromia was chosen because of its complete solid solubility in alumina and its crystal lattice type, which is similar to that of alumina. It was demonstrated that the addition of approximately 20 wt% chromia results in the formation of one solid solution of $(Al\text{-}Cr)_2O_3$ in the α-modification. Finally, this paper discusses the thermal stability of various alumina phases. Phase change routes of heating for different starting alumina modifications are discussed, and a case study of alumina-chromia is presented. Both types of as-sprayed structures, a mixture of α, δ, and γ phases, and 100% $(Al\text{-}Cr)_2O_3$ were annealed up to 1300 °C and the phase composition checked. At lower temperatures and shorter holding times, the amount of α phase decreases while another metastable χ phase appears, and the fraction of γ + δ, if present, increases. At temperatures above 1100 °C, the amount of α phase increases again.

P. Chráska, J. Dubsky, K. Neufuss, and J. Písacka. Cited: *J. Therm. Spray Technol.,* Vol 6 (No. 3), Sept 1997, p 320-326 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-57-0037.

Boron Carbide

Application of Boron Carbide in Gas Thermal Coatings. Boron carbide-based coatings on metallic parts have the most durability. Preliminary nickel cladding is used to prevent boron carbide decomposition. The coating conditions are optimized over its hardness during development of the plasma coating process. The coefficients of regression for process optimization equation are determined with the help of personal computer computations. It was found that the durability of a plasma sprayed layer is equal to 290 to 310 h under conditions of intensive abrasive wearing.

A.V. Kalashnikov. Cited: *Svar. Proizvod.*, Vol 6, June 1997, p 29-31 [in Russian]. ISSN 0491-6441. PHOTOCOPY ORDER NUMBER: 199801-55-0167.

Cored Wires

Development of Cored Wires for Improving the Abrasion Wear Resistance of Austenitic Stainless Steel. Arc sprayed coatings are an attractive means to protect components from abrasive wear provided they contain enough hard phases. Because of their hardness and toughness, 316L-TiB_2 cermets were selected as the basis for developing wear-resistant coatings. Cored wires composed of type 304 stainless steel sheaths filled with 10 to 65 wt% TiB_2, 1 to 15 wt% additives, and the balance with 316L stainless steel were fabricated and arc sprayed with air. The arc sprayed stainless steel-TiB_2 coatings were abrasion tested and the volume loss measured with an optical profilometer. The volume loss decreased as the proportion of TiB_2 increased. However, large differences in volume loss between coatings that contain about the same volumetric proportion of hard phases cannot be explained by a linear relationship. An inverse rule of mixing was proposed and found useful in determining the influence of different additives. Tin, added in the core as a fugitive liquid transfer agent, was the most powerful additive for improving the wear resistance of stainless steel-base coatings. These advanced arc sprayed stainless steel-TiB_2 coatings exhibit greater wear resistance than those obtained by arc spraying commercial solid and cored wires.

S. Dallaire and H. Levert. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 4), Dec 1997, p 456-462 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199803-57-0373.

Magnesium Alloys

Thermal Spraying on Magnesium Alloys to Improve the Corrosion and Wear Resistance. This paper reviews first results of three different thermal spray techniques (arc, plasma and HVOF spraying) on magnesium alloys. Microstructure, hardness, wear resistance, corrosion behavior, and bending strength of NiCrFeSiB and aluminum coatings were investigated.

A. Weisheit, U. Lenz, and B.L. Mordike. Cited: *Metall*, Vol 51 (No. 9), Sept 1997, p 470-474 [in German]. ISSN 0026-0746. PHOTOCOPY ORDER NUMBER: 199803-58-0342.

Molybdenum Disilicide

Recent Advances in Sintering and Plasma Spraying of $MoSi_2$. Refractory metal silicides represent an important class of materials with significant potential applications in the range of 1200 to 1600 °C under oxidizing and aggressive environments. Silicides, particularly those based on $MoSi_2$, are considered to be promising due to their combination of high melting point, excellent oxidation resistance, and an appropriate thermal and electrical conductivity. Potential structural uses include aircraft and power generation, hot-section components, high-temperature heat exchangers, gas burners, and igniters. Plasma sprayed $MoSi_2$ coatings may protect refractory metals, carbon-base materials, and porous ceramics.

C. Deiser, F. Jansen, and E. Lugscheider. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 215-218 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0113.*

Preparation by Thermal Spray

Production of Thermal-Spray-Quality Metal and Alloy Powders by Plasma Processing. Feedstock powders of metals, alloys, and ceramics for thermal spray applications have to meet several specifications. Particle shape, size, and distribution, powder flow characteristics, and density are the important factors that need to be controlled in order to ensure high spray efficiency and better coating properties. Thermal plasma technology can be effectively utilized to produce metal, alloy, and ceramic powders for spray applications. The present paper describes plasma spheroidization of commercially available aluminum powder and nickel-aluminum powder blend in a plasma reactor. Results show that the processed powder particles bear spherical morphology with excellent flow characteristics, which make them ideal for thermal spray applications.

P.V. Ananthapadmanabhan, K.P. Sreekumar, N. Venkatramani, and P.R. Taylor. Cited: *EPD Congress 1997* (Proc. Conf.), Orlando, FL, 9-13 Feb 1997, Minerals, Metals and Materials Society/AIME, 1997, p 209-215 [in English]. ISBN 0-87339-367-8. PHOTOCOPY ORDER NUMBER: 199803-54-0183.

Rhenium-Containing Metal Alloys

Rhenium-Containing Plasma Sprayed NiCoCrAlY Coatings with Improved Oxidation and Interdiffusion Properties. The effect of rhenium additions on the oxidation behavior of various NiCoCrAlY coatings and their interdiffusion properties with an IN 738 substrate at 1000 °C was studied. The results showed that the effect of rhenium depends on the actual coating composition. In coatings with cobalt and chromium contents of ~20%, rhenium appeared to decrease the extent of oxidation and interdiffusion-induced β-phase dissolution. High amounts of rhenium (≥5 wt%) led to coating embrittlement due to excessive α- and σ-phase precipitation.

W.J. Quadakkers, H. Hoven, F. Schubert, E. Wallura, N. Czech, and W. Stamm. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 209-214 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0112.

WC-Co

Microstructural and Analytical Study of Thermally Sprayed WC-Co Coatings in Connection with Their Wear Resistance. The microstructure of high-velocity oxyfuel (HVOF) thermally sprayed WC-Co coatings was quantitatively evaluated in an attempt to describe the transformations that take place during thermal spraying. Slurry erosion tests were performed to measure the weight loss as a function of flow velocity and incident angle. It was found that an optimum amount of transformation is required to ensure a maximum of erosion resistance.

C. Verdon, A. Karimi, and J.-L. Martin. Cited: *11th International Conference on the Strength of Materials* (Proc. Conf.), Prague, Czech Republic, 25-29 Aug 1997, *Mater. Sci. Eng. A,* Vol A234-236, 30 Aug 1997, p 731-734 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199802-58-0181.

Effects of Plasma Output on the Properties of Plasma Sprayed WC-12%Co Coatings. The WC-12%Co coatings were prepared by the plasma spraying with different spraying conditions. The effects of spraying condition on the composition, hardness, adhesive strength, and abrasive wear resistance of the coatings were investigated. The experimental results obtained were as follows: 1) The composition of coatings was not influenced almost by spraying condition at output of plasma torch below 24 kW. But, in the case of output above 32 kW, the decarburization from WC to W_2C, W and the oxidation from cobalt to CoO progressed with rising output. 2) The structure of coatings decreased the number of large pores and were densified with plasma output rising from 12 to 24 kW. At the output above 32 kW, the structure of coatings were not changed remarkably with output rising. 3) The hardness, adhesive strength, and abrasive wear resistance were improved with plasma output rising from 12 to 24 kW and were the best at output of 24 kW. In the case of output above 32 kW, their property were lowered with output rising.

R. Nakamura, K. Iwanaga, and T. Tanaka. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.),* Vol 34 (No. 2), June 1997, p 78-83 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199802-58-0176.

WC-Co Cermets

Wear Behavior of Laser Cladded and Plasma Sprayed WC-Co Coatings. The usefulness of WC-Co cermets as wear-resistant material for coatings is determined by the cladding technique employed. This paper compares the features of an 83%WC-Co coating on an AISI 1043 steel substrate using two different application techniques: plasma spraying and laser cladding. Results show significantly less porosity, improved coating hardness, and better layer-substrate adherence in laser cladded than in plasma sprayed coatings. This causes them to have different wear behavior that was determined using a method developed on the basis of the PV factor theory using sliding linear contact of flat-cylinder type. The method proved that wear rate (V_d') is directly proportional to the product of coefficient of friction (μ), load (C), and applied speed (V), $V_d' = K\mu CV$, where proportionality constant, K, is different for every material and depends on conditions such as lubrication, temperature, etc. To study wear behavior, laser cladded and plasma sprayed 83% WC-Co coatings, under extreme lubrication, were placed against a hardened-and-tempered AISI 1043 steel, at different load and sliding speed rates. As a result constant K was estimated for each coating. The tests also showed that wear rate in laser-deposited coatings is ~34% lower than in plasma sprayed coatings.

