Selected Abstracts of Thermal Spray Literature

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Applications

Biomaterial of Hydroxyapatite

Effect of Water Vapor Pressure and Temperature on the Amorphous-to-Crystalline HA Conversion During Heat Treatment of HA Coatings. X-ray diffraction was used to characterize the increment of crystallinity of HA coatings after heat treatment. Coatings were heated over the temperature (T) interval of 300 to 460 °C with a partial water vapor pressure of 0.01 and 0.001 MPa. Heat treatment also was done in air, as a contrast. It was found that the ratio (n) of the increment of crystallinity to the crystallinity of the as-received HA coatings was more significant for the coatings heated in atmosphere with water vapor than for those heated in air. This ratio also increased with water vapor pressure. The logarithm of the ratio increased linearly with $1/T$, indicating that the ratio is exponential to T. The reason might be that recrystallization of the amorphous phase is a diffusion-controlled process; the nucleation rate and growth velocity of the crystallites are in proportion to the diffusion coefficient, which is exponential to the temperature (T). Incorporation of water vapor in the atmosphere during heat treatment may decrease the activation energy for diffusion, which helps raise the diffusion coefficient of the atoms. Thus recrystallization of the amorphous phase can be accelerated.

W. Tong, Y. Cao, J. Chen, J. Feng, L. Lu, and X. Zhang. Cited: *J. Biomed. Mater. Res.*, Vol 36 (No. 2), Aug 1997, p 242-245 [in English]. ISSN 0021-9304. PHOTOCOPY ORDER NUMBER: 199712-57-1675.

Hydroxyapatite-Coating on Titanium Arc Sprayed Titanium Implants. We developed a new titanium spray technique using an inert gas shielded arc spray (titanium arc spray). Hydroxyapatite (HA) coating can be applied to the implant without any surface pore obstruction after the rough surface is made by this technique. Scanning electron microscopy (SEM) of various porous implant surfaces after HA coating revealed that the bead and fiber metal-coated implants had either a pore obstruction or an uneven HA coating. On the other hand, the Ti arc sprayed implant demonstrated an even HA coating all the way to the bottom of the surface pore. In the first set of animal experiments (Exp. 1), the interfacial shear strength to bone of four kinds of cylindrical Ti-6Al-4V (Ti) implants were compared using a canine transcortical push-out model 4 and 12 weeks after implantation. The implant surfaces were roughened by Ti arc spray (group A-C) and sand blasting (group D) to four different degrees (roughness average, R_a = group A:56.1, B:44.9, C:28.3, D:3.7 μm). The interfacial shear strength increased in a surface roughness-dependent manner at both time periods. However, the roughest implants (group A) showed some failed regions in the sprayed layers after push-out test. In the second set of animal experiments (Exp. 2), four kinds of Ti implants; HA-coated smooth Ti (sHA) with Ra of 3.4 μm, bead-coated Ti (Beads), titanium arc sprayed Ti (Ti-spray) with R_a of 38.1 μm and HA-coated Ti spray (HA + Ti-spray) with R_a of 28.3 μm were compared using the same model as that in Exp. 1. The interfacial shear strength of HA + Ti spray was significantly greater than that of sHA and Beads at both time periods, and that of Ti spray at 4 weeks. Although a histological examination revealed that HA coating enhanced bone ingrowth, sHA showed the lowest shear strength at both time periods. SEM after push-out test showed that sHA consistently demonstrated some regional failure at the HA-implant substrate interface. HA + Ti spray had many failed regions either at the HA-bone interface or within the bone tissue rather than at the HA-implant substrate interface. These results suggested that the HA-coated smooth surfaced implants had a mechanical weakness at the HA-substrate interface. Therefore, HA should be coated on the rough surfaced implants to avoid a detachment of the HA coating layer from the substrate and thus obtain a mechanical anchoring strength to bone. HA coating on this new type of surface morphology may thus lead to a solution to the problems of conventional HA coated and porous-coated implants.

Y. Nakashima, I. Noda, T. Hara, K. Hayashi, T. Inadome, T. Kanemaru, Y. Sugioka, and K. Uenoyama. Cited: *J. Biomed. Mater. Res.*, Vol 35 (No. 3), 5 June 1997, p 287-298 [in English]. ISSN 0021-9304. PHOTOCOPY ORDER NUMBER: 199712-57-1645.

Lightweight Bore Coating

Lightweight Engine Bore Coating. The appeal for the use of aluminum engine blocks has grown in recent years as a means for significantly improving the energy efficiency of the overall performance of the automobile. Currently, the use of cast iron liners is the predominant manufacturing technique that is being utilized to provide a wear-resistant surface on the inside of the cylinder bores. The methodologies for installing these liners is either pressed-in-place, cast-in-place, or wet-sleeve. These approaches have presented manufacturing difficulties as well as being economically very costly. Also, there is significant weight penalty incurred by the block due to the additional mass of the cast iron liner. Another technology that has been used to provide a wear-resistant surface for the cylinder block wall has been the use of an electrochemical process for the application of a electrolytic nickel coating with a codeposition of silicon carbide. This manufacturing approach, while providing an excellent wear-resistant surface, is not considered optimal for large volume manufacture of automobile engines due to the cost and facility constraints.

D.R. Marantz, K.A. Kowalsky, J.R. Baughman, D. Cook, and M.J. Zaluzec. Cited: *29th International Symposium on Automotive Technology and Automation*, Vol I (Proc. Conf.), Florence, Italy, 3-6 June 1996, Automotive Automation Limited, 1996, p 723-729 [in English]. ISBN 0-947719-86-5. PHOTOCOPY ORDER NUMBER: 199711-58-1224.

LPPS of Hydroxyapatite

Low-Pressure Plasma Sprayed (LPPS) Bioceramic Coatings with Improved Adhesion Strength and Resorption Resistance. Prespray annealing of commercially available hydroxyapatite plasma spray powder at 1300 °C for 1 h in air leads to substantial densification without noticeable thermal decomposition. The resulting hydroxyapatite coatings, low-pressure plasma sprayed onto Ti-6Al-4V substrates, show a dense microstructure, improved adhesion strength, and higher resorption resistance when treated for seven days in simulated body fluid (Hank's balanced salt solution).

R.B. Heimann and T.A. Vu. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 145-149 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-57-1522.

MCrAlY for Turbines

On the Suitability and Application of MCrAlY Coatings under Various Operating Conditions. Ever since the efficacy of MCrAlY coatings as a protection layer was proven for in-flight gas turbine engines, the technology has seen a gradual increase in usage in land-based hot-section components. The service environment, however, varies from industry to industry. This has necessitated the tailoring of the coating chemistry to be viable in a particular application. Coating to resist both high temperatures and hot corrosion are still debated. The utility of a particular MCrAlY coating can only be determined after the service conditions are well comprehended. Apart from being useful as overly coatings, MCrAlY coating will continue to be used as a bond coat for thermal barrier coatings.

P. Sahoo and G.W. Goward. Cited: *Coat. Compos. Mater./Rivestimenti Mater. Compos.*, Vol 5 (No. 19), 1997, p 12-15 [in English]. ISSN 1123-9123. PHOTOCOPY ORDER NUMBER: 199712-58-1456.

Mining and Agricultural Equipment

Surface Engineering for Improving Performance of Mining and Agricultural Implements. Numerous implements used in the mining and agricultural sectors undergo constant wear and so require frequent replacement, resulting in significant financial losses. One way of reducing wear-related problems is through surface engineering of the wear prone surface. A variety of surface engineering techniques are commercially available for tribological applications, although cost and convenience in repair and maintenance situations are of considerable importance in selecting a particular method. The most suitable surface modification methods for mining and agricultural implements are welding, hardfacing, and thermal spraying. In addition to attaining the desired wear resistance of these implements, improvements in properties such as corrosion resistance can be imparted through appropriate surface modification techniques. The techniques of surface engineering can also permit the use of a less expensive or inferior substrate material. This paper is an overview of the potential of the different surface engineering techniques for improving tribological performance. A number of case studies are discussed where these techniques have been applied successfully in the mining and agricultural sectors.

