Selected Abstracts of Thermal Spray Literature

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Applications

Cast Iron Molds

The Application of Flame and Plasma Sprayed Coatings for Cast Iron Molds. Molds made of gray iron for casting iron are subjected to severe temperature fluctuations very similar to the die casting process except for the high-pressure erosion that occurs due to molten metal. Therefore, the main life limiting damage for molds is the formation of surface cracks arising from thermal fatigue. Various flame and plasma sprayed coatings were investigated to extend the life of molds for casting iron. Coating materials studied include plasma sprayed ceramic coatings with bond coat (NiCrAl, NiCrAlY, and NiCrAlCoY) and powder flame sprayed oxidation resistant alloys (NiCr, NiAl, and NiCrAl). The results of simulated cyclic furnace tests from room temperature to 1100 °C in air indicated that the failure occurred along the interface between the bond coat and the iron substrate due to iron oxidation rather than the interface between the ceramic coating and the bond coating for superalloy substrate. The results of field tests are also discussed.

H.-J. Kim and Y-G. Kweon. Cited: *Mater. Manuf. Process.*, Vol 11 (No. 2), March 1996, p 233-243 [in English]. ISSN 1042-6914. PHOTOCOPY ORDER NUMBER: 199606-57-1064.

Electrodes

Vacuum Plasma Sprayed Titanium-Manganese Electrode Layers for MnO_2 Deposition. Vacuum plasma sprayed titanium-manganese alloy electrode layers are intended to improve the economy and efficiency of the synthesis of electrolytic manganese dioxide, which is commercially used as cathodic material in primary batteries Titanium anodes with a high content of manganese offer high electrochemical activity and corrosion resistance, but poor mechanical stability. Therefore, dense and well-bonded coatings of this brittle alloy were vacuum plasma sprayed onto ductile substrates using commercially pure titanium and manganese powder mixtures as well as mechanically alloyed powders. The mechanically alloyed powders, fabricated in a planetary ball mill, are suitable for the plasma spray process. The microstructure and electrochemical properties of the anode coatings produced by these two methods are discussed. Results are compared to commercially pure titanium anodes.

H.-D Steffens and M. Brune. Cited *J. Therm. Spray Technol.*, Vol 4 (No. 1), March 1995, p 85-88 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199605-58-0808.

Tubing Industry

Arc Spraying Coatings on a Tube Mill. This article addresses only one of a number of potential uses for the thermal spray process in the tubing industry. With a little imagination and some research into the types of coating materials available, the tubing industry could make major advancements in the development of new and innovative products in the near future.

C.P. Howes, Jr Cited: *TPQ, Tube Pipe Q.*, Vol 7 (No. 1), Jan-Feb 1996, p 28-31 [in English]. ISSN 1051-4120. PHOTOCOPY ORDER NUMBER: 199605-57-0842.

General Overview

Trends and Processes in Thermal Spraying. Thermal spraying is one of the most important surface treatment technologies The main techniques are flame spraying, arc spraying, plasma arc spraying, and metallization. The use of thermal spraying can increase the effectiveness of many components Lighter brakes are fabricated by coating aluminum with ferrous material using an electric arc spraying unit. Hard coatings can be achieved by spraying molybdenum. Application of ceramic coatings can vastly improve temperature resistance and provide protection against high-temperature gases. Ceramics are conventionally plasma sprayed from powder, or flame sprayed from sintered rods. Typical ceramic coatings include zirconia for heat resistance, and alumina or alumina-titania for wear resistance. Coatings of zinc and tin are used on capacitors for electrical contacts.

L Cornish. Cited· *Foundry Heat Treat SA*, Vol 2 (No 5), Sept-Oct 1994, p 22, 24 [in English]. ISSN 1022-8187. PHOTOCOPY ORDER NUMBER: 199606-58-1001.

Book

Spraying of Ceramics

Thermal Spray of Ceramic Coatings. Spray coating of ceramics onto metals by arc, laser, plasma, and powder methods; equipment, processes and methods.