M. Cadenas, H.J. Montes, J.M. Sierra, and R. Vijande. Cited: *Wear,* Vol 212 (No. 2), 10 Dec 1997, p 244-253 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199803-31-1361.

Microstructure

HVOF Coatings

Microstructure Formation of HVOF Sprayed WC-Ni Coatings Deposited on Low-Alloy Steel. A low-alloy steel was coated with WC-Ni by the

high-velocity oxyfuel process, in order to increase the wear resistance and corrosion resistance of the material. The microstructure of the coating was determined using various techniques, such as SEM, TEM, EDAX, EPMA, and x-ray diffraction methods. During spraying, the WC-Ni powder granules were heated to above the melting point of nickel, before arriving at the substrate surface. The molten nickel dissolves WC rapidly, forming Ni-W-C liquid alloys. Some carbon and some tungsten are removed from the WC particles by oxidation. When each droplet strikes the steel substrate, a pancake-shaped splat forms and solidifies with a rapid cooling rate. The structure is built up by the progressive deposition of the splats to produce a continuous coating. The Ni-W-C metallic matrix of the coatings consists of two basic structural types, nickel-rich material with a grain size of 10 to 100 nm and a fcc crystal structure with a lattice parameter larger than that of nickel indicating the presence of dissolved tungsten and carbon. The other metallic phase is tungsten-rich, with a grain size <10 nm, and in some regions it appears to be amorphous. Dispersed within this material there were sometimes small crystals of tungsten and W_2C. In the initial powder the volume fraction of WC was ~75%, but in the sprayed coating the volume fraction of the WC was reduced to ~20%. This is partly due to loss of tungsten by oxidation, but chiefly due to dissolution of tungsten into the metallic phase.

J.M. Guilemany, Z. Dong, J.R. Miguel, and J. Nutting. Cited: *Mater. Manuf. Process.*, Vol 12 (No. 5), Sept 1997, p 901-909 [in English]. ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199801-58-0033.

Nickel- and Iron-Base Coatings

Structural and Phase Transformations in the Nickel- and Iron-Base Plasma Coatings under the Effect of High Energy. Specific features of the structure and phase composition of sprayed coatings were investigated. The main physical and mechanical properties of nickel- and iron-base coatings are determined. The variation of the structure on different levels and of the phase composition of coating with the coating process subjected to the effect of strong ultrasound loading are examined. The consequences of laser and electron beam melting sprayed coatings are studied. Sample coated was steel.

V.A. Klimenov, Yu.F. Ivanov, O.B. Perevalova, and Zh.G. Senchilo. Cited: *Mater. Manuf. Process.*, Vol 12 (No. 5), Sept 1997, p 849-861 [in English]. ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199801-58-0031.

NiCr Coating

Structure and Phase Evaluation of Plasma Sprayed NiCr Coating on Aluminum Substrate after Annealing at 500 and 600 °C. The aim of this study is to supply some basic data about coating/substrate interaction during annealing for nickel, chromium, and aluminum. The specimens were prepared by atmospheric plasma spraying of Ni20Cr layer on Al (5N) substrate. The structure was evaluated by means of light microscopy, microhardness measurement, SEM, and EDS microanalysis. The specimens were studied in the as-received state and after annealing at 500 and 600 °C. The quality of plasma sprayed interface made through-interface diffusion and interface migration possible. The interface migration was relatively fast (180 μm after 200 h at 600 °C). Microanalysis revealed a complicated structure in the transition region.

J. Krejci, J. Brezina, J. Smutná, and O. Ambroz. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 223-226 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0114.

Transformation of PSZ

Transformability of *t*-ZrO_2 and Lattice Parameters in Plasma Sprayed Rare-Earth Oxides Stabilized Zirconia Coatings. Plasma spraying of R_2O_3 stabilized-ZrO_2 powders and coatings was achieved by using mechanical milling and plasma spheroidization as powder preparation steps. This process led to powders and coatings with chemically homogeneous phase and microstructures. The tetragonal phase in the Er_2O_3 and Sm_2O_3 stabilized coatings was stabilized up to 6 mol% while in the Nd_2O_3 coatings, the tetragonal phase was stabilized until 7 mol% Nd_2O_3. By comparing the amount of monoclinic phase present in as-sprayed spheroidized powders and coatings, it shows that the stabilizing effect of Sm_2O_3 and Nd_2O_3 is lower than that of the Er_2O_3 stabilizer. Also, it can be concluded that the thermal stability of Sm_2O_3 and Nd_2O_3 stabilized zirconia is inferior to that of Er_2O_3 stabilized zirconia, while that of Nd_2O_3 stabilized zirconia is the poorest. When subject to grinding, the transformability of tetragonal zirconia decreases with the decrease of its tetragonality (c/a) in all three rare-earth oxide stabilized zirconia coatings.

K.A. Khor and J. Yang. Cited: *Scr. Mater.*, Vol 37 (No. 9), 1 Nov 1997, p 1279-1286 [in English]. ISSN 1359-6462. PHOTOCOPY ORDER NUMBER: 199801-11-0083.

Modeling

Cavity Formation

On Cavities in Thermally Spheroidized Powder Particles. A melted spherical particle begins to solidify on cooling, and the radius of the first thin solid layer is approximately equal to the radius of the melted particle. Because the density of the solid phase is higher than that of the liquid one, porosity forms inside the sphere during further solidification. The pressure in the remaining melted material may decrease considerably. The requirement for a pressure balance implies that a relationship for the pore radius can be derived. The pore arises as a bubble in a boiling liquid. The bubble stability and its minimum radius are derived, as well as conditions for its formation. It is shown that, at most, one bubble can occur in the particle. Analytical results are applied to the case of alumina particles, and the growing process of the cavity is simulated. Craters found on some spheroidized particles stem from asymmetry of the solid shell formation and the simultaneous action of the atmospheric pressure. The practical importance of this effect is that additional porosity may be formed in thermal spray products.

R. Klima and P. Kotalik. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 305-308 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-54-0019.

Flattening of Particles

Flattening of Composite Powder Particles During Thermal Spraying. An investigation is conducted of the time evolution of the splat thickness, radius, and rate characteristics in the process of flattening composites (agglomerated) powder particles at smooth and rough surfaces during thermal spraying. Considerations include the splat solidification, droplet mass loss, solid volume fraction, and variations of splat-surface friction and splat solidification velocity due to the presence of the solid phase. Effective values of the droplet viscosity, impact velocity, and Reynolds number taking into account characteristic features of the flattening process are introduced, and analytical formulas describing the final values of the splat thickness, radius, and rate characteristics are established. Results can be used to predict the splat-flattening parameters. The composite powders consist of metallic binders (nickel, chromium, cobalt, etc.) and a solid phase such as carbides, oxides, etc.

V.V. Sobolev, J.M. Guilemany, and A.J. Martin. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 353-360 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-58-0025.

HVOF Process

Mathematical Modeling of the Gas and Powder Flow in HVOF Systems. A mathematical model was developed to describe the gas dynamics and heat-transfer mechanism in the gas/particle flow of high-velocity oxyfuel (HVOF) systems. A numerical solution was carried out using a PC-based computer program. One-dimensional predictions of the temperature and velocity profiles of gas and particles along the axis of flow were obtained to conduct cost-effective parametric studies and quality optimization of thermal spray coatings produced by HVOF systems. The numerical computer model allows for the variation of the HVOF system parameters, such as air/fuel ratio and flow rates, cooling water inlet temperature and flow rate, barrel length, standoff distance, particle size, and gun geometry. Because of the negligible volume of the powder relative to the gas, the gaseous phase was modeled as continuous nonadiabatic, and friction flow with variable specific heats and changing cross-sectional areas of flow. The generalized continuity, momentum, and energy equations with the influence parameters were used to model the gaseous flow regime and predict its thermodynamic properties. Empirical formulas for the mean axial decay of both velocity and temperature in the supersonic jet plume region were generated from published measurements of these parameters using laser Doppler velocimeter and Rayleigh scattering techniques, respectively. The particle drag and heat-transfer coefficients were calculated by empirical formulas in terms of Reynolds, Nusselt, and Prandtl numbers to evaluate both the momentum and heat transferred between the combustion gases and the powder particles. The model predictions showed good agreement with the particle and gas temperature and velocity measurements that are available in the literature.