R. Dasgupta, S. Das, A.K. Jha, O.P. Modi, B.K. Prasad, and A.H. Yegneswaran. Cited: *Surf. Eng.*, Vol 13 (No. 2), 1997, p 123-127 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199712-57-1705.

Mo and W for X-Ray Targets

Molybdenum and Tungsten Coatings for X-Ray Targets Obtained through the Low-Pressure Plasma Spraying Process. Low-pressure plasma spraying under an argon atmosphere was employed to deposit molybdenum and tungsten coatings on different metallic, ceramic, and composite substrates. Molybdenum coatings obtained through this technique presented a homogeneous structure with an average porosity of ~17%. These coatings exhibited adhesion >40 MPa on Mo and gray cast iron (FT25) substrates. No adhesion was observed on an AlN surface regardless of the preheating temperature and/or surface preparation. Adhesion on AlN-Mo (AM25) composite substrate, containing 25% dispersed metallic phase by volume, showed intermediate results. Tungsten coatings exhibited porosity between 10 and 12% and a typical lamellar structure. The adhesion of W coatings on Mo and FT25 substrates was ~40 MPa.

A.A. Khan, P. Fauchais, A. Grimaud, and J.C. Labbe. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 228-234 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-58-1312.

Screws for Injection Molding

Use of the HVOF Process for Coating of Screws in Injection Molding Machines. The improvement of screw life for injection molding machines by means of high-velocity flame spraying is reported. HVOF coatings on specimens and screws of 42CrMo4 and 16MnCr5 steels are presented. The hard material system WC Cr_3C_2 Ni and the ceramic material Cr_2O_3 with NiCr bond coating are applied. The HVOF process and today's practicable steps are compared for the screw regeneration and life improvement. Difficulties that appeared during the spraying process, solutions, and their realization are described.

R. Kröschel, D. Grasme, and H. Lang. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 237-242 [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-E1-D-0262.

Automation

Automation of Plasma Transferred Arc Surfacing—Concepts for Operation and Control. An analysis of the influencing parameters and conditions for case of the plasma transferred arc (PTA) surfacing was carried out. A modern computer-controlled PTA installation with a problem-orientated software is developed. The installation makes possible the control of the main process parameters along welding direction and also according to across position of the plasma torch by oscillations. Sensing of the welding zone spectrum during the surfacing could be used to control the penetration of the base metal and dilution of surfaced layer.

U. Dilthey, J. Ellermeier, and A. Pavlenko. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 433-437 [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-E7-Z-0274.

Book

DVS Thermal Spray Conference

TS96. Thermal Spraying Conference (Thermische Spritzkonferenz). 88 papers selected and abstracted for Metals Abstracts; 40 papers selected and abstracted for Engineered Materials Abstracts. Some papers are in English, some are in German.

E. Lugscheider. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, 444 pages [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-G2-Z-0174.

Coating onto Composites

Development of External Oxidation Corrosion Resistant Coatings for Continuous Fiber Reinforced Ceramic Composites. Continuous fiber reinforced ceramic composites (CFCC) possess an excellent combination of physical and mechanical properties such as high strength and thermal conductivity, thermal shock, and oxidation resistance. This unique combination of properties makes CFCCs and especially SiC/SiC composites attractive candidates for applications at temperatures above superalloy operation temperatures (1000 °C) on heat exchangers, gas turbines, and advanced internal combustion engines. The successful utilization of SiC/SiC composites in these complex gas atmospheres, withstanding temperature cycling between standdown and service conditions, depend upon the development of suitable external coatings to protect the composite against accelerated environmental degradation. Mullite is a promising coating material. This paper reports on the development and properties of mullite coatings produced by atmospheric plasma spraying and high velocity oxyfuel spraying especially tailored for the protection of SiC/SiC composites.

A.G. Dias, R. Cook, and M. Hoffman. Cited: *Surface 97. Corrosion: Permanent Danger for Society and Environment* (Proc. Conf.), Palanga, Lithuania, 1-4 June 1997, Institute of Chemistry, 1997, p 20-23 [in English]. ISBN 9986-702-09-7. PHOTOCOPY ORDER NUMBER: 199712-E7-D-0290.

Thermal Coatings on CFRP. This paper shows that it is possible to coat carbon fiber reinforced plastic composites (CFRP) with conventional thermal spraying techniques. Main attention must be drawn to the temperature of substrate during coating process. In order to improve adhesion between substrate and coating an interfacial layer is required. Three applications are given as a sample: CFRP-rolls coated with high abrasion-resistant material, CFRP coated for cryogenic applications, and CFRP coated for optical applications.

D. Bittner and M. Bittner. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 85-87 [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-E7-D-0269.

Potentials and Limits of Coated CFRP Shafts. For several years, thermal coating of carbon fiber reinforced plastic (CFRP) has been state of the art. At the Institute of Machine Tools and Manufacturing Technology of the Technical University Berlin manufacturing technologies and quality control mechanisms for shafts of coated CFRP are developed. The properties of components made from this material have been determined. This article presents the results of the investigations and also reviews the economical prospects of this kind of material. The shafts are coated with chromium steel.

G. Spur and A. Kranz. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 226-229 [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-F1-D-0465.

Composite Coatings

Formed by PTA Process

Aluminium Composite Coatings Produced by Plasma Transferred Arc Surfacing Technique. Plasma transferred arc surfacing (PTA) is a hardfacing technique by which a coating is deposited onto a substrate by the injection of metal powder and/or ceramic particles into a weld pool. Establishment of a plasma column initiates this weld pool formation. Few studies have been published on the use of PTA in the surface modification of low-density substrates such as aluminum or titanium alloys. In the present work, the deposition of metal-matrix composite (MMC) coatings onto aluminum 5083 alloy substrates has been achieved. The experimental process involved the codeposition of an Al-Ni (Al-2 wt% Ni) powder containing various ceramics (Al_2O_3, SiC, and TiC) with discontinuous particulate morphology. Composite coatings of varying reinforcement volume fractions V_f (0-40%) and particulate sizes (70-140 μm) have been fabricated. The first part of the research involved optimization of the PTA parameters. The second part concentrated on characterizing the features of the coatings. Two main aspects were assessed in this endeavor, namely bulk coating properties and microstructural features. Parameters such as dilution content, hardness, surface roughness, and coating adhesion were classified as bulk properties. Microstructural features were represented by porosity, Al cell size, matrix structure, and attributes associated with the reinforcement phase, such as V_f, particle length, and aspect ratio. For the optimal values of PTA parameters used, ceramic particle attributes, such as thermal properties, wettability, and V_f, directly influenced the coating structure. With this information a fabrication strategy has been presented for the production of coatings that may offer superior tribological properties.

R.L. Deuis, J.M. Yellup, and C. Subramanian. Cited: *Mater. Sci. Technol.*, Vol 13 (No. 6), June 1997, p 511-522 [in English]. ISSN 0267-0836. PHOTOCOPY ORDER NUMBER: 199712-57-1684.

SiC and Aluminum MMC

The Effects of the Disposition of SiC Particles on the Forgeability and Mechanical Properties of Co-Sprayed Aluminum-base MMCs. An investigation of the forgeability and mechanical properties of unworked and extruded cosprayed metal-matrix composites (MMCs) is reported in this paper. The materials investigated are mainly cosprayed particulate SiC reinforced 2014 and 2618 aluminum-base MMCs. A similar powder metallurgy (P/M) MMC and a cosprayed monolithic Al alloy which is used as the matrix of one of the MMCs are investigated also for baseline comparisons. Forgeability tests were performed on a mechanical press with cylindrical test billets at temperatures ranging from 250 to 450 °C. Tensile tests were performed at room temperature. The forgeability and some tensile properties of cosprayed MMCs were found to be affected greatly by a unique metallurgical pattern designated the tree ring structure (TRS). Metallurgical examination showed that the TRS comprises bands with high and low concentrations of SiC particles. Forged and tensile test specimens show that these bands are easy paths for fractures to propagate along. The more homogeneous distribution of the SiC particles in the P/M MMC resulted in a forgeability superior to that of the cosprayed material.

