Selected Abstracts of Thermal Spray Literature

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Application

Boiler Tubes

Application of Thermal Spray Coating to Boiler Tubes in Refuse Incineration Plants. Recently, in the existing plants, calories of refuse materials tend to be higher, and for newly built boilers, operation design specifications have a tendency to set higher temperatures and pressures to obtain higher efficiency of electric power generation. These conditions accelerate the corrosive thickness reduction of boiler tubes. Hitachi Zosen has therefore undertaken thermal spray methods as a measure to prevent corrosion Therefore, Hitachi Zosen has been studying the application of the thermal sprayed coating to the boiler tubes. In this study the corrosion-resistant property of plasma sprayed coating with self-fluxing alloy material was investigated as a first step. The result indicated the effectiveness of spray coating. However, this coat needs fusing heat treatment after coating. Based on these results the detonation spray method has been developed to obtain high corrosion-resistant quality without any fusing treatments for boiler tubes.

M. Koyama, T. Ohtsuka, M Terashima, K. Toyama, and K. Yamada. Cited: *Hitachi Zosen Tech. Rev.*, Vol 56 (No 3), Oct 1995, p 19-24 [in English] ISSN 0018-2788. PHOTOCOPY ORDER NUMBER: 199706-58-0630.

Coatings for Industry

New Ways in Surface Technique. The article deals with an integrated procedure of surface coating of stressed motor parts (automobile industry, rotating machines, compressors) practiced by Sulzer Innotec, Sulzer Metco, and Sulzer Burchhard (Switzerland), consisting of a multidiscipline analysis of the damage causes and constructional requirements, of a selection of possible coatings and their optimization as well as of a verification of the coating solution. The procedure, based on expert knowledge, data banks and statistical methods leads to the development of layers giving reliable and inexpensive coatings. Layers with a thickness of 1 to 5 μm from diamondlike carbon, TiN, TIC, ceramics on different substrates for tribologic applications having a high hardness (1000 to 3500 HV) and self-lubricating properties are made by physical steaming. A new AbraSol-family of coatings was developed that contains a hard phase of different layers formed by high-speed flame spraying and a solid lubricating phase that is uniformly dispersed in the matrix. These coatings are profitable for the automobile industry against corrosion as compensation for strategic materials, for compressors without oil lubrication in the food, medicine, and natural gas industries

J.A Peters. Cited: *Oberfl. Werkst./Surf. Mater*, Vol 37 (No. 10), Oct 1996, p 6-8 [in German]. ISSN 0048-1270. PHOTOCOPY ORDER NUMBER: 199706-57-0562.

Infrastructure

Metallized and Conductive Coatings as Impressed-Current Anodes for Reinforced Concrete. Steel-reinforcement corrosion can be mitigated by cathodic protection. In order to deliver the protective cathodic current to the rebars, a conductive anode material must be applied to the surface of the protected concrete structure. The performance of two metallized-zinc coating anodes and two conductive paints was investigated. Bond strengths were found to slowly decrease as the current density and the length of the polarization period increased. On the other hand, driving voltages across all coating anodes were found to increase. Evidence of acidification at the anode/concrete interface was only significant for the conductive paints. Arc sprayed zinc performed well in this three-year research program, although it was outperformed by one of the conductive paints. Arc sprayed zinc aluminum (85·15) performed poorly and is not recommended as an impressed-current anode.

R. Brousseau, M. Arnott, and B. Baldock Cited: *Corros. Prev. Control,* Vol 43 (No. 5), Oct 1996, p 119-123 [in English]. ISSN 0010-9371. PHOTOCOPY ORDER NUMBER: 199705-35-0741

Corrosion Behavior of Mild Steel Beneath Porous Plasma Sprayed Coatings. The performance of atmospheric air plasma sprayed bond and ceramic coatings on mild steel was assessed using DC electrochemical methods. Open circuit behavior and results of potentiodynamic polarization were studied for the material in contact with carbonate-bicarbonate solutions containing added chloride ions. The oxides Al_2O_3 and Cr_2O_3 were applied to bond coatings of NiCr and NiAl. The bond coating oxidation resistance and the deposition parameters determined the propagation and location of corrosion sites. Depending on its degree of porosity, the ceramic coating acted as a diffusion barrier to aggressive ions and water. The effects of posttreatment HIPping and superficial laser refusion were also studied. The degradation mechanism is discussed.

V. Costa, L.F. Cruz, C.M. Rangel, and A.M. Dias. Cited: *Br. Corros. J.*, Vol 31 (No 3), 1996, p 227-232 [in English]. ISSN 0007-0599. PHOTOCOPY ORDER NUMBER: 199705-35-0641.

Motor Cylinder Bores

Innovative Impulse for Automobile Motors. The boring of motor cylinders with internal combustion, made from molded alloys of aluminum and silicon, must present internal surface resistant to abrasion. The coating layers executed by the Rota Plasma 500 system with a plasma torch can be realized in operational conditions giving ecologic and economic advantages in comparison with other procedures (inferior to galvanic coating). The system, developed by Sulzer Metco (Swiss), has a projection plasma flexibility that enables the application of almost all fusible powdered materials. The applied layers have a slight friction coefficient, good resistance to thermal shocks, and a high adherence on the AlSi alloy. The microhardness (depending on material) is 350 to 650 HV0.3.

Cited: *Oberfl. Werkst./Surf. Mater.,* Vol 37 (No. 9), Sept 1996, p 6-7 [in French]. ISSN 0048-1270. PHOTOCOPY ORDER NUMBER: 199706-53-0489.

Pig Iron Molds

The Application of Thermal Sprayed Coatings for Pig Iron Ingot Molds. Molds made of gray cast iron for casting pig iron ingots are subjected to severe temperature fluctuations The main life-limiting factor for mold damage is the formation of surface cracks arising from thermal fatigue. Various flame and plasma sprayed coatings were investigated to extend the life of these molds. Coating materials studied include plasma sprayed ceramic coatings with bond coats and flame sprayed oxidation-resistant alloy powders. The results of cyclic furnace tests from room temperature to 1100 °C in air, simulating the thermal cycle in casting, indicated that failure occurred along the interface between the bond coat and the gray iron substrate because of iron oxidation, and not at the interface between the ceramic top coating and the bond coating for a superalloy substrate. The field test results indicated that plasma sprayed alumina coatings with 200 mm top coating thickness are the most promising materials for pig iron casting.