Cited· *Search-in-Print*, Y715, 1995 [in English]. PHOTOCOPY ORDER NUMBER: 199604-57-0690

Spraying of Nonferrous Alloys

Plasma Spray Coating of Nonferrous Alloys. Spraying of metals, powders, ceramics, and carbides for improved service life and high temperature and corrosion resistance; covers Al, Co, Cu, Ni, Ti.

Cited· *Search-in-Print*, G701, 1995 [in English]. PHOTOCOPY ORDER NUMBER: 199604-57-0692.

Spraying of Steels

Plasma Spray Coating of Steels. Spraying of metals, powders, ceramics, and carbides for improved service life and high temperature and corrosion resistance.

Cited: *Search-in-Print*, S703, 1995 [in English]. PHOTOCOPY ORDER NUMBER: 199604-57-0691

Feedstock

Gray Iron

Development of Process of the Powders Producing for Plasma Spraying Using Gray Iron Chips. The feasibility of producing powder from SCh20 and SCh21 gray iron chips for plasma spraying coating was studied. It was found that the gray iron powder with good technological properties might be produced via two-step recycling process. The formation of metastable epsilon-carbide, martensite, and residual austenite, that was absent in initial chips and powder, were revealed. That resulted in the improvement of coating microhardness up to 6000 to 8000 ksi that was by a factor of 2.2 to 2.4 higher than that of the as-cast gray iron.

Yu.S. Borisov, M.L. Kilz', V.N. Korzhik, and M.T. Pan'ko. Cited· *Avtom. Svarka*, No. 6, June 1995, p 7-12 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199606-58-1018.

Microstructure

Amorphous Coatings

Characteristics of Fe-17Cr-38Mo-4C Amorphous Coating Obtained by Low Pressure Plasma Spraying. Fe-17 mass% Cr-38 mass% Mo-4 mass% C alloy was thermal sprayed on SS400 substrate by a use of 80 kW low-pressure plasma spraying apparatus. It is known that the amorphous phase of the same alloy has a very high crystallization temperature ~940 K. The as-sprayed coating is composed of perfectly amorphous phase and shows a high hardness of 1000 DPN. The amorphous phase in the coatings crystallizes at a high temperature of ~920 K A very fine structure of hard chi phase and carbides is formed after crystallization, bringing about an extremely high hardness of 1450 DPN. The hardness of the tempered coating retains a high hardness of 1300 DPN or more even after tempering at 1273 K. The corrosion resistance of the amorphous coating is superior or comparable to SUS316L austenitic stainless steel coating in H_2SO_4 solution.

K. Kishitake, H. Era, and F. Otsubo. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.)*, Vol 32 (No. 3), Oct 1995, p 24-28 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199606-58-0895.

Splat Morphology

Effects of Vacuum Plasma Spray Processing Parameters on Splat Morphology. Several statistical tools (i.e., Gaussian and Weibull distribution analyses, the t-test, and analysis of the variance) were used to examine relationships between vacuum plasma spray processing parameters and the morphology of flattened particles (splats) on a smooth, polished substrate. Astroloy, a nickel-base powder, was vacuum plasma sprayed onto polished copper substrates under various processing conditions. Different flattened particle shape factors, including equivalent diameter, elongation factor, and degree of splashing, were determined using image analysis. The spray parameters (i.e., current intensity, chamber pressure, argon mass flow rate, etc.) strongly influenced splat formation and morphology and thus deposit microstructure and properties.

G. Montavon, C Coddet, C.C. Berndt, H Herman, and S. Sampath. Cited: *J. Therm. Spray Technol.*, Vol 4 (No. 1), March 1995, p 67-74 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199605-58-0806.