K.S. See and T.A. Dean. Cited: *J. Mater. Process. Technol.*, Vol 69 (No. 1-3), Sept 1997, p 58-67 [in English]. ISSN 0924-0136. PHOTOCOPY ORDER NUMBER: 199712-62-2283.

Design

TBC Computer Interactive Model

A Basic Study on High-Temperature Protective Coating Design of Single Crystal Ni-Base Superalloy. A computer-aided interactive system for coating design has been developed, which enables 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 been fully clarified. Four kinds of low-pressure plasma sprayed MCrAlY alloys, namely CoCrAlY, NiCrAlY, CoNiCrAlY, and NiCoCrAlY, and single-crystal CMSX-2 were selected for the experiments. The experimental results showed that the reaction diffusion layers consisted of an aluminum compound layer and a low aluminum layer. In case of the NiCoCrAlY and CoNiCrAlY coatings, the aluminum compound layer could not be observed clearly. It was also indicated that each diffusion thickness could be expressed by the parabolic time dependence. The order of reaction diffusion rate was NiCrAlY>CoCrAlY>CoNiCrAlY>NiCoCrAlY. It was also clarified by the simulation analysis that the diffusion distance during the heating process cannot be ignored in comparison with the total diffusion distance, and the estimation of long time diffusion was made.

Y. Itoh, Y. Takahashi, and M. Tamura. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 6), June 1997, p 684-689 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199712-58-1450.

Environmental

Chromium Replacement

Thermal Spray Coatings Replace Hard Chrome. This article lists the benefits and limitations of hard chrome plating and describes the performance of two thermal spray coatings (tungsten carbide and chromium carbide) that compared favorably with hard chrome plating in a series of tests. It also lists three criteria to determine whether plasma spray or hard chrome plating should be selected.

M. Schroeder and R. Unger. Cited: *Adv. Mater. Process.*, Vol 152 (No. 2), Aug 1997, p 19-21 [in English]. ISSN 0882-7958. PHOTOCOPY ORDER NUMBER: 199712-58-1373.

Influence of HVOF and Plasma

On the Reduction of the Environmental Pollution Produced by Thermal Spraying—Causes, Solutions, Process Efficiency, and Developments. This paper summarizes the impact on the environment of the total working process of depositing a coating using HVOF and plasma spraying. It describes the flow of materials with regard to the production of pollutants and discusses the actions necessary to make thermal spraying more environmentally friendly.

Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 243-245 [in English]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-E7-Z-0275.

Feedstock

Effect of Dopant on Thermal Shock

Influence of Dopant on the Behavior under Thermal Cycling of Two Plasma Sprayed Zirconia Coatings. II. Residual Stresses. The evolution of coating morphology and surface residual stresses was followed for three different powders: zirconia stabilized with 8 wt% yttria (YSZ), 9.9 wt% dysprosia (DSZ), and 9.8 wt% ytterbia (YbSZ). The YSZ reference powder was fused and crushed (−45+22 μm), and the other two were agglomerated and sintered (−90+10 μm). According to the size distributions and manufacturing process, the plasma sprayed YSZ particles were fully molten, resulting in dense coatings with good contact between the splats; the DSZ and, especially, the YbSZ particles were partially molten. In general, the surface residual stresses were slightly compressive before thermal cycling. The YSZ and DSZ coatings were insensitive to aging (600 h in air at room temperature), as shown by the surface stress evolution, which was not the case for YbSZ coatings. Six hundred furnace thermal cycles from 1100 °C to room temperature indicated excellent behavior of YSZ and DSZ coatings, with almost no variation of surface residual stresses, compared to a high dispersion for YbSZ coatings with the development of macrocracks parallel and perpendicular to the substrate within the coating.

R. Hamacha, P. Fauchais, and F. Nardou. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 211-216 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-57-1529.

Partially Stabilized Zirconia

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 were 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: 199712-A1-C-0178.

Samaria-Stabilized Zirconia

Plasma Spraying of Samaria-Stabilized Zirconia Powders and Coatings. Rare-earth oxides are known to stabilize the cubic and tetragonal phases of zirconia. This paper presents the preparation of samaria-stabilized zirconia powders and coatings by plasma spraying. The amount of samaria ranged from 2 to 10 mol%. The tetragonal phase is stabilized when 2 to 6 mol% Sm_2O_3 are added. There are evidences that suggest the formation of enforced solid solution of the tetragonal phase in the composition range 4 to 6 mol% Sm_2O_3. Transformation to the cubic phase occurred after heat treatment at 1400 °C for 10 h.

K.A. Khor and J. Yang. Cited: *Mater. Lett.*, Vol 31 (No. 3-6), June 1997, p 165-171 [in English]. ISSN 0167-577X. PHOTOCOPY ORDER NUMBER: 199711-A1-C-0147.

Microscopy

Investigation on the Microstructure of Spray Coating. Thermal spraying has been used in industry for many years to improve the properties of the surface of a workpiece such as its mechanical and electrical properties and its corrosion resistance. Most of the literature on spray coating has reported spraying techniques, and the properties of the coatings, the literature on microstructure investigation still being weak. In this paper the authors emphasize the microstructure of the coating layer and the constituents of the phases and their distribution within the coating. By observations using a transmission electron microscope and electron diffraction pattern analysis, two solid solutions (γ and Ni-Cr), and some compounds ($M_{23}C_6$, Ni_2B, CrB, $Cr_6Ni_{16}Si_7$) have been found in the coating layer. Substrate used was 1045 boiler-plate steel.

C.F. Yeung and D. Mei. Cited: *J. Mater. Process. Technol.*, Vol 68 (No. 3), 15 Aug 1997, p 275-278 [in English]. ISSN 0924-0136. PHOTOCOPY ORDER NUMBER: 199712-58-1458.

Microstructure

Dependence of Microstructure

Quality Control of the Intrinsic Deposition Efficiency from the Controls of the Splat Morphologies and the Deposit Microstructure. A simple heuristic model was developed to demonstrate the major characteristics of impinging particles prior to impact and during the spreading stages. It is based on the determination of transfer functions between the powder particle size distribution and splat equivalent diameter distributions. The input data consist mainly of the aforementioned distributions, determined experimentally using a particle size analyzer for powder particle size analysis and the wipe test for splat equivalent diameter analysis. Output data relate to the major characteristics of the impinging particles: flattening degree, intrinsic deposition efficiency, impact velocity, etc. Comparisons of the model predictions with experimental data showed reasonable agreement. Implementation of this simple protocol provides understanding of interactions during the process and also has technological and economical impacts. It permits quality control (QC) of deposition efficiency by control of splat morphologies and aids in the definition of specifications for the powders used (for example, in terms of the lower and upper limits of the particle size distribution leading to the formulation of a deposit with given processing parameters), allowing the optimization of the spray parameters to obtain high-integrity deposits.

G. Montavon, C. Coddet, C.C. Berndt, H. Herman, and S. Sampath. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 153-166 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-58-1310.

HVOF Coatings

The Metallography of High-Velocity Oxyfuel (HVOF) Coatings on Metals. One of the newer methods of applying a surface coating to a metal involves the passage of suitable powder through a supersonic gas flame, where it is heated and accelerated before it strikes the appropriate metal substrate. A partially melted splat is formed. The temperature of the powder particle is about 1500 to 1550 °C and, because of its high velocity, it flattens to form a pancake on striking the substrate. The underlying substrate is partially melted, but the subsequent cooling rate is very rapid. A coating may be built up from 20 to 30 layers with the heating from each layer affecting the underlying layers. The whole process has, therefore, similarity to multipass welding, but with much faster heating and cooling rates. As would be anticipated, the metallography of the coatings, the interface with the substrate and the heat-affected zone of the substrate, is complex and its elucidation requires the application of modern electron metallographic techniques. Some examples of the coatings produced with WC-Co and WC-Ni are described, together with newer coatings produced from much less expensive powders based on TiC-Ni, which, if their initial promise can be achieved on a production scale, will greatly increase the use of the HVOF spraying on engineering components.

J. Nutting. Cited: *Metall. Foundry Eng.*, Vol 21 (No. 4), 1995, p 257-264 [in English]. ISSN 1230-2325. PHOTOCOPY ORDER NUMBER: 199712-21-0242.