H.-J. Kim and Y.-G. Kweon. Cited: *J. Thermal Spray Technol.*, Vol 5 (No 4), Dec 1996, p 463-468 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-57-0593

TTBCs

Thick Thermal Barrier Coatings for Diesel Engines. Caterpillar's approach to applying thick thermal barrier coatings (TTBCs) to diesel engine combustion chambers has been to use advanced modeling techniques to predict engine conditions and combine this information with fundamental property evaluation of TTBC systems to predict engine performance and TTBC stress states. Engine testing has been used to verify the predicted performance of the TTBC systems and provide information on failure mechanisms. The objective of Caterpillar's program to date has been to advance the fundamental understanding of thick thermal barrier coating systems. Previous reviews of thermal barrier coating technology concluded that the current level of understanding of coating system behavior is inadequate and the lack of fundamental understanding may impede the application of TTBCs to diesel engines. Areas of TTBC technology being examined in this program include powder characteristics and chemistry; bond coat composition; coating design, microstructure, and thickness as they affect properties, durability, and reliability; and TTBC "aging" effects (microstructural and property changes) under diesel engine operating conditions Methods to evaluate the reliability and durability of TTBCs have been developed that attempt to understand the fundamental strength of TTBCs for particular stress states.

M.B Beardsley. Cited· *Thermal Barrier Coating Workshop* (Proc. Conf.), Cleveland, OH 27-29 March 1995, NASA Centre for Aerospace Information, 1995, p 203-216 [in English]. PHOTOCOPY ORDER NUMBER 199705-57-0474.

Wear of Cermet Coatings

Hard Metal Coatings against Wear and Corrosion. Thermal spray cermet coatings made from WC-Co, TiC-Ni, (Ti,Mo)C-NiCr, and Cr_3C_2-NiCr materials are described. In the application of these coatings, temperature and spray velocity vary depending on the type of process. High-speed flame spraying and detonation gun application processes result in the highest particle velocities and moderate temperatures, while atmospheric plasma spray and vacuum plasma spray processes produce the highest particle temperatures and moderate velocities. WC-Co coatings have high wear resistance, but relatively low corrosion resistance in comparison with other cermet coatings. TiC-Ni coatings have both high wear and corrosion resistance. The morphology and cross sections of WC-10Co-4Cr, WC-12Co, and (Ti,Mo)C-28.4NiCo powders in agglomerated and sintered form are shown. The wear resistances of five different cermet coatings applied by Ar-He and Ar-H_2 plasma spray processes are compared.

L.-M. Berger, M. Nebelung, T Mäntylä, and P Vuoristo. Cited: *Maschinenmarkt,* Vol 102 (No. 8), 19 Feb 1996, p 28-30, 32-33 [in German] ISSN 0341-5775. PHOTOCOPY ORDER NUMBER: 199706-57-0649.

Biomaterial

Characterization of Hydroxyapatite

Characterization of Plasma Sprayed Hydroxyapatite by ^{31}P-MAS-NMR and the Effect of Subsequent Annealing. The characterization of plasma spray induced changes become complicated by the formation of amorphous phases. ^{31}P magic angle spinning (MAS)-nuclear magnetic resonance (NMR) measurements are suited to detect both crystalline and amorphous calcium phosphates. Therefore, we used ^{31}P-MAS-NMR and x-ray diffraction (XRD) to characterize plasma sprayed hydroxyapatite. Besides small quantities of nearly unchanged crystalline apatite, disordered partly x-ray amorphous apatite was detected. Additionally, a nonstoichiometric amorphous calcium phosphate phase possessing a structure similar to TCP, probably calcium enriched, was observed. No indications of tetracalciumphosphate could be found. The decomposition of apatite during plasma spraying is reversible. An additional annealing procedure of plasma sprayed hydroxyapatite at suitable temperatures above 500 °C rebuilds crystalline apatite structure.

J. Vogel, N. Bergner, F. Vizethum, G. Gunther, P. Hartmann, and C. Rüssel. Cited: *J. Mater. Sci.: Mater. Med.,* Vol 7 (No 8), Aug 1996, p 495-499 [in English]. ISSN 0957-4530. PHOTOCOPY ORDER NUMBER 199705-57-0382.

Hydroxyapatite Degradation

Effect of Particle Size on Molten States of Starting Powder and Degradation of the Relevant Plasma Sprayed Hydroxyapatite Coatings. Crystallinity of hydroxyapatite (HA) coatings is an important parameter to evaluate their stability. Variation of the size distribution of the starting powder is one way to alter crystallinity of coatings. The fundamental reason might be the variation of molten states of HA powders with different particle sizes In the experiments, HA particles sized between 1 and 180 μm were divided into six groups by sieving. It was observed that the trend of crystallinity of coatings on particle size is not linear but fluctuates. The fluctuation of crystallinity was caused by the alteration of molten states of HA powders with different size distributions. It is concluded that the molten state of starting powder also fluctuated with particle size, but the trend was different from that of crystallinity. Coatings sprayed with different particle sizes were immersed in deionized water for 1 month. After immersion, severe degradation and breakup were observed on the surface of coatings with the highest crystallinity, which were sprayed with large sized HA powders. It may be the high porosities in these coatings that cause the severe degradation. This shows that high crystallinity is not necessarily related to high stability of coatings, and microstructure is of great importance when stability of coatings is considered. Coatings were sprayed on titanium substrates.

W. Tong, Y. Cao, J. Chen, J. Feng, X. Li, Z. Yang, and X. Zhang Cited: *Biomaterials,* Vol 17 (No. 15), Aug 1996, p 1507-1513 [in English] ISSN 0142-9612. PHOTOCOPY ORDER NUMBER: 199705-57-0404.