H.H. Tawfik and F. Zimmerman. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 345-352 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-57-0038.

Modeling of Substrate-Coating Thermal Interaction During High-Velocity Oxyfuel (HVOF) Spraying of WC-Ni Powder. The mathematical simulation of thermal processes occurring during the formation of a WC-Ni coating on a low-alloy steel by HVOF spraying has been carried out. The factors assessed during the simulation include overall temperature changes, the solidification of the coating, the melting and subsequent solidification of the interface regions of the substrate, and the thermal interactions between different layers of the coating. The mathematical simulation of parameters that could influence the structural characteristics of the coating and the interfacial region of the substrate has also been undertaken. The variations in the solidification velocity, the thermal gradients, and the cooling velocity in the first

layer of the coating have been determined. Similar parameters have been determined for the substrate, but in this case attention has also been given to the melting velocity. The influence of these parameters on the formation of amorphous and noncrystalline structure in the coating is discussed together with the development of fine crystalline structures in the interfacial region of the substrate. The results obtained agree well with those obtained by direct metallographic examination of the coating and the substrate interfacial regions. The optimum conditions for the formation of good structures in the coating and the adjacent substrate are estimated.

V.V. Sobolev, J.A. Calero, J.M. Guilemany, and J.R. Miguel. Cited: *Mater. Manuf. Process.*, Vol 12 (No. 5), Sept 1997, p 877-899 [in English]. ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199801-58-0032.

Processing of Coatings

Mathematical Modeling and Methods of Calculation of Construction Elements Surface Strengthening by Plasma Spraying. The generalization of the mathematical model of processes occurring in the preparation of gas-thermal coatings for computing radiation energy, thermal effects of turbulent flow of the gas jet of a plasmatron, spraying distance, and required degree of preliminary heating (cooling) of the base has been elaborated. The boundary conditions obtained describe the radiational and convective heat exchange of bodies with a medium through thin coatings with regard for the speed of flow of the gas jet. The analytical and numerical procedures of solving problems of mathematical physics with nonclassical boundary conditions have been built. The mathematical model that is proposed makes it possible to compute rational regimes of spray coating, residual stress levels, and other characteristics on every typical stage of spraying process (preliminary heating or cooling of the base, spraying, and following thermal treatment) in order to obtain coatings with improved properties.

O. Gavrys and P. Shevchuk. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 253-256 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0118.

Multilayers

Fracture Behavior

Transformation-Toughened Ceramic Multilayers with Compositional Gradients. The processing and the thermomechanical characteristics of zirconia-toughened alumina (ZTA) ceramic multilayers, with through-thickness gradients in the concentrations of the tetragonal and monoclinic zirconia phases, are studied both theoretically and experimentally. Analytical solutions for the evolution of thermal strains, internal stresses, and the overall curvature changes in response to various temperatures were derived using known plate theory formulations. Compositionally graded multilayer stacks and complex shapes of ZTA ceramics were fabricated by three-dimensional printing (3DP). The relative fractions of the tetragonal to monoclinic ZrO_2 phases were varied in a prescribed fashion. Phase transformation of ZrO_2 in ZTA during cooling from the sintering temperature was controlled by doping different amounts of Y_2O_3 through the thickness of the ZTA multilayer plate. The local content of monoclinic ZrO_2 through the thickness was characterized by x-ray diffraction analysis. The microstructure, some basic mechanical properties, and thermal expansion behavior of the 3DP ZTA system were also characterized. Thermally induced curvature of the ZTA multilayer plate was measured, and the experimental results were compared with the predictions based on the analytical solutions. Symmetric ZTA multilayers with surface compression were also prepared by 3DP and tested for flexural strength. Results showed a significant increase in strength from the monolithic specimens to the compositionally controlled ones. Results from the compression tests of notched ZTA blocks demonstrated the role of m-ZTA shield zones in enhancing the load-bearing characteristics. This study also demonstrated the possibility that commonly available computational tools can be used to design and construct complex shapes with compositional variation to enhance and control mechanical properties.

J. Yoo, W.S. Bae, K.-M. Cho, M. Cima, and S. Suresh. Cited: *J. Am. Ceram. Soc.*, Vol 81 (No. 1), Jan 1998, p 21-32 [in English]. ISSN 0002-7820. PHOTOCOPY ORDER NUMBER: 199803-E4-D-0112.

Nondestructive Evaluation

Infrared Sensor

Integrated Infrared Sensor System for On-Line Monitoring of Thermally Sprayed Particles. The structure and properties of thermally sprayed coatings depend directly on the state of the particles before impact on the substrate or the already deposited coating layers. Monitoring particle parameters can thus provide a unique tool for optimizing coating properties and controlling spraying processes during coating deposition. In this paper, a new optical sensing device for on-line monitoring of temperature, velocity, diameter, and trajectory of in-flight particles during coating production is described. Thermal radiation emitted by in-flight particles is collected by a sensing head that can be attached to the gun providing continuous monitoring of the spray process. The collected radiation is transmitted through optical fibers to a detection cabinet located away from the dusty environment around the operating spray gun. Tests were carried out on two identical plasma torches with significant differences in deposition efficiency. Measured particle flow rates were in agreement with efficiency differences.

J. Blain, P. Gougeon, L. Leblanc, C. Moreau, F. Nadeau, and L. Pouliot. Cited: *Surf. Eng.*, Vol 13 (No. 5), 1997, p 420-424 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199803-58-0364.

Post-treatment

Flame Spraying

Characteristics of Heat Treated Tungsten Carbide Embedded Nickel-Base Hard Surfacing on Structural Steel Produced by Gas Thermal Spray Process. Hard surfacing (1.2 to 1.4 mm thick) of mild steel substrate was carried out by thermal spraying of commercially available nickel-base tungsten carbide powder under a neutral oxyacetylene flame. At different preheat levels of 573 and 623 K, the influence of postspray heating, at 873, 1023, and 1173 K on microstructure of the substrate adjacent to interface, morphology, hardness, and friction characteristics of the coating was studied. During thermal spraying a dark band of carbon-rich microstructure (pearlite) was found to form in the mild steel adjacent to the interface, but this was diffused under the postspray heat treatment. Hardness of the matrix and embedded tungsten carbide particles of the coating was found to be comparatively higher and lower, respectively, in the region close to the coating surface than that observed in the region close to its interface with the mild steel. Hardness of the matrix and tungsten carbide particles of the coating was relatively increased with the rise in preheating temperature, but hardness was enhanced considerably with the increase in temperature of postspray heating. As a result, coefficient of friction of the coating was found to decrease, relatively and considerably, with the increase of preheating and postspray heating temperatures, respectively.

P.K. Ghosh and N. Ram. Cited: *Int. J. Join. Mater.*, Vol 9 (No. 3), Sept 1997, p 114-121 [in English]. ISSN 0905-6866. PHOTOCOPY ORDER NUMBER: 199803-58-0357.

HVOF Coatings

Effect of Heat Treatment on Characteristics of High-Velocity Oxygen-Fuel Flame Sprayed Coatings (WC-27 mass% NiCr). The effect of heat treatment on the characteristics of WC-27 mass% NiCr sprayed coatings on 13% Cr steel made by the high-velocity oxygen-fuel (HVOF) flame spraying was studied. Specimens were heated to 673 K and held at 5, 10, 20, and 30 h in air. Corrosion resistance was measured by a salt-spray test (CASS test) and strength was measured by a three-point bend test. The results obtained were as follows: (1) Corrosion resistance increased with heating time. This increase is dependent on the surface void ratio of the sprayed coatings that decrease as the temperature increases. (2) The three-point bending strength decreases at 5 h heating, and increases again with continued heating. The initial decrease at 5 h heating was due to release of compressive stress in the coatings, and the increase afterward was due to the surface void ratio decreasing.

R. Okada. Cited: *J. Jpn. Inst. Met.*, Vol 61 (No. 7), July 1997, p 625-628 [in Japanese]. ISSN 0021-4876. PHOTOCOPY ORDER NUMBER: 199802-57-0214.