Nickel-Base Self-Fluxing Alloy

Structure of Ni-Base Self-Fluxing Alloy Coating and Interface Reaction with Substrate. The structure and phases revealed in two kinds of self-fluxing alloy coatings (MSFNi1 and MSFNi4 alloys) after fusing were investigated by using EPMA, XRD, and TEM. An interface reaction for MSFNi4 coating and the substrate by heating was also examined. MSFNi1 coating is composed of primary Ni phase and divorced eutectic Ni_3B phase. In the MSFNi4 coating having higher content of chromium and boron, two kinds of rodlike and cuboidal phases are seen in addition to Ni-Ni_3B eutectic. It was found that rodlike phase is $M_7(C,B)_3$ borocarbide and cuboidal phase is M_6B boride from TEM observation and the electron diffraction analysis. Metals of the $M_7(C,B)_3$ phase are composed of mainly chromium and a little part of molybdenum. Metals of the M_6B phase are nickel, chromium, and molybdenum. Fe_2B boride is formed at the interface of MSFNi4 coating and the substrate after heating at elevated temperatures above 873 K for long time. Adhesion strength of the coatings is not lowered by the precipitation of Fe_2B phase at the interface. Coatings were deposited on SS400 low-carbon steel.

K. Kishitake, H. Era, H. Ohhara, and F. Otsubo. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.)*, Vol 33 (No. 4), Dec 1996, p 7-15 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199711-58-1215.

WC-Co Interface Structures

Interface Structures of High-Velocity Oxyfuel Sprayed WC-Co Coating on a Copper Substrate. Microstructures developing at the interface of a high-velocity oxyfuel (HVOF) sprayed WC-Co coating onto a copper substrate have been studied by preparing thin foils from the interfacial region and examining them using transmission electron microscopy. Two types of substrate surfaces have been considered: smooth and grit blasted. Modeling of the development of the interface structure has also been undertaken. Both experimental and theoretical results, which agree well, show that the interface structure depends significantly on the morphology of the substrate surface. The results obtained enable new views to be put forward on the factor leading to the adhesion between a coating and a substrate material.

J.M. Guilemany, J.A. Calero, J.M. de Paco, Z. Dong, J. Fernandez, J. Nutting, and V.V. Sobolev. Cited: *Mater. Sci. Eng. A*, Vol A232 (No. 1-2), 31 July 1997, p 119-128 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199712-12-1829.

Modeling

FEM for Residual Stress

Modeled and Measured Residual Stresses in Plasma Sprayed Thermal Barrier Coatings. Thermal barrier coatings consisting of a NiCrAlY bond coating and a 1.4 mm thick partially stabilized zirconia top coating were air plasma sprayed onto grit-blasted nickel-base substrates (Hastelloy X). Two samples were produced using different amounts of external cooling during spraying of the top coatings. The residual stress profiles in the samples were measured after each manufacturing process step with a layer removal technique. A finite element model including a thermal analysis and a stress-strain analysis of the deposition was developed to model the origin of the thermal stresses and to verify the measured residual stresses. The main components for the residual stresses in the sprayed coatings were identified as stresses developing during the rapid cooling of individual droplets (quenching stresses) and stresses formed during cooling from deposition temperature to room temperature. In the substrate, compressive residual stresses reaching ~200 MPa were found in a zone to a depth of 0.3 mm into the substrate. The stresses were found to have originated during the grit blasting of the substrates prior to bond coating deposition. A correlation between modeled inelastic strain and measured densities of vertical microcracks in the top coating was obtained. High values were found close to the bond coating, which were correlated to a low substrate temperature during spraying of the top coating material.

P. Bengtsson and C. Persson. Cited: *Surf. Coat. Technol.*, Vol 92 (No. 1-2), June 1997, p 78-86 [in English]. ISSN 0257-8972. PHOTOCOPY ORDER NUMBER: 199712-57-1659.

Numerical Modeling of Residual Stresses in Boride Layers on Steel. The properties of boride layers produced by a plasma boriding process are described, and the residual stresses in these layers are analyzed using a numerical modeling method. It has been shown that a new method combining electroless nickel deposition, and plasma boriding is possible. The results of the present study show that compressive residual stresses in the $(Fe,Ni)_2B$ layers are reduced by ~1500 MPa, relative to those in the thin surface (Fe,Ni)B layers. This should reduce the brittleness of the borided case and hence improve wear resistance, as was observed in the preliminary studies reported.

D. Golánski, P. Bielínski, and T. Wierzchón. Cited: *Surf. Eng.*, Vol 13 (No. 2), 1997, p 145-148 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199712-56-1104.

Post Processing

Influence of HIP on Coating

Effect of Hot Isostatic Pressing on Mechanical Properties of Spray Coating of High-Carbon High-Chromium Iron Alloy by HVOF Process. A high-carbon and high-chromium iron alloy was thermal sprayed by using a high-velocity oxyfuel flame spraying process. Many unmelted spherical powder particles are embedded in the coating. The coatings are composed of a mixture of crystalline and amorphous phases. The amorphous phase decomposed to ferrite and fine M_3C carbide when hot isostatically pressed or heat treated in vacuum at 873 K. Compared with the as-sprayed coating and the coating heat treated in vacuum, the hot isostatically pressed coating possesses improved properties, such as the hardness, tensile strength and wear resistance. When hot isostatically pressed at 1173 K, the hardness of the coating reaches the maximum value of 1044 DPN, and the tensile strength is 335 MPa, which is twice as high as that of the as-sprayed coating. Coatings were sprayed on SS400 low-carbon steel substrates.

T. Irisawa, K. Kajihara, K. Murakami, and W. Chen. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.)*, Vol 33 (No. 4), Dec 1996, p 23-31 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199711-58-1217.

Laser-Melt Bonding

Laser Metal-Ceramic Bonding. The use of laser metal-ceramic bonding has been a trend since years ago due to the good properties of these materials, mainly corrosion and abrasion resistance. However, some of the deposition processes can lead to a nonhomogeneous layer and, sometimes, porosity, and this can hinder the appropriate use of material properties. Using a laser treatment after the deposition of ceramics it is possible to produce a homogeneous layer without porosity. This paper analyzes the surface treatment influence on the ceramics in a metal-ceramic junction, which was obtained by flame spraying deposition on a mild steel substrate, and evaluates the benefits of laser treatment and its effects on the metal. Of additional interest is the determination of the appropriate parameters (power density and speed) of the laser treatment and assessing any possible inconvenience this treatment could cause.

A. Oliveira Luz, M.C.F. Ierardi, and Z. Zhou. Cited: *Metal. Mater. ABM*, Vol 52 (No. 457), Sept 1996, p 538-540 [in Portuguese]. ISSN 0104-0898. PHOTOCOPY ORDER NUMBER: 199712-57-1559.

Laser Melting of Ni-Cr-B-Si

Laser Remelted Ni-Cr-B-Si Coating on Al-Si Alloy. The plasma sprayed coating zone (Ni-Cr-B-Si) on an Al-Si alloy surface was remelted by a 5 kW CO_2 laser. SEM and TEM analysis showed that there is crystalline and amorphous coexistent regions. As the annealing effects caused by heat transfer of following melt and latent heat of crystallizing, some Ni_3Al nanocrystallites (2-5 nm) formed and some of them grew gradually into globular grains (0.1-0.2 μm). The hardness in amorphous region is up to HV1235 which is three times that of plasma sprayed coating zone.

G. Liang, C. Li, and J. Su. Cited: *Acta Metall. Sin. (China)*, Vol 33 (No. 3), 18 March 1997, p 315-319 [in Chinese]. ISSN 0412-1961. PHOTOCOPY ORDER NUMBER: 199712-58-1432.