Titanium Porous Coating

The Development of New Titanium Arc Sprayed Artificial Joints. A new method of applying titanium porous coating onto Ti-6Al-4V and the coating layers and the substrates has been developed and evaluated The new method is inert gas-shielded arc spraying (ISAS), operated in an inert gas stream at atmospheric pressure, and the coatings showed far fewer voids and cracks in the layers and interfacial areas between the layer and the substrate compared with low-pressure plasma spray (LPPS) coatings commercially available currently. Wear of ISAS coatings by the blast erosion test was one-sixth that of LPPS coatings, so the bonding strength between titanium porous particles is six times higher for ISAS coatings than for LPPS. The temperature of the heat treatment after ISAS coating process is 650 °C, which is β transus and far lower than that of beads or wire mesh coatings, and the fatigue strength of the substrates is 38 2% relative to uncoated materials. Chemical analysis and x-ray diffraction analysis revealed that very few titanium reactants with oxygen and nitrogen were produced during the ISAS coating process. The new method of HA flame spray coating onto the surface of the ISAS coating (HS/ISAS) was also developed in the study. Animal experiments showed that the interfacial shear strength with surrounding bone was higher for the ISAS and HA/ISAS coatings than for the control smooth surface From the histological findings, sound new bone formation was recognized around the HA/ISAS coatings at an early stage compared with ISAS coatings. The results indicate that ISAS and HA/ISAS coatings can be successfully used clinically for cementless joint replacements, and HA/ISAS coatings are expected to contribute more satisfactory clinical results in the long term.

A. Fujisawa, Y. Nishio, I Noda, and H Okimatsu. Cited: *Mater. Sci. Eng. C: Biomimetic Mater., Sens. Syst.,* Vol C2 (No. 3), July 1995, p 151-157 [in English] ISSN 0928-4931. PHOTOCOPY ORDER NUMBER: 199706-58-0632.

Composites

Aluminum Matrix Composites

Manufacture of Long Fiber Reinforced Aluminum Matrix Composites by Means of Powder Flame Spraying. The application of thermal spraying to manufacture carbon long fiber reinforced Al (5001)-matrix-composites (MMC) is a novel technological method. This possibility to manufacture MMCs described as "prepreg-technique." Spread fiber rovings are enveloped through wire flame spraying or powder high-velocity oxygen fuel spraying (HVOF) with the matrix material. The advantage of the thermal spraying lies in the slight time of contact of the carbon fibers with the molten matrix metal. Chemical reactions between fibers and the matrix can lead to the education of carbides The consequence is a reduction of the composite tensile strength The forming of these carbides can be excluded nearly completely by using carbon fibers without barrier coating Prepregs can be consolidated to MMC by hot pressing process. These are used as semifinished products (inserts) and serve the partial strengthening by poured parts in high loaded areas. The investigations presented in this publication have as their goal the critical judgment of the results of the powder-HVOF for the production of carbon fiber/aluminum prepregs.

B. Wielage and J Rahm. Cited: *Tenth International Conference on Composite Materials. II Metal Matrix Composites* (Proc. Conf.), Whistler, British Columbia, Canada, 14-18 Aug 1995, Woodhead Publishing, 1995, p 207-213 [in English] ISBN 1 85573 223 8 PHOTOCOPY ORDER NUMBER: 199704-62-0601.

Feedstock

Iron Amorphous Coatings

Thermal Sprayed Fe-10Cr-13P-7C Amorphous Coatings Possessing Excellent Corrosion Resistance. An alloy of Fe-10Cr-13P-7C was thermally sprayed by three different processes: (1) 80 kW low-pressure plasma spraying (LPPS), (2) high-velocity oxyfuel (HVOF) spraying, and (3) 250 kW high-energy plasma spraying (HPS). The as-sprayed coating obtained by the LPPS process was composed of an amorphous phase. In contrast, the as-sprayed coatings obtained by the HVOF and HPS processes were a mixture of amorphous and crystalline phases The as-sprayed coatings showed a high hardness of 700 DPN A very fine structure composed of ferrite, carbide, and phosphide was formed, producing a maximum hardness of >1000 DPN in the LPPS coating just after crystallization on tempering. The corrosion resistance of the amorphous coating was superior to a SUS316L stainless steel coating in 1 *N* H_2SO_4 solution and 1 *N* HCl solution. Furthermore, the amorphous coating underwent neither general nor pitting corrosion in 1 *N* HCl solution and 6% $FeCl_3$ $6H_2O$ solution containing 0.05 *N* HCl, whereas the SUS316L stainless steel coating was attacked aggressively. Coatings were applied to mild steel.

K. Kishitake, H Era, and F. Otsubo. Cited: *J Thermal Spray Technol.,* Vol 5 (No. 4), Dec 1996, p 476-482 [in English] ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-58-0582.

Magnetite

Magnetite Plasma Coatings and Their Application in Electrolyze Process. The features of forming the plasma spraying coatings of magnetite on the metallic substrates (titanium, St3, and 12Kh18N10T steels) are studied to use the results for sputtering the active layers onto sectional electrodes of water treatment plants. Structure and phase composition of the coatings are determined by the methods of optical microscopy, microdurometry, and x-ray analysis. An influence of plasmatron arc power, spraying distance, and powder grain size on structure, porosity, and adhesive strength is investigated.

V.Kh. Kadyrov, A.E. Terent'ev, and L.K Shvedova. Cited: *Poroshk. Metall*, Vol 5-6, May-June 1996, p 52-56 [in Russian]. ISSN 0032-4795. PHOTOCOPY ORDER NUMBER· 199705-57-0516.