Laser Remelting

Cermet Ni-Cr/Cr_3C_2 Coating Optimization by Superficial Laser Remelting. Plasma spraying is often used to create coatings protecting parts against physical and chemical aggression or improving superficial mechanical properties. The projection of ceramic or cermet coatings involves several problems because of the high temperatures of the process: cracks, porosity, coating adhesion, residual stress. The authors study the optimization of cermet coating Cr_3C_2/Ni-Cr (deposited on NiCrAlY covered steel) using a superficial remelting by laser. The treatment is realized under nitrogen as protection gas (pressure: 0.4 bar) with a CO_2 nonfocused laser beam (diameter: 0.8 mm). The variable parameters are the laser power (80 to 410 W), the scanning velocity (0.5 to 7 m/min), and the overlap rate (0 to 100%). The microstructural and the mechanical studies are consistent and clarify the influence of the treatment parameters. It is shown that the cermet microstructure is refined and homogenized by the laser treatment. The cracks and porosity are reduced. There is not any segregation phenomenon. The scanning velocity acts upon the coating hardness and leads to a hardness gradient increasing with the velocity value. The final coating thickness depends too on the velocity. The adhesion between steel and coating is determined by interfacial indentation test; the decohesion occurs at cermet/NiCrAlY interface. A coating fracture toughness/residual stress ratio (K_{ic}/σ_r) is introduced. It is characteristic of the

interfacial behavior, and it allows treatments grading. The residual (tensile) stress is never relaxed. The optimum laser treatments in that study are: medium laser power (212 W), medium overlap rate (50%). The scanning velocity depends on the desired hardness or mechanical properties.

P. Hivart, J.-P. Bricout, J. Crampon, and J.-C. Walrick. Cited: *Matér. Tech. (Paris)*, Vol 85 (No. 1-2), Jan-Feb 1997, p 43-50 [in French]. ISSN 0032-6895. PHOTOCOPY ORDER NUMBER: 199803-58-0252.

Pretreatment

Influence on Adhesion

The Influence of Pretreatment on the Adhesion of Ceramic Coatings on Steel. Pretreatment of the substrate in the form of grit blasting is shown to exert a critical effect on coating adhesion. The adhesion of plasma sprayed alumina coatings increases linearly with the average roughness of the substrate and reaches a maximum at an optimum peak spacing. The optimum spacing is found to increase with increasing particle size of the feedstock powder. The underlying mechanism of this behavior is shown to be related to the effect of the microgeometry of the substrate surface on the flow of the impacting molten particles. The optimum pretreatment provides a surface texture that suppresses splashing by dissipating the kinetic energy of the incoming droplets. Material used was plain carbon steel, 080M40 grade.

D.T. Gawne, G. Dong, and B.J. Griffiths. Cited: *Trans. Inst. Met. Finish.*, Vol 75 (No. 6), Nov 1997, p 205-207 [in English]. ISSN 0020-2967. PHOTOCOPY ORDER NUMBER: 199802-57-0285.

Process

Electric Arc

Electric Arc Deposition of Carbon Steel Coatings with Improved Mechanical Properties. To achieve high deposition rate and efficiency, electric arc spraying has been routinely used to deposit carbon steel coatings. Although retention of carbon in these coatings is poor due to the use of compressed air during spraying, the coatings are sufficiently hardened by brittle iron oxide inclusions to be suitable for hardfacing mechanical components used in mild adhesive and abrasive wear environments. However, carbon steel coatings can be employed for hardfacing mechanical components used in more aggressive wear environments, provided they are hardened by the carbon retention rather than by iron oxide inclusions. Therefore, to increase retention of carbon, reduce inclusion of iron oxides, and improve hardness and wear properties of carbon steel coatings, deposition experiments were carried out using an inexpensive nitrogen, which is produced on-site by a pressure swing adsorption or a membrane separation system, instead of compressed air during spraying.

Z. Zurecki, D. Bowe, and D. Garg. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 4), Dec 1997, p 417-421, [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199803-58-0300.

HVOF

Thermal and Mechanical Properties of High-Velocity Oxygen-Fuel Sprayed MCrAlY Coatings. The high-velocity oxygen-fuel (HVOF) system in air has been established for producing various coatings that are extremely clean and dense. It is thought that the HVOF sprayed MCrAlY (M is Ni, Co, or Fe) coating can be applied to protect the oxidation and corrosion in the hot section of gas turbines. Also, it is well known that thicker coating can be sprayed by this system for improving the residual stress in comparison with any other thermal spraying system. However, the mechanical properties of HVOF coating have not always been clarified. In this paper, the mechanical properties were measured in order to compare with a low-pressure plasma sprayed MCrAlY coating. In case of the as-sprayed coating, the Young's modulus and bending strength of HVOF MCrAlY coating were inferior in comparison with those the low-pressure plasma sprayed MCrAlY coating. However, the experimental results suggest that the strength of HVOF MCrAlY coating can be improved by a diffusion heat treatment. These phenomena may be attributed to the fact that the HVOF MCrAlY coating is built up by semifused sprayed particles. Coatings were deposited on IN738LC alloy.

Y. Itoh, M. Saitoh, and M. Takahashi. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 7), July 1997, p 763-768 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199802-58-0198.

Low-Pressure Plasma Spray

Reaction Diffusion Analysis for Interface between Nickel-Base Superalloy and MCrAlY Coating. A computer-aided interactive system for coating design has been developed, which makes it possible to analyze conveniently the reaction diffusion of bonded materials. The object of this study is the overlay coatings of MCrAlY alloy sprayed by a low-pressure-plasma spray (LPPS) process for protection against high-temperature corrosion and oxidation in the field of gas turbine components. However, the reaction diffusion behavior at the interface between the MCrAlY coating and the substrate, which has an important effect on coating degradation, has not always been clarified. Three kinds of substrate, such as equiaxis IN738LC, directional solidified CM247LC and single-crystal CMSX-2, and four kinds of LPPS MCrAlY coating were selected for the experiments. The experimental results showed that the reaction diffusion layers consisted of aluminum compound layer and aluminum decrease layer, basically. However, the aluminum decrease layer could not be observed in the cases of CoNiCrAlY and NiCoCrAlY coatings. It was also indicated that each diffusion thickness changed in parabolic time dependence. The order of reaction diffusion rate was NiCrAlY > CoCrAlY > CoNiCrAlY > NiCoCrAlY4 independent of the kind of substrate. It was also clear that the estimation of long-time diffusion behavior by simulation analysis was possible in comparison with the experiments.

Y. Itoh, Y. Takahashi, and M. Tamura. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 8), Aug 1997, p 927-932 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199802-58-0206.

Processing

Dry-Jet Spraying

Fabrication of Ti-Al_2O_3 Functionally Graded Material by Dry-Jet Spraying of Ultrafine Particles and Subsequent Temperature-Gradient Sintering. Ti-Al_2O_3 functionally graded material (FGM) is tentatively fabricated by dry-jet spraying of ultrafine particles (UFPs) onto a titanium substrate and subsequent temperature-gradient sintering. The FGM layer is formed by gradually decreasing the ratio, $r = Ti/(Ti + Al_2O_3)$, during the dry-jet spraying. It is found to be effective to add titanium- or zirconium-hydrides to the titanium substrate to decrease the number of cracks that appear in the FGM layer due to the difference in the amounts of shrinkage during sintering. Because the composition range between $r = 1$ and $r = 0.5$ is known to show large shrinkage, it is better to start the dry-jet spraying from $r = 0.5$ than to start from $r = 1$ to decrease the size of voids. Despite the existence of the skipped r range, the r in the sintered composite changes from $r = 1$ to $r = 0$, which is considered to be due to the abnormally rapid diffusion of titanium atoms. The fabrication of an FGM in the shape of a cylinder with locally different diameters was also tried, and it was found that by adjusting the pressure of isostatic pressing of the dry-jet sprayed composite the formation of cracks in the neighborhood of the protrusions is suppressed.

A. Otsuka, K. Iwasaki, and H. Tanizaki. Cited: *J. Jpn. Soc. Powder Powder Metall.*, Vol 44 (No. 3), April 1997, p 334-339 [in Japanese]. ISSN 0532-8799. PHOTOCOPY ORDER NUMBER: 199802-62-0345.

Fused Coatings

New Fused Coatings for Combined Wear and Corrosion Resistance. Fused coatings produced by thermal spraying and subsequent fusion have been used in industry for >50 years. In the field of thermal spraying, fused coatings have the advantage that they exhibit a metallurgical bond to the substrate and a very low level of porosity (no through porosity) as a result of the fusion step. Over the last years, new alloys have been developed that extend the range of applications toward more corrosive conditions. However, even these alloys were not adequate when used in waste-fired boilers (mainly due to the presence of chlorine) or in highly aggressive aqueous media, as are found, for instance, under conditions of dew point corrosion. For this reason, a development program was undertaken to create a new family of fusible alloy powders for thermal spraying. Coated carbon steel plate samples were finally prepared of the most promising alloys by combustion spray and fuse and HVOF spraying and by plasma transferred arc (PTA) deposition. The samples were evaluated with respect to their wear and corrosion performance and hardness in the temperature range up to 500 °C. The results for the spray-and-fused coatings presented here show that the new alloys have an excellent combination of high corrosion resistance in different corrosive environments and very good wear characteristics.

P. Heimgartner, P.A. Kammer, I. Kretschmer, and R. Polak. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications,* Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 109-113 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0102.