Laser Modification of TBC

Pulsed Laser Processing of Plasma Sprayed Thermal Barrier Coatings. The requirements for thermal barrier coatings on turbine blades in jet engines and gas turbines are stringent due to the extreme temperatures and constant thermal cycling that demand a material with excellent thermal shock resistant and thermal insulation properties. Plasma sprayed zirconia alloys have been found to fit this role with some degrees of success. However, the presence of surface pores and a network of interconnecting micropores within the coatings accentuates the oxidation of the bond coat, often leading to spallation of the ceramic coat. A pulsed-mode Nd:YAG laser was used in the present study to process plasma sprayed zirconia alloy coatings. The results indicated the effective melting of the ceramic layer that yielded a shiny surface finish. Scanning electron microscopy observation of the fractured surfaces revealed distinct zones comprised of columnar grains, granular structures similar to that of sintered ceramics and the typical lamellar structure of plasma sprayed ceramic coatings. The crack area and depressions formed were quantified using an image and analyzer. The results show that the average crack area in the treated surface increases with increasing laser energy density. However, the average area of depressions in the treated surface appears to be independent of the laser energy density input.

K.A. Khor and S. Jana. Cited: *J. Mater. Process. Technol.*, Vol 66 (No. 1-3), April 1997, p 4-8 [in English]. ISSN 0924-0136. PHOTOCOPY ORDER NUMBER: 199711-57-1531.

Microstructure of Laser Melting

Formation and Crystallization of Amorphous Structure in the Laser-Cladding Plasma Sprayed Coating of Al-Si Alloy. An Al-Si alloy surface was plasma sprayed with a Ni-Cr-B-Si coating. This coating was remelted by a 5 kW CO_2 laser, and the resulting microstructure was characterized by both scanning and transmission electron microscopy. Both crystalline and amorphous structures were observed to coexist in the remelted layer. Heat resulting from laser scanning precipitated some Ni_3Al in the amorphous region. A distribution in Ni_3Al precipitate size, from nanometer to submicrometer, was observed. Microhardness in the amorphous region measured to 1235 HV, which is four times as hard as the untreated plasma sprayed zone.

T.T. Wong and G.Y. Liang. Cited: *Mater. Charact.*, Vol 38 (No. 2), Feb 1997, p 85-89 [in English]. ISSN 1044-5803. PHOTOCOPY ORDER NUMBER: 199711-58-1276.

Process

Arc Spray for Turbine Industry

Arc Spray Process for the Aircraft and Stationary Gas Turbine Industry. Technological advances in arc spray have produced a system that competes favorably with other thermal spray processes. In the past, arc spray was thought of as a process for very large parts that need thick buildups. However, an attachment device known as the arc jet system has been developed that focuses the pattern and accelerates the particles. This attachment device, coupled with the introduction of metal-cored wires that provide the same chemistries as plasma sprayed powders, provides application engineers with a viable economic alternative to existing spray methods. A comparative evaluation of a standard production plasma spray system was conducted with the arc spray process using the attachment device. This evaluation was conducted by an airline company on four major parts coated with nickel-aluminum. Results show that, for these applications, the arc spray process offers several benefits.

M.P. Zwetsloot and E.R. Sampson. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 150-152 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-58-1309.

Composites via PTA

Properties of NbC-TiAl and TiB_2-TiAl Composites Produced by Plasma Transferred Arc Processing. Intermetallic compound based composites (IMCs) consisting of particles of NbC and TiB_2 in Ti-36 wt% Al (NbC-TiAl and TiB_2-TiAl, respectively), with varying volume fraction of reinforcing particles, were produced by a plasma transferred arc process. In NbC-TiAl IMCs, the hardness and 0.2% compressive proof stress increased steadily with increasing volume fraction of NbC whereas the tensile strength was lower than that of the unreinforced TiAl regardless of the volume fraction of NbC. In TiB_2-TiAl IMCs, the hardness and 0.2% compressive proof stress exhibited maximum values at a volume fraction of 5 vol% TiB_2. The maximum tensile strength of ~500 MN/m^2, which is almost twice that of the unreinforced TiAl, was obtained at a volume fraction of 5 vol% TiB_2. The initial improvement of mechanical properties due to the addition of TiB_2 was considered to be caused by the reinforcing effect of the TiB_2 particles, grain refinement, and the disappearance of γ grains in 3 to 5 vol% TiB_2-TiAl IMCs. The deterioration of the mechanical properties observed for a volume fraction of >5 vol% TiB_2 may be attributed to the increase in the amount of γ grains with increasing volume fraction of TiB_2 particles form 7 to 15 vol% and the increase in coarse TiB_2 particles that can act as crack initiation sites in tensile tests.

A. Hirose, K. Abotani, R. Aoki, and K.F. Kobayashi. Cited: *Mater. Sci. Technol.*, Vol 12 (No. 12), Dec 1996, p 1057-1063 [in English]. ISSN 0267-0836. PHOTOCOPY ORDER NUMBER: 199711-62-1874.

Particle Distributions in Plasma

Particles Creating Plasma Sprayed Al_2O_3 + 13% TiO_2 Coating. We studied types of powder particles and their distribution with respect to the center of coating after plasma spraying at constant position of plasma gun and substrate. The coating formed by plasma spraying of Al_2O_3 + 13%TiO_2 powder consists of different types of particles—deformed particles (splats), partially deformed particles, and undeformed particles. Distribution of the particles on the substrate surface is not homogeneous. Small, undeformed powder particles, with their maximum dimensions less than 5 μm, are present in all studied coating areas. The basic assumption of particle deformation after impingement on the substrate is particle melting in plasma torch. We can find essentially more melted powder particles in case of injector angle $\alpha = 75°$, comparing with the position $\alpha = 90°$. Angle α determines the position of powder injector to the axis of plasma torch.

V. Pálka, V. Kolençiak, and E. Pôstrková. Cited: *Kovové Mater.*, Vol 34 (No. 6), 1996, p 367-375 [in Czech]. ISSN 0023-432X. PHOTOCOPY ORDER NUMBER: 199712-57-1640.

Thermal Spraying and Nitriding

Production of Duplex Coatings by Thermal Spraying and Nitriding. Limitations of surface treatments can be apparent under the complex loading experienced by engineering parts and components. These limitations can be removed by using duplex techniques. The process combination of thermal spraying and nitriding makes it possible to produce coatings with increased resistance for applications involving complex stress and loading conditions. The interactions between thermal spraying and nitriding have been investigated and both processes optimized to achieve improved properties of the compound coatings. Material: 16MnCr5 with various coatings including alumina, C steel, 13Cr steel, NiCrBSi, self-fluxing alloy, 17Cr-12Ni steel, and Ni-20Cr-10W-9Mo.

M.C. Nestler, K. Herrmann, and H.-J. Spies. Cited: *Surf. Eng.*, Vol 12 (No. 4), 1996, p 299-302 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199712-58-1424.

Process Parameters

Influence on HVOF Coatings

The Influence of Process Parameters on HVOF Deposits. Thermal spray is a well-developed technique for producing coatings of more than 50 μm thickness ("thick coatings") in a wide range of materials such as metals, ceramics, and cermets. In particular, HVOF (high-velocity oxygen fuel), the most recent addition to the thermal spray family, is able to make thick coatings, with the distinctive properties of low porosity, high density, hardness, and bond strength with the substrate. These characteristics are especially suitable for the production of hard coatings for wear-resistant applications. Because of the great importance of the spray apparatus configuration for coating characteristics, in the present work tungsten carbide coatings (88% WC, 12% Co) are produced using two HVOF systems, with differing torch geometry and running pressure; the first with converging nozzle and axial injection of powders into the combustion chamber (system 1) and the second with high operating pressure, converging/diverging nozzle (Laval nozzle), and radial injection of the powders directly into the torch barrel. To study the influence on coating characteristics, in a single-spray apparatus configuration, of the variation in spray parameters, the consequence on the wear resistance of the M2 steel sample is analyzed by the variation of pressure in combustion chamber.

F. Mor and G.M. La Vecchia. Cited: *Tratt. Finit.*, Vol 36 (No. 11-12), Nov-Dec 1996, p 33-39 [in Italian]. ISSN 0041-1833. PHOTOCOPY ORDER NUMBER: 199711-58-1226.