Mechanically Alloyed Nickel Material

A Study on the Thermal Spraying Characteristics of Mechanically Alloyed Nickel-Base Self-Fluxing Alloy Powders and Wear Characteristics of Coating Layer. The effect of spraying conditions on the mechanical properties of flame sprayed coatings of a mechanically alloyed nickel-base alloy was investigated. Mechanically alloyed powder of the nickel-base alloy Ni-14Cr-2.75B-4Fe-3 5Si-0.6C (wt%) was prepared by single-shaft attritor mill under argon gas atmosphere. Powders milled for more than 35 h showed nickel solid solution and unimodal particle size distribution with a mean particle diameter of 12 μm. The powders milled for 35 h were used for flame spraying The spraying conditions studied were type of spray gun, gas pressure, carrier gas, substrate, travel speed, and spray distance. The objective was to optimize the flame spraying conditions for the nickel-base self-fluxing powder in relation to the wear resistance, microhardness, and cracking behavior of the coatings A spraying distance of 15 cm produced the best results Sliding wear behavior of the coating prepared on cast iron substrate was examined by ball-on-disc type wear test using an AISI 52100 steel ball as the counter material. Volumetric wear rates of coatings and the substrate were calibrated using the Habig's equation, which involves measurement of wear volume of ball and disc The relative volumetric wear rate of the coatings showed considerable improvement as compared to that of the cast iron substrate.

S.-M. Seo, B.-Y. Lee, and S.-Y. Lee. Cited: *J Korean Inst. Met Mater*, Vol 34 (No. 7), July 1996, p 870-876 [in Korean]. ISSN 0253-3847. PHOTOCOPY ORDER NUMBER. 199705-58-0468.

Variations in WC-Co Coatings

Effect of Powder Structure on the Structure of Thermally Sprayed WC-Co Coatings. Five representative types of WC-Co powders were selected to clarify the dependence of the structure of sprayed coatings on the structure of powders themselves. The WC-Co coatings were sprayed with the Jet-Kote process and plasma spraying. The structure of WC-Co coatings was primarily characterized by x-ray diffraction. The x-ray diffraction patterns of the sprayed coatings were illustrated compared with those of powders to obtain a better understanding of the structure of thermally sprayed WC-Co coatings. The selected coating was also analyzed by differential scanning calorimetry (DSC) The decarburizing process and the effects of powder structure and spray conditions on the crystal structure of sprayed WC-Co coatings are discussed in detail.

C.-J. Li, A. Ohmori, and Y. Harada Cited *J. Mater. Sci.*, Vol 31 (No. 3), 1 Feb 1996, p 785-794 [in English] ISSN 0022-2461. PHOTOCOPY ORDER NUMBER: 199704-62-0714.

Microstructure

Flame Sprayed Alumina

Structural Modifications on Flame Sprayed Alumina. Substrate-free coatings of alumina on aluminum substrates produced by oxyacetylene flame spraying were heated at 500 to 1700 °C. The porosity of coatings initially increased during the heating, then decreased for higher temperatures. These changes were associated with the solid-state transformations followed by heating and stress relaxation. The phases present, true density, and microstructure for as-sprayed and heated coatings were examined using x-ray diffraction, differential thermal analysis, helium pycnometer, and scanning electron microscopy.

R S. Lima, C.P. Bergmann, and J.A C Martins. Cited *Elevated Temperature Coatings: Science and Technology II* (Proc Conf.), Anaheim, CA, 4-8 Feb 1996, Minerals, Metals and Materials Society/AIME, 1996, p 69-76 [in English]. ISBN 0-87339-313-9. PHOTOCOPY ORDER NUMBER· 199706-57-0632.

HVOF Chromium Carbide

Microstructural Examination of HVOF Chromium Carbide Coatings for High-Temperature Applications. Chromium carbide/nickel chromium coatings obtained by the high-velocity oxyfuel thermal spray process were characterized using conventional and high-resolution microscopy to identify the complex microstructure that results from this thermal spraying technique. Thermal cycling and long isothermal treatment were studied, as were the adhesion properties of as-coated and thermally treated samples Coatings were deposited on a 34Cr-4Mo carbon steel substrate.

J M. Guilemany, N. Llorca-Isern, and J. Nutting Cited: *J Thermal Spray Technol.*, Vol 5 (No. 4), Dec 1996, p 483-489 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-58-0583.

Interface of HVOF Coating

Microstructure of Interface between HVOF Sprayed WC-Co Coating and Spring Steel Substrate. The microstructure of the interface between the high-velocity oxygen-fuel flame (HVOF) sprayed WC-Co coating and 60Si2Mn spring steel substrate was characterized by electron microscopy. The WC particles embedded in the adhering γ-phase of nanometer crystallites were observed in the WC-Co coating. A 2 mm thick diffusive layer of tungsten atoms is present in the spring steel substrate, which implies that atomic movements between the ceramic coating and the metal substrate occur during the HVOF spraying and that may be the main reason of excellent bond between the HVOF sprayed WC-Co coating and the spring steel substrate.

B Shao, Y Li, A. Liu, C Shi, J Wang, X Wang, J. Zhang, Y. Zhou, and L Zou. Cited: *Trans. Nonferrous Met Soc China*, Vol 6 (No. 4), Dec 1996, p 76-81 [in English]. ISSN 1003-6326. PHOTOCOPY ORDER NUMBER: 199706-58-0619

Pore Structure

A Study on the Microstructural Development of Plasma Sprayed Ceramic Coatings. Plasma sprayed ceramic coatings consist of layers of rapidly solidified splats and usually have pores, such as vertical microcracks and interlamellar gaps, which significantly influence the properties of the coating. Alumina powder was plasma sprayed in air on 2 mm thick mild steel plate substrates, and the effects of velocity and temperature of sprayed particles and of the substrate temperature on this porosity were experimentally studied. The obtained statistical characteristics of the pore network, such as mean crack spacing and crack depth, were compared with the results of a simple theoretical calculation. The stress due to thermal contraction of individual splats was almost completely relaxed by microcracking Interlamellar contact improved when the substrate temperature during deposition was raised from 470 to 800 K

S Kuroda, T. Fukushima, and S. Kitahara Cited· *Elevated Temperature Coatings: Science and Technology II* (Proc. Conf.), Anaheim, CA, 4-8 Feb 1996, Minerals, Metals and Materials Society/AIME, 1996, p 21-30 [in English]. ISBN 0-87339-313-9. PHOTOCOPY ORDER NUMBER: 199706-57-0630.