Graded Structures

Manufacturing of Plasma Sprayed Graded Structures. Graded NiCrAlY/ZrO_2-Y_2O_3 interlayers have been designed and fabricated for thermal barrier coating structures on Inconel 718. Air plasma sprayed step-graded interlayers and low-pressure plasma sprayed parabolic-graded interlayers were manufactured using multiple powder feeders. The coating microstructures were dependent upon the powder size and plasma spray processing conditions. The microstructure of the step-graded interlayers consisted of a coarse layered distribution of the metallic and ceramic phases, while the microstructure of the parabolic-graded interlayers consisted of a fine lamellar phase distribution.

M.I. Mendelson. Cited: *21st Annual Conference on Composites, Advanced Ceramics, Materials, and Structures.* (Proc. Conf.), Cocoa, FL, 12-16 Jan 1997, *Ceram. Eng. Sci. Proc.*, Vol 18 (No. 4), 1997, p 731-738 [in English]. ISSN 0196-6219. PHOTOCOPY ORDER NUMBER: 199803-57-0425.

HVOF Nozzle Design

The Influence of Nozzle Design on HVOF Exit Gas Velocity and Coating Microstructure. A simple device was constructed for determining a value for the average combustion gas velocity at the exit plane of a high-velocity oxyfuel gun. This device was used to measure the velocities of a standard factory-made barrel nozzle and a specially designed de Laval nozzle as a function of the fuel/oxygen ratio and the total mass flow rate. The Mach number of the de Laval nozzle was 1.42. The maximum combustion gas exit velocities determined for the standard and the de Laval nozzles were 1100 and 1550 m/s, respectively. The maximum velocity depends on the fuel/oxygen ratio, but is independent of the total flow rate. The effect of increased combustion gas velocity on coating quality is demonstrated.

K. Korpiola, L. Laas, F. Rossi, and J.P. Hirvonen. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 4), Dec 1997, p 469-474 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199803-57-0375.

Laser Cladding

Comparison of Two Kinds of Materials for Laser Cladding Coating. Laser coating technology has been studied and applied more and more widely. In the case of wear- and/or corrosion-resistant coating, two kinds of alloys are often applied: nickel-base alloy (NBA) and ferro-base alloy (FBA). In order to decide which is more suitable both technically and economically, experiments of laser cladding and corrosive wear have been carried out. The two kinds of powders were prepared onto AISI 1045 steel by flame spraying, then remelted by 3 kW CO_2 continuous-wave laser. Corrosive wear has been conducted on an MLS-23 rubber wheel wear tester. By comprehensive comparison, it is concluded that nickel-base alloy is the better one.

P.-Z. Wang, X.-D. Ma, J.-X. Qu, and H.-S. Shao. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 143-146 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0107.

Nanostructures

Microstructure and Mechanical Properties of Thermally Sprayed Silica/Nylon Nanocomposites. High-velocity oxyfuel thermal spray processing was used to produce ceramic/polymer (silica/nylon) nanocomposite coatings. By optimizing spray parameters such as nozzle design, spray distance, oxygen-to-fuel ratio, powder feed position, and substrate cooling, dense coatings with relatively uniform particulate distribution could be achieved. Compared to pure nylon coatings, scratch resistance improved by 30% and wear resistance by 50%. The surface chemistry of the silica filler affected the final coating properties. Silica particles with a hydrophobic (methylated) surface resulted in better mechanical properties than those with a hydrophilic (hydroxylated) surface.

L.S. Schadler, K.O. Laul, E. Petrovicova, and R.W. Smith. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 4), Dec 1997, p 475-485 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199803-57-0376.

Oxidation

Properties of Alloy Steel Coatings Oxidized During Plasma Spraying. Plasma spraying of metals in air is usually accompanied by oxidation reactions resulting in the presence of oxides in plasma deposited coatings. Oxides in plasma sprayed high-alloy steel coatings can strongly affect their protective and mechanical properties. Two high-alloy steels were plasma sprayed onto plain steel substrates using a water-stabilized plasma gun. Both coating types, composed as usual of metallic lamellae (splats), contained considerable amounts of oxides present mainly as thin oxide films enveloping the splats. The compressive behavior of cubic samples cut out of the coatings was studied. The results indicate an appreciable anisotropy of the response to compressive loading. If the pressure is parallel to the coating surface, strong cracking occurs. For loading perpendicular to the surface, cracking is less pronounced and high values of plastic deformation are observed. Though the coating structure and the presence of oxides preclude a satisfactory tensile strength the coating can withstand high purely compressive loading. In this respect, plasma sprayed steels are comparable to those produced by conventional metallurgy.

P. Chráska, J. Dubsky, K. Neufuss, V. Novák, and K. Volenik. Cited: *11th International Conference on the Strength of Materials* (Proc. Conf.), Prague, Czech Republic, 25-29 Aug 1997, *Mater. Sci. Eng. A*, Vol A234-236, 30 Aug 1997, p 493-496 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199802-58-0180.

Oxide Formation

Oxides in Plasma Sprayed Chromium Steel. Products of oxidation reactions accompanying plasma spraying of chromium steel by a water-stabilized plasma gun were separated from the metallic matrix by a chemical method. This enabled gravimetric determination of the oxide content in plasma sprayed chromium steel and characterization of the composition and structure of oxides by diffraction and spectroscopic techniques. Both the random and inherent errors of the gravimetric method were estimated. The phase composition of oxides was compared with the results of thermodynamic calculations. It was shown that in spite of the highly nonequilibrium character of plasma spraying, the thermodynamic approach can yield useful predictions for the overall phase composition and for the stoichiometry of the prevailing spinel oxide phase.

K. Volenik, J. Dubsky, F. Hanousek, B. Kolman, and J. Leitner. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 327-334 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-58-0023.

Polymers

Plasma Spray Deposition and Engineering Applications of Magnesium Hydroxide-Polyamide Composite Coatings. Magnesium hydroxide is shown to dehydrate endothermically to magnesium oxide over a similar temperature range to that of the thermal degradation of polyamide. The extent of dehydration in plasma spraying is shown to be a function of particle size. However, the research indicates that the use of magnesium hydroxide as a filler in plasma sprayed polyamide composite coatings does not significantly increase the quality of the matrix by suppressing its degradation. A high content of unreacted magnesium hydroxide can be obtained in plasma sprayed polyamide composites by control of the feedstock particle size. The practical implications of the results for potential engineering applications of the composite are discussed in terms of wear resistance and fire retardance.

Y. Bao and M. Pearson. Cited: *Trans. Inst. Met. Finish.*, Vol 75 (No. 5), Sept 1997, p 189-193 [in English]. ISSN 0020-2967. PHOTOCOPY ORDER NUMBER: 199802-57-0270.

Underwater Spraying

Cavity Formation on Underwater Thermal Spraying. The objective of this study is to develop underwater-feasible and high corrosion-proof surface treatment technology for a longer life span of offshore structures. A cavity formation is a prerequisite to underwater plasma spraying in a fluid stabilized local cavity. By using pure titanium wire as a spraying material, plasma sprayed coating was formed underwater. As a result, when the clearance was 2 mm, the protection tube having the slit angle of 75°, formed broader cavity than that having the angle of 45°; however, the clearance of 6 mm brought the opposite result. A cavity that has enough dimensions of spraying distance and diameter for the purpose of underwater spraying was formed under the conditions of the clearance of 2 to 6 mm. In the macroscopic appearance, neither cracks nor peelings were observed in the underwater sprayed coating. X-ray analysis revealed that the underwater sprayed coating obtained consisted mostly of titanium phase.

N. Minami, T. Araki, M. Nishida, Y. Nojiri, T. Hongawa, and M. Katsumura. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.)*, Vol 34 (No. 2), June 1997, p 71-77 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199802-58-0175.

YSZ Coatings

The Influence of Plasma Spraying Parameters on the Microstructure and the Properties of ZrO_2-7 wt% Y_2O_3 Thermal Barrier Coatings. Superalloy samples were coated with a thermal barrier coating (TBC). This TBC system consists of two layers. The first one is a vacuum plasma sprayed, corrosion-resistant (MCrAlY) layer that additionally acts as a bond coat. The Y_2O_3-stabilized ZrO_2 ceramic top layer is atmospheric plasma sprayed. In order to produce different microstructures, the plasma spraying parameters for the production of the ceramic coating were varied. These different ceramic coatings were characterized in terms of porosity and elastic constant.

B. Siebert, C. Funke, D. Stöver, and R. Vassen. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 205-208 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0126.