Processing

Graded Coatings

Graded Plasma Spraying of Premixed Metal-Ceramic Powders on Metallic Substrates. The mismatch between the thermal expansion coefficients of ceramics and metals and the differential stresses it causes at the interface create problems in metal to ceramic joining. Research has been conducted to solve this problem in thermal barrier coating technology. Previous studies have considered metal-ceramic multilayers or graded coatings, which include a metallic bond coat. In this study, a graded plasma sprayed metal-ceramic coating is developed using the deposition of premixed metal and ceramic powders without the conventional metallic bond coat. Influences of thickness variations, number, and composition of the layers are investigated. Coatings are prepared by atmospheric plasma spraying on Inconel 718 superalloy substrates. Ni-Cr-Al and ZrO_2-8%Y_2O_3 powders are used for plasma spraying. Adhesive and cohesive strength of the coatings are determined. The concentration profile of the elements is determined by x-ray energy-dispersive analysis. The microstructure and morphology of the coatings are investigated by optical and scanning electron microscopy (SEM). Results show that the mixed metal-ceramic coating obtained with the deposition of premixed powders is homogeneous. The morphology and microstructure of the coatings are considered satisfactory.

C.R.C. Lima and R.-E. Trevisan. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 199-204 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-57-1527.

Properties

Adhesion of HVOF Coatings

Coating-Substrate Bonding after HVOF (High-Velocity Oxyfuel) Thermally Spraying WC-Co onto a Ti-6%Al-4%V Alloy. Earlier papers studied the interfacial structures that develop when using the high-velocity oxyfuel (HVOF) technique to thermally spray WC-Co coatings onto a variety of substrates including steel, Al-4% Cu alloy, and pure copper. The results indicated that in order to obtain good adhesion between the coating and the substrate, partial melting or full melting of the substrate was required so that a metallic bond could develop between the liquid phase in the coating and the melted region of the substrate. In order to test the validity of this conclusion, a similar experimental approach to that used previously has been adopted; however, the substrate material chosen was Ti-6Al-4V alloy. The evidence suggests that a metallic bond is developed at the interface. This bond, particularly in relation to WC, αTi, cannot involve liquid phase bonding because the maximum temperature attained is well below the melting point of either phase. It seems likely that solid phase bonding has developed as a result of the high impact pressure from the initial splats which is a characteristic of HVOF spraying. A clearly defined bond between the originally cobalt-rich liquid phase and the solid αTi substrate material has also formed. Again, it would seem that the high-impact pressure has helped to form the good bond.

J.M. Guilemany, Z. Dong, and J. Nutting. Cited: *J. Mater. Sci. Lett.*, Vol 16 (No. 12), 15 June 1997, p 1043-1044 [in English]. ISSN 0261-8028. PHOTOCOPY ORDER NUMBER: 199711-57-1454.

Adhesion of HVOF WC

Effect of Heat Cycles on the Delamination Strength of WC Film Coated by High-Velocity Flame Spraying. Tungsten-carbide cermet was coated on the smooth tensile specimens of annealed tool steel (JIS:SKD6) by high-velocity flame spraying. After the specimens were heat cycled between high temperatures and room temperature, the tensile tests of the specimens were carried out to examine the change of interfacial energy by heat cycles, where the load was applied parallel to the film. For the specimen that is not heat cycled, the film is divided by parallel and straight cracks repeatedly with an increase in load, and the film delamination occurs after the division is completed. For the heat cycled specimens, three types of delamination patterns are observed: (1) The film is delaminated almost in the same way as the non-heat-cycled specimen, but the cracks are curved, (2) the small blocks of film are delaminated after the division finishes, and (3) the film is heavily damaged by oxidization and the delamination occurs in the film without the division. When the heating temperature, T, is 773 or 873 K and the holding time at the temperature is short, the interfacial energy $2\gamma_{12}$ increases to reach a maximum with an increase in heat cycles and decreases with further heat cycles. When T are 973 and 1073 K, $2\gamma_{12}$ decreases with small increase in heat cycles. The change in interfacial energy with heat cycles can be explained both by the strengthening due to the diffusion of Fe and Cr atoms to film and by the accumulation of fatigue damage due to the difference in thermal expansion coefficient between film and substrate. The crack interval just before delamination changes depending on the heating temperature and heat cycles, the decrease in which corresponds to the decrease in critical tensile strength of film and/or the increase in critical shear strength of interface.

M. Kato, N. Hara, M. Kamata, F. Egawa, and K. Nakasa. Cited: *J. Soc. Mater. Sci., Jpn.*, Vol 46 (No. 3), March 1997, p 315-321 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199712-58-1409.

Corrosion of Al and Zn Coatings

Corrosion Behavior of Thermal Spray Coating Layers in a Simulated Marine Environment. The objective of this study is to evaluate thermal spray coating layers for corrosion protection of off-shore steel structures such as Barge Mount Plant (BMP) at splash zone. The coating systems considered are flame spray coating layers of Al, Zn, and Zn-15Al. Thermal spray coating of each alloy system was performed on a mild steel substrate to build a coating layer of around 200 to 250 μm thickness. Salt-spray tests were conducted on spray coated specimens to simulate corrosion behavior of each specimen at splash zone. The result shows that the most corrosion-resistant system is flame sprayed aluminum coating. After 580 h test time, it shows almost no corrosion, whereas a thick corrosion product (white rust) was observed on Zn, Zn-15Al coating layers. Potentiodynamic behavior of Fe, Al, and Zn in NaCl solution was observed to explain corrosion behavior of thermal spray coating layers in salt-spray tests. The result shows that, in 3.5 to 10% NaCl solution, aluminum has low corrosion potential (E_{corr}), low corrosion current (I_{corr}), as well as high Tafel constant (β_a), whereas zinc has low E_{corr}, high I_{corr}, and low β_a. This result can be interpreted as follows: (1) the most appropriate coating system for corrosion protection at splash zone would be thermal sprayed aluminum coating system due to its low corrosion potential as well as low corrosion rate, and (2) zinc and its alloy systems would not be appropriate for corrosion protection at splash zone not because of its effectiveness of sacrificial activity, but because of its short lifetime (high current density at corrosion potential (E_{corr}) and at any mixed potential with iron).

J.K. Sung. Cited: *RIST J. R&D*, Vol 10 (No. 4), Dec 1996, p 447-462 [in Korean]. ISSN 1225-486X. PHOTOCOPY ORDER NUMBER: 199712-35-2234.

Electrochemical Behavior of Coatings

Comparison of the Electrochemical Behavior of Mild Steel Substrates, Using Conventional Aluminum Spray, Plasma Sprayed Ni-Al, and Hot Dip Aluminizing and Composite Galvanizing. It is well known that sprayed type of coatings, using conventional spray-gun, e.g., mild steel substrates, sprayed with aluminum and zinc, are being widely used for all commercial applications. But these sprayed coatings, although they show resistance to atmospheric corrosion, lack resistance under immersed conditions, particularly in low pH, and in the presence of aggressive anions like Cl^-, S^-, etc. This is attributed to the interconnected-type porous texture of these coated panels. On the contrary, hot dip coated M.S. substrate, like Zn + 3% Al + 1% SiC, in presence and absence of modification by mischmetal, reveal better resistance to chloride attack. This is attributed to the alloy-layer formation and also to the reinforcement of anodic sites, by lower concentration ceramic particles. This paper discusses the plasma sprayed ceramic coatings, conventional thermally sprayed Al coating, and zinc composite coated M.S. substrate by hot dipping and electroplating along with the performance of ultrafine lower concentration SiC-reinforced Al alloys.

D. Mukherjee, K. Balakrishnan, D. Jayaperumal, and S. Muralidharan. Cited: *Tool Alloy Steels*, Vol 31 (No. 7), July 1997, p 16-18 [in English]. ISSN 0377-9408. PHOTOCOPY ORDER NUMBER: 199712-35-2294.