Rapid Solidification

Rapid Solidification and Microstructure Development During Plasma Spray Deposition. Plasma spray processing is a well-established method for forming protective coatings and free-standing shapes from a wide range of alloys and ceramics. The process is complex, involving rapid melting and high-velocity impact deposition of powder particles. Due to the rapid solidification nature of the process, deposit evolution also is complex, commonly leading to ultrafine-grained and metastable microstructures. The properties of a plasma sprayed deposit are directly related to this complex microstructure. This paper examines the solidification dynamics and the resultant microstructures in an effort to establish a processing/microstructure relationship. Existing models in the literature developed for splat cooling have been extended and applied for examining the rapid solidification process during plasma spraying. Microstructural features of the splats that are produced by individual impinging droplets are examined through scanning and transmission electron microscopy. The relation of dimensions and morphologies of these individual splats to the consolidated deposit microstructure is considered. In addition, the distinguishing features in the solidification and microstructural development between air plasma spraying and vacuum plasma spraying are explored, and a unified model is proposed for splat solidification and evolution of the microstructure. Nickel-base alloys were studied due to their wide use in plasma spraying Powders used included pure nickel, pure aluminum, Ni-5Al, and Ni-50Cr

S Sampath and H. Herman Cited *J. Thermal Spray Technol.*, Vol 5 (No. 4), Dec 1996, p 445-456 [in English] ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-58-0580

Structural Changes for Flame Spraying

Structural Modifications of Eutectic Alloys under Gas-Thermal Spraying. The alloys of Ni-Al, Fe-Ni-Cr-Al-C-Si, Fe-Ni-Zr-Al-Si-C, and Fe-Cr-Al-C-Si systems are considered with intermetallic, carbide, and silicide-carbide hardening. The coatings are produced by plasma and explosive spraying. Microstructure is investigated by the methods of optical and scanning microscopy as well as x-ray diffraction analysis. It is shown that the eutectic alloys undergo essential structural changes during spraying Redistribution of the phase components takes place with the rise of content of the oversaturated solid solutions of alloying elements (titanium, chromium, cobalt) on the base of main alloy element

A.Yu. Koval', P.V. Nazarenko, I.E Polishchuk, and A E Ostranitsa. Cited: *Poroshk. Metall.*, Vol 5-6, May-June 1996, p 57-63 [in Russian]. ISSN 0032-4795. PHOTOCOPY ORDER NUMBER: 199705-54-0392.

Modeling

APS Process

Modeling of the APS Plasma Spray Process. Coating production by means of thermal spraying processes offers a wide range of applications such as coatings for wear and corrosion protection or decorative applications. Thermal spraying methods for the production of functional coatings on technical surfaces have been developed and optimized for more than 30 years Especially, due to the high process temperatures, the plasma spraying method enables the use of all different kinds of materials such as metals, ceramics, cermets, or organic materials. The development of new coating systems and the optimization of materials processing procedures is still mainly carried out through time-intensive and expensive trial-and-error approaches. For a more effective development of plasma sprayed coatings, it is necessary to reach a full understanding of the underlying physical processes and the correlations between process parameters and coating characteristics The present paper is an approach to systematize the atmospheric plasma spraying process in order to create a basis for numerically modeling the plasma dynamics and the coating formation mechanisms.

E. Lugscheider, C. Barimani, P. Eckert, and U. Eritt Cited: *Computational Modelling of the Mechanical Behaviour of Materials* (Proc. Conf.), Aachen, Germany, 27-29 Nov 1995, *Comput. Mater. Sci*, Vol 7 (No. 1-2), Dec 1996, p 109-114 [in English]. ISSN 0927-0256. PHOTOCOPY ORDER NUMBER: 199705-58-0556.

Dynamic Processes During HVOF

Dynamic Processes During High-Velocity Oxyfuel Spraying. High-velocity oxyfuel spraying is a new, rapidly developing technology for coating formation that is now challenging plasma spraying. Dynamic processes during HVOF spraying have considerable influence on the coating quality The dynamic processes considered are as follows: combustion and gas dynamics, mechanical and thermal inflight behavior of the powder particles, and droplet flattening. The corresponding literature is also reviewed The following points are taken into account: fluid behavior inside and outside a spraying gun; fluid-particle interactions; particle shape and morphology; internal heat conduction in powder particles; mass transfer (dissolution, diffusion, etc.) inside the composite particles; particle heating, fusion, cooling, and solidification, and mass loss of the droplet liquid phase during droplet flattening Good agreement between theoretical and experimental results is shown to exist The results obtained can be used for prediction of the optimal conditions of spraying. Experimental data concerning the spraying of cemented carbides (e.g., WC-Co, Cr_3C_2-NiCr) and ceramics (e.g., Al_2O_3) is shown. For comparison between the analytical and experimental data, the experimental values of the final splat radius obtained during the plasma spraying of zirconia on to a steel substrate are used

V.V. Sobolev and J.M. Guilemany. Cited: *Int. Mater. Rev.*, Vol 41 (No. 1), 1996, p 13-32 [in English]. ISSN 0950-6608. PHOTOCOPY ORDER NUMBER: 199706-57-0579.

Thermoelastic Behavior

Modeling of the Thermoelastic Plastic Behavior of a Plasma Coating. Observation of Thermal Residual Stress. An analytical modeling of the quenching of a plasma coating on a substrate is presented to predict its thermoelastic-plastic behavior. The heat transfer problem is solved with convection boundary conditions for the transient temperature distribution for different thicknesses of plasma coating and substrate. Then the thermal strains are introduced in the mechanical equations of the inhomogeneous structure considered as elastic-plastic for the calculations of the residual stresses in the plasma coating and in the substrate. The influence of the thickness of the coating is tested for a substrate-coating interface considered as ideal. The case presented involves an aluminum plasma coating on steel.