Properties

Composite Coatings

Composite Coatings: Manufacture, Properties, and Applications. The surface properties of structural components have a strong influence on their behavior. In many cases such components are stressed in the surface region by a combination of mechanical, tribological, corrosive, and thermal factors. Under these circumstances, deposition of composite coatings can

provide effective surface protection. Deposits can be coated on steel, light metals, ceramics, plastics, and other materials. Composite coatings consist of a metal matrix with, in general, nonmetal solid particles or short fibers. The most important coating processes are electrochemical or electroless plating and thermal spraying. This paper reviews the manufacture, properties, and applications of composite coatings and summarizes new developments in this field. Fine particles with diameters <100 nm are available and are investigated in connection with electroplating experiments. Thermal sprayed aluminum composite coatings on light metals have been manufactured and evaluated. Finally, thermal sprayed composite coatings with short fibers are described.

S. Steinhäuser and B. Wielage. Cited: *Surf. Eng.*, Vol 13 (No. 4), 1997, p 289-294 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199801-58-0155.

Corrosion

Investigation of Corrosion Behavior of Decorated Al_2O_3 Coatings with Copper. In this study, the corrosion behavior of decorated Al_2O_3 coating with copper was investigated on AISI 304L stainless steel substrates. Plasma spray technique was employed on substrate with the deposition of Al_2O_3 ceramic powder. The copper decoration technique was used to study the types of defects in coatings. Potentiodynamic polarization measurements were also employed to determine the corrosion behavior of Al_2O_3 coating and decorated Al_2O_3 coating with copper. The microstructure of coating was investigated by means of an optical microscopy. In addition, x-ray diffraction of the used powders and coatings was utilized. It was obtained that the passivation range of Al_2O_3 coating decorated with copper increased considerably.

E. Çelik and E. Avci. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 353-358 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-35-0169.

Corrosion by Liquid Zinc

The Resistance of Thermally Sprayed Coatings to the Corrosion Influence of Liquid Zinc. Corrosion processes cause the damage of the steel surface by the dissolution of iron in the place of contact with molten zinc. The corrosion resistance tests of the chosen oxide and intermetallic coatings, which are thermally sprayed by the plasma and HVOF methods, are presented in the article. The Al_2O_3-$3TiO_2$ and ZrO_2-$8Y_2O_3$ coatings were plasma sprayed with a 7MB Metco gun. These coatings were also surface sealed with inorganic binder substances containing phosphates. The coatings containing tungsten carbides and their modifications were obtained in JET-Kote II system by HVOF method. The results were evaluated by a macroscopic method and microstructure examinations in the damaged places and also the changes in the phase composition of coatings. Durability of the obtained coatings was determined. Relatively high corrosion resistance has aluminum oxide coatings, sealed with aluminum-chromium phosphates and boron modified with tungsten carbide including cobalt. The damage mechanism of the tested coatings was presented.

P. Liberski, B. Formanek, A. Gierek, J. Mendala, and P. Podolski. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 257-260 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0129.*

Delamination

Division and Delamination Processes of WC + Co Film Coated by High-Velocity Flame Spraying. WC + Co cermet film was coated by high-velocity flame spraying on smooth tensile specimens of a tool steel, and the tensile load was applied parallel to the film to investigate the division and delamination process of film. With increasing load, the film is divided by parallel cracks repeatedly until the divided film delaminates under the plastic deformation of substrate. The residual stress measurement by an x-ray diffraction method shows the existence of compressive stress in the film, and tensile stress in the substrate, and the change of stress distribution is more sharp when the film thickness is thin. The progress of film division with increasing applied tensile stress and the increase in the division interval at delamination with increasing film thickness is expressed relatively well by the theoretical and FEM analyses.

K. Nakasa, M. Kato, and D. Zhang. Cited: *Fracture and Strength of Solids. II. Behavior of Materials and Structure* (Proc. Conf.), Hong Kong, China, 8-10 Dec 1997, *Key Eng. Mater.*, Vol 145-149 (No. 2), 1998, p 907-912 [in English]. ISSN 1013-9826. PHOTOCOPY ORDER NUMBER: 199802-58-0230.

Erosion Resistance

Erosion Resistance of Ni-WC Self-Fluxing Alloy Coating at High Temperature. The erosion behavior of nickel-base self-fluxing alloy, thermally sprayed coating on a metal substrate is affected by several factors, including the microstructure of the coatings, the porosity, the angle of impingement of solid particles, and the hardness of the coatings. In this study, the erosion properties of thermally sprayed coatings with different tungsten carbide contents were investigated. Reinforced by tungsten carbide in the Ni(γ) matrix, the erosion resistance of the coating has been modified. With increasing tungsten carbide content, an erosion mechanism that involved a large amount of plastic deformation in the Ni(γ) matrix was found to represent the brittle fracture of carbides. Test results showed that an Ni-WC coating with an optimum composition ratio of nickel-base alloy to WC of 65:35 has the highest microhardness and improved erosion resistance compared with coatings of other compositions. The substrate in the experiments was mild steel.

J.P. Tu, M.S. Liu, and Z.Y. Mao. Cited: *Wear*, Vol 209 (No. 1-2), Aug 1997, p 43-48 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199801-31-0327.

Erosive Wear

Relationship between Microstructure and Erosive Wear Resistance of Plasma Sprayed Alumina Coatings. Pure alumina coatings deposited on metallic substrates by plasma spraying in air (APS) and in low vacuum (VPS) were subjected to erosive wear by silica sand particles at 50 m/s. The APS coatings were porous and exhibited poor resistance to erosion. The VPS coatings produced at high substrate temperatures and lower chamber pressures exhibited low porosity and good erosion resistance, while those deposited at lower substrate temperatures and higher chamber pressures were more porous and eroded more rapidly, in some cases with erosion rates higher than those of the APS coatings. A pronounced lamellar structure was found to be the most important factor in reducing the erosion resistance. The extent of the lamellar structure and the coating porosity depended on the spraying conditions. For VPS coatings, the effects of residual stresses arising from differential thermal contraction were studied by using substrates with different thermal expansion coefficients and by controlling the substrate temperature during spraying. Microstructural effects in these experiments obscured any clear influence of residual stress on erosion behavior, although there were indications that high residual stresses may lead to microcracking, which in turn may promote more rapid erosion.

X.S. Zhang, T.W. Clyne, and I.M. Hutchings. Cited: *Surf. Eng.*, Vol 13 (No. 5), 1997, p 393-401, [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199803-57-0448.

Fatigue

Fatigue Properties of Thermal Sprayed Steel with Cobalt-Base Self-Fluxing Alloy. Rotational-bending fatigue tests were performed on a specimen having cobalt-base self-fluxing alloy thermally sprayed coating, with special focus on the effect of mixed NiCr weight ratio on coating microstructure and on fatigue properties. Effects of post heat treatment (fusing treatment) on coating microstructure and on fatigue strength for 10^7 cycles were also discussed. It was found that (1) there is considerable scatter in observed fatigue life for specimens sprayed with cobalt-base self-fluxing alloy. This is because each specimen has its own fatigue strength associated with different porosity and microstructure of coatings. (2) Fusing treatment temperature strongly affects the characteristics of sprayed coating in terms of microstructure and porosity. A great improvement of fatigue strength of a sprayed specimen having poor fatigue property has been achieved through well-controlled fusing treatment.

J. Komotori, N. Qu, M. Shimizu, and K. Shirai. Cited: *Advances in Fracture Research, ICF9*, Vol 3, *Fatigue of Metallic and Non-Metallic Materials and Structures* (Proc. Conf.), Sydney, Australia, 1-5 April 1997, Elsevier Science Ltd., Kidlington, Oxford, United Kingdom, 1997, p 1725-1731 [in English]. ISBN 008-042820-7. PHOTOCOPY ORDER NUMBER: 199801-31-0405.

Evaluation of Fatigue Strength of WC Cermet and 13Cr Steel-Sprayed Materials. Rotating bending fatigue tests have been conducted at room temperature in air using the specimens of medium-carbon steel (S45C), low-alloy steel (SCM435), and titanium alloy (Ti-6Al-4V) with HVOF sprayed coating of a cermet (WC-12%Co) and S45C with WFS sprayed coating of a 13Cr steel (SUS420 J2). The fatigue strength and fracture mechanisms were studied. The fatigue strength evaluated by nominal stress was strongly influenced by substrate materials and the thickness of sprayed coatings. Detailed observation of crack initiation on the coating surface and fracture surface revealed that microcracks initiated at the WC grain boundary coalesced, and then the crack grew rapidly in the coating. Cracks in the substrate were initiated by the stress concentration of the crack in the coating, which was modeled by finite element analysis. For the specimens tested, the fatigue strength of sprayed specimens was dominated by that of sprayed coating. Thus, the fatigue strength could be evaluated uniquely by the true stress on the coating surface.

T. Ogawa, T. Ejima, K. Tokaji, Y. Harada, and Y. Kobayashi. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 10), Oct 1997, p 1124-1129 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199803-58-0304.