Fatigue of TBCs

Fatigue Behavior of a Plasma Sprayed 8% Y_2O_3-ZrO_2 Thermal Barrier Coating. Thick thermal barrier coatings with thicknesses on the order of a few millimeters are being developed for use in diesel engines with operating temperatures of ~800 °C. In this environment, a coating will experience thermomechanical cycling due to differences in elastic and thermal expansion properties between the coating and the substrate. The inelastic constitutive behavior of the coating material results in both compressive and tensile stresses. To observe the effects of such stresses, specimens of plasma-sprayed 8% Y_2O_3-ZrO_2 were fabricated to allow testing of the coating material independent of the substrate. Cyclic compression fatigue tests were conducted at room and high temperature (800 °C) to simulate the loading environment to which the coating materials will be exposed during service. At high temperature, the compressive fatigue strength of the coating material increased by ~100%. Fatigue tests in tension and combined tension/compression were conducted at room temperature to evaluate the effect of mean stress. It was observed that a varying mean stress had no significant impact on the fatigue lives of the coating material, and the fatigue life was controlled by the maximum tensile stress of the cycle. Results from fatigue tests and SEM observations indicated that the damage accumulated during the tensile and the compressive portions of the fatigue cycle were independent of each other.

E.F. Rejda, B. Beardsley, and D.F. Socie. Cited: *Fatigue Fract. Eng. Mater. Struct.*, Vol 20 (No. 7), 1997, p 1043-1050 [in English]. ISSN 8756-758X. PHOTOCOPY ORDER NUMBER: 199712-57-1666.

Protection of Bridge Infrastructure

The Heat Is On—Protecting Steel with Thermal Sprayed Zinc Coatings. The Tsing Ma Bridge, Hong Kong, is a double-deck road/rail suspension bridge. It is the main link between mainland Kowloon and Lantau island, the new site for the Hong Kong airport. The lower decking of the bridge permits road and rail traffic during periods when the upper decking would be closed, e.g., adverse weather conditions. Each unit is 41 m wide and 18 m long. There are 126 of these units between the pillars, which are 126 m high, and 50 on the two approaches. The whole of the upper decking has been protected from corrosion by a thermally sprayed coating of zinc, followed by a sealant. This was overlaid with waterproofing and tarmacadam. The zinc coating is nominally 0.007 in. thick, applied by the electric arc process. The total surface area of 63,000 m^2 was zinc sprayed using ~120 t of zinc. Faying surfaces were sprayed with aluminum.

I. Hoff. Cited: *Weld. Met. Fabr.*, Vol 65 (No. 4), April 1997, p 12-13 [in English]. ISSN 0043-2245. PHOTOCOPY ORDER NUMBER: 199712-35-2140.

Residual Stress

Determination of Residual Stress Distribution from in situ Curvature Measurements for Thermally Sprayed WC/Co Coatings. An in situ monitoring of curvature of the specimens during spraying using a high-speed video system was implemented to determine stresses in thermally sprayed WC/Co coatings. Influences of different spraying techniques (atmospheric plasma spraying and high-velocity oxygen fuel) and cooling levels were considered using a mathematical model. Results show that temperature history of a part is of paramount importance in stress generation and distribution.

H. Liao, C. Coddet, and Y. Yang. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 235-241 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-58-1313.

Thermal Shock on W Coatings

High Heat Load Testing of Plasma Sprayed W Coatings. The influence of five spraying parameters on the thermal shock resistance of plasma sprayed tungsten coatings was evaluated with a pulsed electron beam gun. The pulse duration was 0.2 s and the absorbed power density 60 MW/m^2. Two series of samples were tested. Both were plasma sprayed in controlled inert atmosphere, one at atmospheric pressure (AP) and the other at low pressure (LP). The porosity seems to be a positive factor for thermal shock resistance: the cracks are more numerous and thinner in less dense specimens. Moreover, the coating thickness is a crucial factor. Indeed, the 100 μm thick coatings (LP and AP) showed no delamination whereas 1 mm thick AP coatings suffered edge delamination.

M. Urquiaga Valdes and R.G. Saint-Jacques. Cited: *J. Nucl. Mater.*, Vol 241-243 (No. 1-3), 1 Feb 1997, p 750-754 [in English]. ISSN 0022-3115. PHOTOCOPY ORDER NUMBER: 199711-58-1227.

Wear and Corrosion on Oxide Coatings

Wear and Corrosion Properties of Plasma Sprayed Al_2O_3 and Cr_2O_3 Coatings Sealed by Aluminum Phosphates. Plasma sprayed aluminum oxide (Al_2O_3) and chromium oxide (Cr_2O_3) coatings were sealed by aluminum phosphates. Phosphates were formed throughout the coating, down to the substrate, and were verified by scanning electron microscopy and hardness measurements. The sealing increased the hardness of the coatings by 200 to 300 HV measurements. Abrasion and erosion wear resistances were increased by the sealing treatment. Sealing also substantially closed the open porosity, as shown in electrochemical corrosion tests. The sealed structures had good resistance against corrosion during 30 days of immersion in both acidic and alkaline solutions with pH values from 0 to 10. No decrease in abrasion wear resistance was observed after immersion.

E.M. Leivo, T.A. Mäntylä, P.P.A. Sorsa, M.S. Vippola, and P.M.J. Vuoristo. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 205-210 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-57-1528.

Review

Engineering and Knowledge-Based Systems

New Approaches to Surface Engineering. The integrated approach to surface engineering is described. It is a knowledge-based system requiring the use of science to select the coating and optimize the application of that coating to the piece's surface considering the application, costs, and service conditions. Innovative techniques include thermal spraying, laser surfacing, physical vapor deposition, and slurry coating. Hard coatings of diamondlike carbon, titanium carbide, titanium nitride, and other carbides and nitrides can be applied by thermal spraying. These thin films have excellent tribological properties. A high-velocity oxyfuel spray gun is used to apply starved lubrication coatings. This approach also serves to protect against corrosion.

J.A. Peters. Cited: *Metallurgia*, Vol 64 (No. 10), Oct 1996, p 408-409 [in English]. ISSN 0141-8602. PHOTOCOPY ORDER NUMBER: 199712-57-1561.

TBCs in the United States

Thermal Barrier Coatings Issues in Advanced Land-Based Gas Turbines. The Department of Energy's Advanced Turbine Systems (ATS) program is aimed at fostering the development of a new generation of land-based gas turbine systems with overall efficiencies significantly beyond those of current state-of-the-art machines, and greatly increased times between inspection and refurbishment, improved environmental impact, and decreased cost. The proposed duty cycle of ATS machines will emphasize different criteria in the selection of materials for the critical components. In particular, thermal barrier coatings (TBCs) will be an essential feature of the hot-gas path components in these machines. The goals of the ATS will require significant improvements in TBC technology, because these turbines will be totally reliant on TBCs, which will be required to function on critical components such as the first-stage vanes and blades for times considerably longer than those experienced in current applications. Important issues include the mechanical and chemical stability of the ceramic layer and the metallic bond coat, the thermal expansion characteristics and compliance of the ceramic layer, and the thermal conductivity across the thickness of the ceramic layer.

W.P. Parks, W.Y. Lee, I.G. Wright, and E.E. Hoffman. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 187-192 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-58-1311.

Standardization

ISO 9000 in Europe

Current CEN Standardization Projects Show for Thermal Spray Companies the Way to Assure Quality of Their Products. Caused by the European common market, installation of a quality management system according to ISO 9000 is also expected of thermal spray companies by their customers. This series of standards represents a commonly applicable example for quality management. That is why new EN-standards are created for establishing quality management systems related to the specific demands of thermal spraying and also for defining tasks and responsibilities of thermal spray personnel. The standard proposals divide in three levels of quality requirements of thermally sprayed structures. They also fix the education and qualification profile of thermal spray personnel (thermal spray coordinator, sprayer). The EN standard "approval testing of thermal sprayers," to be released as a prestandard, will complete the series of standards for the qualification of thermal spray personnel.

D. Böhme and A. Ohliger. Cited: *TS96. Thermal Spraying Conference (Thermische Spritzkonferenz)* (Proc. Conf.), Essen, Germany, 6-8 March 1996, Deutscher Verlag für Schweisstechnik GmbH, 1996, p 209-212 [in German]. ISBN 3-87155-480-4. PHOTOCOPY ORDER NUMBER: 199712-E7-Z-0271.