F. Hugot and J C. Boyer. Cited: *Eur. J Mech. Eng.*, Vol 41 (No. 3), Autumn 1996, p 131-136 [in French]. ISSN 0035-3612 PHOTOCOPY ORDER NUMBER: 199705-58-0555

Post-Treatment

Densification of Titanium and Tantalum

Densification of Plasma Sprayed Titanium and Tantalum Coatings. Thermal spraying of corrosion-resistant coatings of titanium and tantalum is difficult; dense coatings are not produced, and oxidation of these metals increases coating porosity. In this study, oxidation during plasma spraying was reduced with a shrouding system. Porosity and oxide content also were minimized by optimizing the spraying parameters. After optimization, the coatings still had open porosity and thus were incapable of protecting the substrate material (steel or stainless steel) against corrosion in water solutions containing 3% NaCl. Therefore, posttreatments for improvement of corrosion resistance were studied. Electron beam fusion produced corrosion resistance equal to or better than that of bulk commercial samples of titanium and tantalum.

T. Kinos, S.L. Chen, P. Kettunen, and P. Siitonen Cited *J. Thermal Spray Technol.*, Vol 5 (No. 4), Dec 1996, p 439-444 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-58-0579.

Process

Laser Cladding

Investigation of Microstructure of Laser Cladding Ni-WC Layer on Al-Si Alloy. A plasma sprayed Ni-WC layer was deposited on an Al-Si cast alloy surface, and then it was further melted by a 5 kW CO_2 laser. The microstructure and chemical composition of the laser-melted zone were investigated, and the microhardness in different parts was measured. Experimental results showed that the chemical composition of the samples was not uniform Compositional segregation in the laser-melted zone was found. Some amorphous structure appeared in the nickel-rich locations after laser melting. Owing to the thermal effect of the laser scanning, an intermediate-phase Ni_3Al segregated from this region and formed Ni_3Al grains and amorphous grains. Some WC particles melted in the matrix, and chromium carbide $Cr_{23}C_6$ and (Cr,W)C separated during the cooling process. The highest microhardness (1027 HV) was found in the high-nickel region.

G.Y. Liang and T.T. Wong. Cited: *J. Mater. Eng. Perform*, Vol 6 (No. 1), Feb 1997, p 41-45 [in English]. ISSN 1059-9495. PHOTOCOPY ORDER NUMBER. 199706-58-0672.

Laser Spray

Application of Ceramic Coating and Spherical Ceramic Particle Synthesis Using Laser Spray Technique. A laser spray method, which is melting and quenching of random-shaped powder dropped perpendicularly to a focused CO_2 laser beam in the air was developed. Ceramic coatings were deposited on copper plate substrates using this method. First, by using a high-speed camera, it was investigated whether the ceramic particles in the ZrO_2-9 mol% Y_2O_3, γ-Al_2O_3, TiO_2, and Al_2O_3-Cr_2O_3 system were spheroid while passing through laser beam or not. The melting kinetics, residence time of particles within the laser beam, and melting efficiency of particle with change of laser power were estimated. Second, this rapid melting-solidification technique was applied to ceramic coating for improving several problems that arise from poor efficiency, production rates, and controllability of the deposited structure. The properties of the coated layer produced by the CO_2 laser spray method are discussed.

M. Okutomi and K. Tsukamoto Cited: *Elevated Temperature Coatings: Science and Technology II* (Proc. Conf.), Anaheim, CA, 4-8 Feb 1996, Minerals, Metals and Materials Society/AIME, 1996, p 59-67 [in English]. ISBN 0-87339-313-9. PHOTOCOPY ORDER NUMBER: 199706-57-0631.

Ultradispersed Particles in High-Speed Flows

Promising Methods for Producing the Ultradispersed Particles in High-Speed Flows. Physical and mathematical models for process of the ultradispersed particles forming during flowing in Laval's nozzle are presented. A possibility for simultaneously producing the ultradispersed particles and their use in particular technological process is an essential feature of this method So, coating using laser-electrical technique is possible. The use of these particles as the ice-formation nucleuses is possible also. The sputtering problem is solved by using the proposed method of producing the ultradispersed particles.

U G. Pirumov. Cited: *Probl Mashinostr. Nadezhn. Mash.*, Vol 1, Jan-Feb 1996, p 94-99 [in Russian]. ISSN 0235-7119. PHOTOCOPY ORDER NUMBER: 199704-54-0287.

Processing

Materials Modification with Thermal Plasmas

Materials Processing with Thermal Plasmas. Thermal plasma technology is becoming increasingly more attractive for industrial applications. It can be used for refining materials, hardfacing to conserve materials, and as a route for advanced processing of materials. Thermal plasma is already used for densification of powders with mean particle diameters of 45 to 76 μm and the application of coatings such as metals and ceramics. Wire-arc spraying is one of the most common surface coating methods. Examples of its application are given along with a discussion of the gases used in the spray. With new advances, wire-arc sprayed coatings are high quality, tightly adherent, and possess excellent wear resistance. By replacing air with an inert gas, wire-arc sprayed films can be applied to alter the surface properties. Finally, thermal plasma can be used to synthesize powders, especially refractory metals

M. Boulos and E Pfender. Cited: *MRS Bull.*, Vol 21 (No. 8), Aug 1996, p 65-68 [in English]. ISSN 0883-7694. PHOTOCOPY ORDER NUMBER: 199704-16-0107.

Properties

Corrosion of Carbide Cermet

Corrosion Behavior of Thermal Sprayed Carbide Cermet Coatings. Corrosion behavior of thermal sprayed carbide cermet coating in an alkaline aqueous solution that was exposed to air and aerated was examined by electrochemical processes. In this study, the galvanic corrosion due to contact with undercoating or substrate was considered. The results obtained are following: (1) anodic polarization of thermal sprayed Cr_3C_2/NiCr coating indicates active dissolution. The NiCr matrix may have major influence on it, (2) the corrosion rate of thermal sprayed NiP undercoating tends to be faster than that of carbon steel, and (3) chloride ions in 1 *M* NaOH solution may have minor influence on the corrosion behavior of thermal sprayed Cr_3C_2/NiCr and NiP coatings and carbon steel.

Y. Takatani, T. Tomita, Y. Harada, M. Inaba, and K Tani. Cited: *J. Soc. Mater. Sci, Jpn.*, Vol 44 (No. 506), Nov 1995, p 1332-1337 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER: 199704-35-0610.