HAP on Shape Memory Alloys

Physics of Hydroxyapatite Plasma Coatings on TiNi Shape Memory Materials. The microstructure of hydroxyapatite (HAP) ceramics coatings on TiNi shape memory alloy substrates was investigated. From the point of view of adherence, these coatings have higher strength than ~30 MPa. The three levels of power input parameters were applied during the spraying process (55, 50, and 45 V). At lower voltage, the prepared HAP coatings contained pure $Ca_{10}(PO_4)_6(OH)_2$ with a Ca/P ratio of 1.65. At the highest voltage (55 V), the transition phase $Ca_{10}(PO_4)_6(OH)_{0.5}O_{0.75}$ was detected. The observed good metal/ceramic interface strength is given by the formation of chemical bonding and by the energy dissipation due to stress-induced martensite formation (SIM) and/or martensite reorientation (RE) during stressing the investigated composite.

K. Mazanec, P. Filip, and A.C. Kneissl. Cited: *11th International Conference on the Strength of Materials* (Proc. Conf.), Prague, Czech Republic, 25-29 Aug 1997, *Mater. Sci. Eng. A*, Vol A234-236, 30 Aug 1997, p 422-425 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199802-57-0212.

High-Temperature Corrosion

The Influence of HCl-Containing Atmospheres on High-Temperature Corrosion of Coated and Uncoated Nickel-Base Superalloys under Complex Loading Conditions. The influence of 100 ppm HCl in synthetic air on the high-temperature corrosion behavior of the directionally solidified nickel-base superalloy CM 247LC DS with CoNiCrAl and CoNiCrAlY plasma sprayed coatings and of the two uncoated directionally solidified nickel-base superalloys CM 247LC DS and IN 792DS + Hf was investigated at 1000 °C up to 2000 h. The investigations included isothermal and thermocyclic tests in synthetic air and in synthetic air + 100 ppm HCl. Furthermore, thermomechanical fatigue tests in synthetic air were carried out. Both coatings formed an Al_2O_3-scale. The yttrium-free coating showed an Al_2O_3-scale mainly growing in outward direction, whereas the yttrium-modified coating revealed substantial internal oxidation, resulting in rapid wastage of the coating. Yttrium has a beneficial effect on scale adherence, even in HCl-containing atmospheres. After oxidation in synthetic air + 100 ppm HCl metal-chlorides were detected underneath the Al_2O_3-scale of yttrium-free coatings, leading to scale spallation. In synthetic air and in HCl-containing atmospheres the uncoated alloy CM247LC DS was superior to the alloy IN 792DS + Hf.

A. Jeutter and M. Schütze. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 223-226 [in English]. ISBN 90-803513-1-8. PHOTOCOPY ORDER NUMBER: 199802-35-0270.

Remelted Ceramic Coatings

Structural Investigations of Plasma Sprayed and Remelted Ceramic Coatings. This paper presents the results of the investigations of oxide and carbide coatings as applied onto the steel substrate by the plasma spraying method and subsequently remelted using plasma. In order to obtain more complete information on the processes that take place during the treatment, diverse methods of remelting were used in the experiments, the single and repeated treatments with the continuous plasma arc, and the impulsive remelting technique. The coatings were examined both prior to and after the plasma treatment with the use of light and scanning microscopy, x-ray structural analysis, and the measurements of surface roughness. The structural and morphological changes found in the area of heat source action, i.e., the reduction of porosity and roughness, and the increase in the intensity of diffraction reflexes have given a basis for the positive evaluation of the remelting technique used in the experiments.

Z. Nitkiewicz and J. Iwaszko. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 1, *Metals and Composites* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 261-264 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0130.

Residual Stress

Measurement of the Residual Stress Field in Plasma Sprayed Thermal Barrier Coatings. The residual stress fields in 7.5 wt% yttria partially stabilized zirconia (Y-PSZ) thermal barrier coatings (TBCs) deposited by plasma spray on aluminum components was measured by synchrotron radiation x-ray diffraction, at the station 2.3 of the Daresbury (UK) facility. Taking advantage from the possibility of changing beam wavelength without moving the sample, diffraction patterns were collected with different radiation penetration depths. The traditional $\sin^2\psi$ method was modified to account for the presence of a biaxial stress that changes with the depth. In this way it was possible to measure a stress gradient in the outer region of the coatings. It was also shown that Y-PSZ coatings deposited in reducing conditions (argon atmosphere and cooling medium) tend to develop an intense compressive stress due to the progressive phase transformation taking place after low temperature aging.

P. Scardi, F. Cernuschi, V. Regis, and M. Leoni. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 4, *Characterization and Production/Design* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 107-110 [in English]. ISBN 90-803513-4-2. PHOTOCOPY ORDER NUMBER: 199802-22-0143.

Residual Stress Characteristics of High-Velocity Oxygen-Fuel MCrAlY Coatings. High-velocity oxygen-fuel (HVOF) system in air has been established for producing the coatings that are extremely clean and dense. It is thought that the HVOF-sprayed MCrAlY (M is Ni, Co, or Fe) coatings can be applied to prevent oxidation and corrosion in the hot section of gas turbines. Also, it is well known that thicker coatings can be sprayed for improving the residual stress in comparison with any other thermal spraying system. However, the thermal and mechanical properties of HVOF coatings have not always been clarified. In this paper, the thermal and mechanical properties of MCrAlY coatings were measured in both cases of as-sprayed and heat treated coatings. From the results, it is confirmed that the thermal and mechanical properties of HVOF MCrAlY coatings could be improved by a diffusion heat treatment up to the level of vacuum plasma sprayed MCrAlY coatings. On the other hand, the experimental results suggest that the residual stress of HVOF coatings is decreased by the shot-peening effect in comparison with the vacuum plasma sprayed coating. Coatings were deposited on IN738LC substrates.

Y. Itoh, M. Saitoh, and M. Takahashi. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 9), Sept 1997, p 1057-1063 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199802-58-0210.

Measurement of the Residual Stress in Plasma Sprayed TBCs. Measurement of the residual stresses in plasma sprayed thermal barrier coatings (ZrO_2-8 wt% Y_2O_3) is still very difficult due to the complex microstructure. We have compared the layer removal method with the more established $\sin^2\psi$ and hole drilling methods on specimens which were sprayed with different settings of the flow rate and composition of the plasma gas. The results showed, due to some experimental problems, a discrepancy between the layer removal method (stresses between −200 and 200 MPa) and the $\sin^2\psi$ and hole drilling methods (stresses between 10 to 100 MPa). The latter two experiments provided insight into the influence of the spray parameters on the stress state. It is tentatively concluded that, due to the difficulties with the accuracy of the strain measurement, the layer removal method is not workable for the determination of the relatively low residual stresses in TBCs.

M.F.J. Koolloos, J.M. Houben, P.P.J. Ramaekers, and P.F. Willemse. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 227-230 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0127.

Scratch Behavior

The Scratch Behavior of Aluminum Composite Coatings. Wear data obtained from single and multiple scratch passes, combined with the examination of the reinforcement-matrix interfacial structure by transmission electron microscopy (TEM) and toughness measurements made on the reinforcement phase, were used to evaluate the wear behavior of aluminum-base composite coatings. Reinforcement properties such as reinforcement volume fraction (V_f), size, interfacial bonding and toughness appear to be important variables in deciding the abrasive wear resistance of composite coatings. Scratch testing appears to be a valuable tool in providing information regarding the nature of the reinforcement-matrix interfacial structure, which is a deciding parameter in the abrasive wear resistance of metal-matrix composite (MMC) coatings.

R.L. Deuis, G.P. Cavallaro, and C. Subramanian. Cited: *Tribol. Lett.*, Vol 3 (No. 4), Aug 1997, p 327-338 [in English]. ISSN 1023-8883. PHOTOCOPY ORDER NUMBER: 199803-57-0355.

Self-Lubricating Coatings

Thermal Spraying of Self-Lubricating Coatings with Solid Lubricants. In the present project, the relationship between the production parameters of thermally sprayed self-lubricating coatings with solid lubricants and their structural, wear, and lubricating properties is analyzed. The coatings consist of a wear-, corrosion-, and temperature-resistant matrix material and a homogeneously distributed solid lubricant. The research is focused on CaF_2 as the solid lubricant dispersed in a Cr_2O_3 matrix. The production method consists of a preparation step where a powder blend of the matrix and lubricating component is agglomerated, followed by plasma spraying of the agglomerates. Results of the ongoing research are presented. Selection of the most appropriate agglomeration method and the structure of the coatings are discussed.

L. Froven, M. De Bonte, L. Delaey, and F. Vos. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.),

Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 187-190 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-57-0123.