Surface Preparation

Grit-Blasting Parameters

Alumina Grit Blasting Parameters for Surface Preparation in the Plasma Spraying Operation. This paper examines how the grit-blasting process influences the surface roughness of different substrates, the grit residue, and the grit erosion. The influence of grit-blasting conditions on induced substrate residual stresses is also discussed. Aluminum alloy, cast iron, and hard steel were blasted with white alumina grits of 0.5, 1, and 1.4 mm mean diameters. Grit blasting was performed using either a suction-type or a pressure-type machine equipped with straight nozzles made of B_4C. The influence of the following parameters was studied: grit-blasting distance (56-200 mm), blasting time (3-30 s), angle between nozzle and blasted surface (30°, 60°, and 90°), and blasting pressure (0.2-0.7 MPa). The roughness of the substrate was characterized either by using a perthometer or by image analysis. The grit residue remaining at the blasted surface was evaluated after cleaning by image analysis. The residual stresses induced by grit blasting were determined by using the incremental hole drilling method and by measuring the deflection of grit-blasted beams. Grit size was determined to be the most important influence on roughness. The average values of R_a and R_t and the percentage of grit residue increased with grit size and the depth of the plastic zone under the substrate. An increase of the pressure slightly increased the values of R_a and R_t, but also promoted grit breakdown and grit residue. A blasting time of 3 to 6 s was sufficient to obtain the highest roughness and limit the grit breakdown. The residual stresses generated under the blasted surface were compressive, and the depth of the affected zone depended on the grit diameter, the blasting pressure, and the Young's modulus of the substrate. Moreover, the maximum residual stress was reached at the limit of the plastic zone (i.e., several tenths of a millimeter below the substrate surface).

M. Mellali, P. Fauchais, A. Grimaud, A.C. Leger, and J. Lu. Cited: *J. Therm. Spray Technol.*, Vol 6 (No. 2), June 1997, p 217-227 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199711-57-1530.

Synthesis

Nickel Aluminides

Synthesis of Nickel Aluminides by Vacuum Plasma Spraying and Exothermic in situ Reactions. This paper describes our efforts at combining vacuum plasma spraying and exothermic in situ reaction processing techniques to obtain a cost-effective method of producing dense intermetallic materials for high-temperature structural applications. It has been demonstrated that it is possible to produce, using this technique, a layered interpenetrating $Ni_3Al/NiAl$ composite with <5 vol% residual Ni and <3% residual porosity. Exothermic reaction control through powder mixture composition and deposit thermal management proved to be critical steps in synthesizing this composite. Mechanical testing of the $Ni_3Al/NiAl$ composite produced in this study revealed that the presence of Ni_3Al improved appreciably the room-temperature properties of the composite (compared to NiAl) and imparted an anomalous yield behavior, where the yield strength initially increased with temperature. Furthermore, the layered structure of the $Ni_3Al/NiAl$ composite was observed to yield a marked anisotropy in its fracture toughness. The mechanical properties of the $Ni_3Al/NiAl$ composite produced in this study were observed to be in good agreement with properties reported in literature for similar materials produced by other techniques, indicating that with further process optimization the technique explored here can become a viable alternative to currently employed techniques.

S.R. Kalidindi, R.W. Smith, and T.S. Hussey. Cited: *Mater. Sci. Eng. A*, Vol A229 (No. 1-2), 30 June 1997, p 137-146 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199712-62-2215.

Wear

Abradable Materials

Erosion Wear of AlSi-Graphite and Ni/Graphite Abradable Seal Coatings. Erosion wear of AlSi-graphite, Ni/graphite medium-temperature abradable seal coatings for turbine engine was investigated. The results showed that at 90° impact angle, the erosion resistance, $1/E_V$, increases linearly with the increase of volume fraction of metal phase in the coatings, f_M. At high angle impact, abrasive particles impinge on the coating surface and produce indents and extruded lips, then the lips fall off; and the flattened metal grains exfoliate. At low angle, microcutting, plowing, and tunneling via pore and nonmetal phase are predominant.

M. Yi, J. Zheng, J. He, G. Ji, and X. Zhang. Cited: *Trans. Nonferrous Met. Soc. China*, Vol 7 (No. 2), June 1997, p 99-102 [in English]. ISSN 1003-6326. PHOTOCOPY ORDER NUMBER: 199712-62-2128.

Al-Rich Hard Coatings on Al Alloy

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

K. Nakata and M. Ushiroda. Cited: *Surf. Eng.*, Vol 13 (No. 1), 1997, p 45-49 [in English]. ISSN 0267-0844. PHOTOCOPY ORDER NUMBER: 199711-58-1269.

Increasing Ferrous Substrate Properties

Increasing the Wear Resistance of Ferrous Materials by Means of Duplex Surface Layer Techniques. The resistance of steels to wear and corrosion can be improved by means of special surface layers. Duplex surface layer techniques open up new possibilities of optimization in this respect. Available combinations of techniques include: nitriding/coating with carbide tool materials, thermal spraying/nitriding, and beam-assisted technologies such as electron beam hardening/nitriding.

H.-J. Spies. Cited: *Stahl Eisen*, Vol 117 (No. 6), 16 June 1997, p 45-52 [in German]. ISSN 0340-4803. PHOTOCOPY ORDER NUMBER: 199712-57-1595.

Sn-P Bronze Hardfacing

Wearing Resistance Property of Sn-P Bronze Hardfacing. By using plasma arc method, an Sn-P bronze hardfacing was formed on steel 25, which contains more strengthening phases. The wearing property of the friction pair consisting of Sn-P bronze and Cr-plated wheel is better than that of bronze QAl 9-4 and Cr-plated wheel.

Y. Yin, C. Li, and Z. Xue. Cited: *Acta Metall. Sin. (China)*, Vol 33 (No. 5), 18 May 1997, p 529-532 [in Chinese]. ISSN 0412-1961. PHOTOCOPY ORDER NUMBER: 199712-58-1436.

Stellite Coatings

Stellite Wear Resistance Coatings on Austenite Stainless Steel Substrates. This paper presents the studies about hard coatings deposited on stainless steel substrates, using as coating material powder with a Co base. During the exploitation, some parts require, besides a good corrosion resistance, also a good wear resistance, corresponding to a high strength at variable stresses. It was decided to use the plasma spray process, due to the high working speed, the high power and the great stability of the plasma arc, and last, but not least, for the high deposition quality. The measuring of the quality class was made both by nondestructive examination and by destructive testing.

Gh. Marina and V. Randasu. Cited: *Metalurgia (Bucharest)*, Vol 49 (No. 1), Jan 1997, p 45-47 [in Romanian]. ISSN 0461-9579. PHOTOCOPY ORDER NUMBER: 199712-58-1406.

Titanium Nitride Coatings

Wear Performance of CAP-Titanium Nitride-Coated High-Speed Steel in Different Dry Sliding Conditions. Load and speed are the most important sliding-wear parameters for coated tools used against counter materials but have been rarely discussed, particularly the popular CAP-titanium nitride-coated tool. This study presents a wear test to profile the tribobehavior of a CAP-titanium nitride-coated steel tool contacting with chromium steel as a function of load and speed. Wear-loss and friction-coefficient measurements were assessed to evaluate the sliding-wear resistance, and scanning electron microscopy and optical microscopy were used to identify wear modes. Experimental results show that the wear modes observed were polishing wear and mass transfer in low wear-load conditions of <39.2 N, while low stress-abrasion wear, macroparticle drop-off, Brinelling and mass transfer were found in high wear load conditions ranging from 39.2 to 88.2 N. Only mass-transfer and macroparticle drop-off wear modes were found at high sliding speeds. If a low wear-load was employed independent of the sliding speed (up to 37 m/min in this case), it had a minor effect on wear loss because the detrimental wear modes such as low stress abrasion and Brinelling do not occur. This study reveals the wear-immune region of the CAP-titanium nitride-coated tool. Macroparticles, which are usually thought to reduce wear life, do not affect the wear performance at all in this dry sliding contact wear test.

J.L. He, K.C. Chen, and Y.H. Lin. Cited: *Wear*, Vol 208 (No. 1-2), July 1997, p 36-41 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199712-31-5696.

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