Corrosion Resistance

Engineering Aspects of Plasma Spraying on the Corrosion Resistance Properties of Metallic Materials. This paper discusses the surface modification processes, based on spraying of ceramic particulates, on the surface of different metallic materials, highlighting the corrosion-resistance properties of these coatings Emphasis has been put on the engineering aspects of these coatings, particularly, the pressure and temperature of the spray, and the rate of particulate transfer on the substrate. Some considerations on the size and shape of the specimens and on the thickness of these coatings, have also been included.

V. Arumugam, S. Krishnamoorthy, and D. Mukherjee. Cited: *Tool Alloy Steels*, Vol 30 (No. 11), Nov 1996, p 12-15 [in English]. ISSN 0377-9408. PHOTOCOPY ORDER NUMBER: 199705-57-0503.

Interfacial Adhesion Test

Adhesion Properties of Thermal Sprayed Coatings, Deduced from the Interface Indentation Test. One of the most important limitations to the use of coated materials is the adhesion of the coating on its substrate. Among the various methods of measuring or estimating adhesion, the interface indentation test seems to offer interesting prospects. From indentation tests performed on the interface between a hypersonic thermal sprayed chromium carbide coating and several hypersonic thermal sprayed chromium carbide coating and several metallic substrates, it is shown that it is possible to obtain a critical load that may represent adhesion. This critical indentation load is independent of the coating thickness if an appropriate annealing treatment is realized in order to remove the residual stresses appearing during the cooling of the sprayed material. From tests performed on as-received specimens, the effect of residual stresses is also discussed.

J. Lesage, D. Chicot, P. Demarecaux, and G. Mesmacque Cited: *49th International Congress on the Technology of Metals and Materials*, Vol IX, *Non-Metallic Materials: Development of Polymers, Ceramics and Composites*, (Proc. Conf.), São Paulo, Brazil, Oct 1994, Associaçao Brasileira de Metalurgia e Materiais, 1995, p 475-484 [in English]. PHOTOCOPY ORDER NUMBER: 199704-57-0442.

MCrAlY Coatings

Mechanical Properties of Aluminized MCrAlY Alloy Coatings. A low-pressure plasma spray (LPPS) process is used to overlay coatings of MCrAlY alloy for protection against high-temperature corrosion and oxidation This coating process has been found to be very effective for gas turbine components. On the other hand, diffusion coating processes have been applied for many years to improve similarly the environmental resistance by enriching the surface of a substrate with chromium, aluminum, or silicon. Recently, aluminizing on the MCrAlY coatings is used for improving further the high-temperature oxidation resistance. However, the mechanical properties of aluminized MCrAlY coating, which have an important effect on coating life, have not always been clarified. In this study, five kinds of free-standing MCrAlY specimens (CoCrAlY, CoNiCrAlY, CoNiCrAlY + Ta, NiCrAlY, NiCoCrAlY) were machined from the thick LPPS coatings. And, the heat treated MCrAlY specimens (1393 K, 2 h, argon atmosphere) and the aluminized specimens (Al-Cr-Al_2O_3-NH_4Cl pack, 1173 to 1273 K, 10 h) after heat treatment were used in the experiments. The Vicker's hardness, Young's modulus, Poisson's ratio and four-point bending strength of the aluminized MCrAlY coatings were measured at room temperature in comparison with the MCrAlY substrates. The experimental results suggest that the volume percentage of precipitated aluminum compound in the MCrAlY coatings and the residual stress induced by the aluminizing have an important effect on the bending strength. Namely, there is a tendency that the bending strength decreases by the alumizing and also with increasing the volume percentage of aluminum compound. The Vickers hardness and Young's modulus of the aluminized layers show higher values in comparison with the MCrAlY coatings.

Y. Harada, J.-I. Takeuchi, Y. Itoh, M. Saitoh. Cited: *J Soc. Mater. Sci., Jpn*, Vol 44 (No. 506), Nov 1995, p 1361-1366 [in Japanese]. ISSN 0514-5163. PHOTOCOPY ORDER NUMBER· 199704-58-0450.

Nondestructive Testing

The Effectiveness of Nondestructive Techniques for Assessment of Quality of Plasma Sprayed Coatings. This chapter gives an overview of some of the more promising contemporary research into nondestructive testing methods, which may have potential for the assessment of the "quality" (or "integrity") and thickness of plasma sprayed coatings Nondestructive methods discussed include acoustic emission, dielectric monitoring, interferometry, eddy current testing, and holography.

M.E Houghton. Cited *Surface Engineering. Processes and Applications*, Technomic Publishing, 1995, p 313-330 [in English]. ISBN 1-56676-154-9. PHOTOCOPY ORDER NUMBER 199705-22-0364

Residual Stresses

Relationship to Adhesion

Residual Stresses, Adhesion, and Thermal Sprayed Coatings. Most coatings are applied with a specific aim in mind, such as improving the corrosion and wear resistances of the base material or providing a thermal barrier against high temperatures These aims can obviously be achieved if the coating is properly bonded to the substrate. One important factor that contributes to the failure of plasma sprayed coatings is the residual stress produced during its manufacture. In the present work, residual stresses were determined in the coating systems: NiCrAlY metallic bonding layer, a Cr_2O_3 ceramic layer, and a WC-Co cermet layer. The coatings were deposited by plasma spraying on 30NCD16 steel, cast iron, and nickel-base superalloy substrates. To study the effect of the residual stresses on the properties of the coatings (particularly on the adhesion of coatings to their substrates), two techniques are used· a Vicker's indentation test is performed at the substrate/coating interface (in order to determine, by a simplified model based on mechanics concepts, the interfacial toughness) and a four-point bending test assisted by an acoustic emission system.

C Richard, G. Beranger, and J. Lu Cited: *Elevated Temperature Coatings: Science and Technology II* (Proc. Conf.), Anaheim, CA, 4-8 Feb 1996, Minerals, Metals and Materials Society/AIME, 1996, p 77-86 [in English]. ISBN 0-87339-313-9. PHOTOCOPY ORDER NUMBER: 199706-31-2452.