Modeling

Deposition Process

Modeling the Deposition Process of Thermal Barrier Coatings. Thermal barrier coatings produced by plasma spraying have a characteristic microstructure of lamellae, pores, and cracks. The lamellae form when particles splash onto the substrate. As the coating grows, the lamellae pile on top of one another, producing an interlocking structure. In most cases the growth is rapid and chaotic, resulting in a microstructure characterized by pores and cracks. This paper presents an improved model for the deposition process of thermal barrier coatings. The task of modeling the coating growth is divided into two parts. First, a description of the particle on arrival at the film is given based on the available theoretical, numerical, and experimental findings. Second, a set of physically based rules for combining these events to obtain the film is defined and discussed. The splats run along the surface and are permitted to curl up (producing pores) or to interlock. The computer model uses a mesh to combine these processes and build the coating. The proposed model can be used to predict microstructures and hence to correlate the properties of these coatings with the parameters of the process used to make them.

J.H. Harding, P.A. Mulheran, S. Cirolini, G. Jacucci, and M. Marchese. *J. Therm. Spray Technol.*, Vol 4 (No. 1), March 1995, p 34-40 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER: 199605-58-0805.

HVOF Process

Dynamic Processes during In-Flight Motion of Cr_3C_2-NiCr Powder Particles in High Velocity Oxyfuel (HVOF) Spraying. By means of the mathematical simulation, the dynamic processes taking place during the motion of the chromium carbide-nickel-chromium powder particles in HVOF spraying are investigated. These processes include combustion, fluid and particle dynamics, and heat and mass transfer. The latter occurs due to the chromium carbide dissolution and the formation of the chromium oxide during a particle flight. The particle mechanical and thermal behavior is studied. The mass transfer inside the particles is shown to significantly influence its thermal behavior. The obtained results permit the establishment of optimal HVOF spraying conditions.

V.V. Sobolev and J.A Calero, and J.M Guilemany. Cited: *J. Mater. Process. Manuf. Sci.*, Vol 4 (No. 1), July 1995, p 25-39 [in English] ISSN 1062-0656. PHOTOCOPY ORDER NUMBER: 199605-58-0706.

Process

Diagnostics

Coatings Spraying from Self-Fluxing Alloys on the Base of Iron by the Plasma-Arc Technique. I. Estimation of Temperature and Speed of the Powder Particle Flight in Plasma Flow. Mathematical simulation was used to estimate the effect of technological parameters on the regularities of thermal and dynamic interaction of particles with the high-energetic gas flow in the process spraying iron powder containing 20Ni, 8Cr, 4Cu, 3B, 2Si, 08C wt%. The influence of plasma generator arc current, discharge gases (propane, butane) and their ratio, powder particle size, plasma generator nozzle diameter, and other factors were analyzed. Optimal spraying conditions were determined for various powder fractions.

E.P. Martsevoi and A.A. Nechiporenko. Cited: *Poroshk. Metall.*, No 1-2, Jan-Feb 1995, 35-40 [in Russian]. ISSN 0032-4795. PHOTOCOPY ORDER NUMBER: 199606-54-0644.

Electric Arc

Structure and Properties of Ferrochromium- and Ferrochromium/Aluminum-Base Coatings Produced by Electric Arc Metallizing from Powder Wires. The use of powder wires permits coatings with high physicomechanical properties. Structure, phase composition, gas content and such properties as hardness, strength, and adhesion to a base are found. Young's modulus, shear modulus, and thermal coefficient of linear expansion of mentioned coatings are studied. Recommendations are given to use these coatings in the restoration of agricultural machine components of 45 steel.

A.L. Borisova, T.V. Kaida, and I.V. Mits. Cited: *Avtom. Svarka*, No 6, June 1995, p 3-6 [in Russian]. ISSN 0005-111X. PHOTOCOPY ORDER NUMBER: 199606-58-1017.

High-Power Plasma

High Power Plasma Spray Coatings of Alumina Powders Coated with Nickel. Some properties of thermal sprayed coatings on JIS A5052P-H24 aluminum base alloy prepared from alumina powder coated with nickel by plasma spraying at 250 kW were investigated. Thermal sprayed coatings consisted of alumina film with pieces of nickel plates The coatings prepared from alumina coated with nickel gave better properties than that from noncoated alumina on hardness, abrasion resistance, thermal shock, and fracture roughness resistance. The alumina particles in the thermal sprayed coatings increased with increasing size of starting alumina powder The transformation from alpha- to gamma-alumina was suppressed by increasing size of alumina powder and content of nickel, resulting in a possibility of the production of coating with less change in composition.