Thermal Barrier Coatings

Thermal and Mechanical Properties of ZrO_2-CeO_2 Plasma Sprayed Coatings. The thermal and mechanical properties of ZrO_2-CeO_2 plasma sprayed coatings were evaluated to examine their potential as a thermal barrier coating. ZrO_2-CeO_2 solid-solution powders containing up to 70 mol% CeO_2 are successfully plasma sprayed, but certain content decreases during spraying due to the vaporization of cerium oxide. Hardness is greatest at 30 mol% CeO_2. With increased CeO_2 content, the thermal conductivity decreases to 0.5 W/m · K and the thermal expansion coefficient increases to 12.5×10^{-6}/K. Increased torch input power causes both the relative density and the hardness to increase monotonically, while the thermal conductivity and the thermal expansion coefficient are not significantly affected. When heated above 1300 K, the coating shrinks considerably due to sintering and its thermal conductivity increases abruptly. Substrate was carbon steel JIS-SS400.

S. Sodeoka, M. Ando, H. Sakuramoto, T. Shibata, M. Suzuki, and K. Ueno. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 3), Sept 1997, p 361-367 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199801-57-0039.

WC-Co Coatings

The Evaluation of Tungsten Carbide Thermal Spray Coatings as Replacements for Electrodeposited Chrome Plating on Aircraft Landing Gear. Tungsten carbide (WC) thermal spray coatings applied by the high-velocity oxyfuel (HVOF) process are considered the leading candidates for replacement of hard chrome plating. This article describes the decision-making process followed to establish the acceptability of WC thermal spray coatings for aircraft landing gear applications. Descriptions of both the laboratory testing phase and the in-service evaluation phase are given.

B.E. Bodger, D.A. Somerville, and R.T.R. McGrann. Cited: *Plat. Surf. Finish.*, Vol 84 (No. 9), Sept. 1997, p 28-31 [in English]. ISSN 0360-3164. PHOTOCOPY ORDER NUMBER: 199801-57-0155.

Wear

Study of the Tribological Behavior of a Nickel Electron Brush Plating Layer on a Base of an Arc Sprayed Coating. Toolmaking by arc sprayed metal is a new field of arc spraying application, a low-cost, high-efficiency method for producing molds for plastic products. Aluminum- or zinc-base wires can only be used as spray materials at the present stage. In order to improve the antiwear property of the arc sprayed mold, the nickel layer is electron brush plated on the arc sprayed coating to enhance the service life of the mold. Tribological properties of the nickel layer on a base of aluminum-zinc pseudoalloy coating and the effects of loads and temperature on wear of specimens were evaluated using a Falex tester; at the same time, an aluminum-zinc pseudoalloy arc sprayed coating and a nickel brush plating layer on No. 45 mild steel were used for a comparative test. Behaviors and mechanisms of wear of the nickel brush plating layer were studied in detail by x-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and morphology analysis. Results show that the microstructure, microhardness, cohesion strength, and antiwear of the nickel plating layer on the aluminum-zinc pseudoalloy arc sprayed coatings are the same as those of the nickel plating layer on the No. 45 steel. The nickel electron brush plating layer shows delamination wear, the relative antiwear property of the nickel plating layer is two to four times higher than that of the aluminum-zinc pseudoalloy coating, and the nickel electron brush plating on the arc sprayed coating is an effective way to improve the antiwear property of the mold's coating surface.

X. Liu, Z. Chen, S. Ma, and B. Xu. Cited: *Wear*, Vol 211 (No. 2), Nov 1997, p 151-155 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199803-31-1294.

Effect of Carbide Grain Size on the Sliding and Abrasive Wear Behavior of Thermally Sprayed WC-Co Coatings. The carbide size and cobalt content of thermally sprayed tungsten carbide-cobalt coatings (WC-Co) can influence their microstructure, fracture strength, friction response, and abrasion resistance. In this paper, these properties have been determined for one commercially available and three experimental WC-17 wt% Co thermally sprayed coatings. The experimental coatings were processed from starting powders containing median carbide size distributions of 1.2, 3.8, and 7.9 μm, respectively. All the coatings were produced using a high-velocity oxyfuel (HVOF) spray process. The present results indicate that coatings with a higher percentage of finer carbide size distribution in the starting powder display a higher degree of decomposition of the WC phase to W_2C phase and, consequently, display lower fracture toughness and abrasion resistance values. Unidirectional, unlubricated sliding wear tests did not reveal major differences in the sliding wear response of the coatings as a function of carbide size. The microscopic analysis of the sliding wear-tested surfaces showed particle delamination and fracture, providing insight into wear mechanisms in these materials.

S. Usmani, D.L. Houck, S. Sampath, and D. Lee. Cited: *Tribol. Trans.*, Vol 40 (No. 3), July 1997, p 470-478 [in English]. ISSN 0569-8197. PHOTOCOPY ORDER NUMBER: 199803-31-1185.

Development of TiC-Ni-Base Thermally Sprayed Wear- and Corrosion-Resistant Coatings. Plain and chromium-alloyed WC-Co and WC-Ni and Cr_3C_2-NiCr are standard materials for highly wear-resistant coatings produced by thermal spray processes. New wear-resistant coatings have been developed by alloying plain TiC-Ni spray powders and preparation of spray powder granules with high green density where a hardmetallike microstructure can be formed in a conventional sintering process.

L.-M. Berger, M. Nebelung, T. Mäntylä, P. Vuoristo, P. Ettmayer, and W. Lengauer. Cited: *EUROMAT 97: 5th European Conference on Advanced Materials and Processes and Applications*, Vol 3, *Surface Engineering and Functional Materials* (Proc. Conf.), Maastricht, Netherlands, 21-23 April 1997, Netherlands Society for Materials Science, Zwijndrecht, Netherlands, 1997, p 191-194 [in English]. ISBN 90-803513-3-4. PHOTOCOPY ORDER NUMBER: 199801-58-0110.

Wear Behavior of Laser-Treated Plasma Sprayed ZrO_2 Coatings. The effect of laser remelting on the wear behavior of plasma sprayed ZrO_2 ceramic coatings was studied. The results showed that the porosity and roughness of the coatings were reduced significantly after laser treatment, and the bonding strength was apparently increased by the remelting process. However, there were extensive network cracks, and a few large bubbles, in the laser-treated coatings. Unlubricated pin-on-disk wear tests revealed that, when compared with as-sprayed ceramic coatings, the wear resistance was improved significantly after laser treatment. The wear resistance of laser-treated specimens increased with increasing laser power, and the minimum weight loss of the coating specimen occurred at a specific travel speed in laser processing. The main wear mechanism of the as-sprayed coatings was spallation of the coating, whereas the wear of laser-remelted specimens was dominated by ploughing and gouging (scratching). The substrate material was aluminum alloy AA 6061.

Y. Fu, A.W. Batchelor, Y. Gu, and H. Xing. Cited: *Wear*, Vol 210 (No. 1-2), Sept 1997, p 157-164 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199801-57-0179.

Wear Mechanism of Plasma Sprayed Cr_3C_2-NiCr against TiO_2 Coating. The friction and wear performance of plasma-sprayed Cr_3C_2-NiCr against TiO_2 coating was investigated with a block-on-ring arrangement at different sliding speeds and loads. Furthermore, the morphologies, elements, phases, and element valences of the worn surface and debris were observed, examined, and analyzed employing scanning electron microscopy, energy disperse spectrum, x-ray diffraction, and x-ray photoelectron spectrometer, respectively. It was found that the friction coefficient decreased with increase in loads and sliding speeds. However, the exponent of load against wear rate of the C_3C_2-NiCr coating appeared as two values on changing from the lower to higher load. The wear mechanism of the coating was explained in terms of fatigue-induced detachment of transferred TiO_2 layer at lower load, and plastic deformation, shear fracture, and melting wear at higher load.

J.F. Li, C.X. Ding, J.Q. Huang, and P.Y. Zhang. Cited: *Wear*, Vol 211 (No. 2), Nov 1997, p 177-184 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199803-31-1298.

Review

Plasma Processes

Plasma Projection: The Influence of Gas. Plasma has been used in the process of coating metals for more than half a century, and its use is still growing today. Economically the future looks bright; the American plasma projection market has a turnover of about 650 million dollars and it looks set to triple by the year 2000. Plasma projection consists of spraying solid particles, such as ceramic and metals onto a surface in a jet of plasma. In the last few years, the system of projection has become completely automatic. There are also systems of projection in a controlled atmosphere that produce new possible applications. The role of the gas in plasma projection has often been considered marginal in the past, but it plays an important role as it moves the powder and affects the exchange between the plasma and the particles. The role that gas plays is studied in detail in this article.

G. Valli. Cited: *Tratt. Finit.*, March-April 1997, p 126-128 [in English, Italian]. ISSN 0041-1833. PHOTOCOPY ORDER NUMBER: 199802-58-0227.