Review

Residual Stresses in Thermal Spray Coatings and Their Effect on Interfacial Adhesion: A Review of Recent Work. An overview is presented of the development of residual stresses in thermal spray coatings and their effects on interfacial debonding. The main experimental techniques for measurement of residual stresses are briefly described, with particular attention given to the method of continuous curvature monitoring. Boundary conditions satisfied by all residual stress distributions are identified and expressions derived for the curvatures and stress distributions arising from a uniform misfit strain between coating and substrate. It is noted that stress distributions in thick coatings rarely correspond to the imposition of such a uniform misfit strain, so that recourse to numerical methods becomes essential for quantitative prediction of stress distributions Relationships are presented between residual stresses and corresponding strain energy release rates during interfacial debonding. The effect on this of superimposing stresses from an externally applied load is outlined. The initiation of debonding is then considered, covering edge effects and other geometrical considerations. Finally, some specific case histories are briefly outlined to illustrate how the various theoretical concepts involved relate to industrial practice. Data are shown for titanium, mild steel, aluminum, tungsten, and nickel substrates and alumina, zirconia, and boron carbide sprayed coatings. Case histories include edge effects in piston crown and piston ring coatings for marine diesel engines and stability of zirconia thermal barrier coatings used in aerospace engines.

T.W. Clyne and S.C Gill Cited: *J. Thermal Spray Technol.*, Vol 5 (No. 4), Dec 1996, p 401-418 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199706-57-0591.

Thermoelastic FEM Study

Thermal Residual Stresses in Spray Atomized and Deposited Ni_3Al. Thermoelastoplastic finite element analysis was used to study the thermal residual stresses developed in the deposited preform from spray atomization and deposition process. Thermal residual stresses were developed in the spray deposited Ni_3Al during cooling from the fabrication temperature to ambient temperature. The radial, hoop, and axial stresses were found to be mostly compressive at the central region of the deposited preform. The magnitude of the stresses increases for the region closer to the outer edge of the preform. The results estimated using the finite element analysis were in good agreement with those measured using the x-ray diffraction technique.

E.J. Lavernia and S Ho. Cited: *Scr. Mater.*, Vol 34 (No. 4), 15 Feb 1996, p 527-536 [in English]. ISSN 1359-6462. PHOTOCOPY ORDER NUMBER: 199704-31-1611.

Thermomechanical Properties

B_4C Coatings

Thermomechanical Characterization of B_4C Vacuum Plasma Sprayed Coatings on Stainless Steel Tubular Substrates. Vacuum plasma sprayed B_4C coatings on stainless steel tubular substrates were characterized for their thermal and mechanical properties. The B_4C coatings were deposited on a cermet bond coat of Mo and B_4C on the stainless steel substrate. The coatings were 500, 100, and 1500 μm thick. The bending strength, linear thermal expansion, and thermal diffusivity of the coatings were determined The results showed a degradation of some of the thermomechanical properties of VPS B_4C thick coatings but not of thermal expansion.

A. Riccardi and A. Pizzuto. Cited: *J. Mater. Sci. Lett.*, Vol 15 (No. 14), 15 July 1996, p 1234-1236 [in English]. ISSN 0261-8028. PHOTOCOPY ORDER NUMBER: 199705-57-0432.

Tribology

Dependence on Feedstock

Structure and Properties of Hardmetallike Coatings Prepared by Thermal Spray Processes. Thermal spray processes represent an important group of surfacing technologies to produce hardmetallike coatings for wear protection. WC with cobalt or nickel (often alloyed with chromium) binders and Cr_3C_2-NiCr are the most common systems used in these technologies. The structures and the properties of the coatings depend strongly on composition, on the technology of spray powder preparation, and on the spray process parameters Service conditions for cutting applications and for coatings are quite different. Therefore, the development of new hardmetal systems for coating applications has to take into account the specific process and service conditions.

L.-M. Berger, W. Hermel, T. Mäntylä, P. Vuoristo, P. Ettmayer, and W. Lengauer. Cited: *1996 European Conference on Advances in Hard Materials Production* (Proc. Conf.), Stockholm, Sweden, 27-29 May 1996, European Powder Metallurgy Association, 1996, p 443-450 [in English]. ISBN 1-899072-03-9. PHOTOCOPY ORDER NUMBER: 199705-58-0557.

Diamond Coatings of WC-Co

Tribological and Microstructural Evaluation of Biased Smooth Hot Flame Deposited Diamond Films. In the present investigation a novel method for producing smooth, as-deposited diamond coatings on WC-Co cemented carbide substrates is presented. The coatings are subjected to crystallographic and morphological analysis using scanning electron microscopy (SEM), x-ray diffraction (XRD), Raman spectroscopy, and transmission electron microscopy (TEM). Tribological evaluation by sliding and abrasive testing is also performed. The microstructural evaluation showed that the average grain size in the biased diamond coatings in 8 nm, and that no graphite is present. Steady-state friction when sliding against cemented carbide was 0.07 to 0.1, with small fluctuations Different sliding speeds did not influence the shape of the friction curve In all wear tracks a tribofilm (~1 μm thick) was formed. When a drop of water was applied, the friction coefficient was reduced to 0.05 In sliding contact, the biased diamond coatings were extremely wear resistant—about 2000 times as wear resistant as CC. All diamond coatings also displayed a superior abrasion resistance as compared to CC. It is concluded that (1) the biased hot flame method offers the possibility of simple and cost-efficient production of smooth diamond coatings, (2) deposition of diamond coatings using the biased hot flame method extends the range of applications for diamond coatings into regions that hitherto had been closed, due to the high surface roughness of conventional diamond coatings, and (3) the extremely good performance of the biased coatings in tribological tests, particularly in water-lubricated friction, implies that this type of coating probably can replace (and outperform) conventional diamond coatings in many applications, e g., water-lubricated bearings.

P. Hollman, A. Alahelisten, P. Hedenqvist, and S. Hogmark. Cited· *1996 European Conference on Advances in Hard Materials Production* (Proc. Conf.), Stockholm, Sweden, 27-29 May 1996, European Powder Metallurgy Association, 1996, p 387-395 [in English]. ISBN 1-899072-03-9. PHOTOCOPY ORDER NUMBER: 199705-62-0950.