Y. Mito, S. Ito, H. Miyamoto, T. Yamamoto, S. Ishida, and T. Onaka. Cited: *Zairyo Gijutsu (Mater. Technol.)*, Vol 14 (No 2), 1996, p 52-59 [in Japanese]. ISSN 0289-7709. PHOTOCOPY ORDER NUMBER: 199606-57-1086.

Laser-Plasma System

Material Processing by Combined Laser and Plasma Spray System. Higher demands are being placed on materials in terms of performance characteristics and their ability to meet stricter environmental standards. Surface process technology is often mentioned as a way to meet increasingly strenuous demands This paper describes new surface processing technology that combines plasma spraying and laser treatment for possibilities in future applications. Molybdenum on SS substrate, WC-Co, Al_2O_3, and titanium nitride, AlN coatings are discussed.

K. Kamada. Cited: *Matsushita Denko Giho (Matsushita Electr. Works Tech. Rep.)*, Vol 53, March 1996, p 56-60 [in Japanese]. ISSN 0285-5054. PHOTOCOPY ORDER NUMBER: 199606-57-1085.

Simultaneous Shot Peening

Optimizing the Functional Properties of Thermal Sprayed Coatings by Simultaneous Shot Peening in an Inert Process Atmosphere. An economic method of manufacturing high-quality anticorrosion coatings of Cr-Ni steels is presented. The principle on which the coating unit constructed operates (which permits a combination of arc spraying with simultaneous shot peening) is explained. The results of the tests carried out into coating characterization, which in addition to metallographic analyses, adhesive pull tests, and residual stress measurements on the coating also included corrosion tests by polarization and aging, are illustrated and discussed in comparison with the properties of conventional thermal sprayed coating systems.

H.-D. Steffens, U. Erning, and J. Wilden. Cited: *Schweissen Schneiden*, Vol 5, May 1995, p E85-E88 [in English]. ISSN 0036-7184. PHOTOCOPY ORDER NUMBER: 199604-58-0463.

Wet Powder Spraying

Processing Fiber-Reinforced MMCs Using the Wet Powder Spraying (WPS)-Technology. There are a few different technologies existing for the production of fiber-reinforced MMCs, but they all still have some disadvantages. They are either rather expensive or the mechanical properties of the MMCs are not satisfying due to fiber-fiber contacting. Wet powder spraying (WPS) is a new alternative based on the P/M-route that has the potential to overcome some of these difficulties The matrix material (powder < 50 μm) is mixed with a carrier fluid and a binder and sprayed onto wound up or in a plane aligned fiber. During the spraying and shortly after the deposition on the substrate the fluid evaporates, and a few seconds later the layer of matrix material and binder becomes rigid. Straight after this the next layer of fibers can be wound onto the previous layer and WPS-coated. The binder, which is just 1 to 2 vol% of the greenbody, is removed in a degassing step prior to the final capsule-HIP consolidation. In comparison to other production technologies for fiber-reinforced MMCs, WPS is less expensive, and fiber-fiber contacts can be avoided due to the spraying of powders with a mean particle diameter that is much smaller than the fiber-to-fiber spacing. Composites with an Al (6061) matrix and SiC fibers have been processed and were tensile tested up to 400 °C.

M. Fubi, H.P. Buchkremer, D. Stover, and E. El-Magd Cited: *P/M in Aerospace, Defense and Demanding Applications—1995* Proc. Conf. (Anaheim, CA), 8-10 May 1995, Metal Powder Industries Federation, Princeton, NJ, 1995, p 167-172 [in English]. ISBN 1-878954-57-1. PHOTOCOPY ORDER NUMBER: 199604-62-0630

Properties

Corrosion Behavior

Study of Plasma Arc Hot Wire Surfacing with the Duplex Materials X2 CrNiMoN 22 5 3 and X2 CrNiMoN 25 7 4. Final Report. The research project aimed at obtaining verifiable knowledge of structural development during welding, precipitation and embrittlement tendencies, changes of the austenite-ferrite ratio, and corrosion behavior for the application of such coatings to chemical apparatus and plant construction and to flue gas desulfurization systems and off- and onshore technologies.

U. Draugelates and B. Bouaifi. Cited: *Gov. Res. Announc. Index,* 1995, p 13 [in German]. ISSN 0097-9007. PHOTOCOPY ORDER NUMBER. 199606-58-0950

Fatigue Resistance

Fatigue Resistance of Titanium Alloys with a Detonation Coating of VK Type. The influence of structural, phase, and size factors of coatings of WC-Co powders and base of VT6 and VT8 titanium alloys bonding strength in coating-base system on the mechanism of its destruction under sign alternating loads is studied. Determining dependence of fatigue resistance of the VK-coated materials on the spraying regimes is ascertained. Phenomenologic model describing three stages of fatigue fracturing process is presented

V.K. Fedorenko, V.S. Klimenko, V.V. Sergeev, and I.N. Shkanov Cited *Poroshk Metall.,* No. 1-2, Jan-Feb 1995, p 47-52 [in Russian]. ISSN 0032-4795. PHOTOCOPY ORDER NUMBER: 199604-57-0558.

Hot Corrosion

Hot Corrosion Behavior of Plasma Sprayed $2CaO{\cdot}SiO_2$-15 mass% $CaO{\cdot}ZrO_2$/NiCrAlY Thermal Barrier Coating. Hot corrosion behavior of plasma sprayed thermal barrier coatings (TBC) consisting of $2CaO\ SiO_2$–15 mass% $CaO{\cdot}ZrO_2$ ($C_2S{\cdot}15\%$ CZ) and Ni-22Cr-10Al-1 mass% Y (NiCrAlY) on SUS304 was comparatively investigated focusing on the TBC structure, double layer and graded multilayer. TBC specimens were sprayed with atmospheric plasma spraying method. The hot corrosion test was carried out for the sprayed coatings by heating the specimens at 1273 K for 3 h in an atmosphere with four kinds of corrosive ashes consisting of V_2O_5, Na_2SO_4 and NaCl placed on the coating surface. After the test hot corrosion behavior of the TBC specimens was investigated using SEM and EPMA C_2S 15% CZ ceramic coating was not damaged by the reaction with the corrosive ashes whether the TBC structure was double layer or graded multilayer. However, NiCrAlY oxidized seriously along the interface with C_2S 15% CZ, and it was thought to accompany a large volume change. In the case of the graded TBC, NiCrAlY existed independently as a particle in the intermediate layer, the influence of the oxidation was thought to be larger than the double-layer TBC, because of the increase of the reaction area. It was pointed out that a large volume change caused by the oxidation of NiCrAlY particles resulted in the fracture of the interface with $C_2S{\cdot}15\%$ CZ and then facilitated the hot corrosion in the graded TBC.

R. Yamasaki, Y. Harada, N. Mifune, and A. Nakahira. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.),* Vol 32 (No. 3), Oct 1995, p 17-23 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199606-57-1021.

Quenching Stress

Quenching Stress in Plasma Sprayed Coatings and its Correlation with the Deposit Microstructure. Quenching stress arises within a thermally sprayed splat as its thermal contraction after solidification is constrained by the underlying solid. Dependence of the quenching stress in plasma sprayed deposits of Ni-20Cr alloy and alumina on the substrate temperature during spraying was discussed in conjunction with the change in the nature of the interlamellar contact between splats. It was found by mercury intrusion porosimetry and observation of cross sections of impregnated deposits that the interlamellar contact is improved significantly by raising the substrate temperature during deposition from 200 to 600 °C. The positive dependence of the quenching stress on the substrate temperature in this temperature range was attributed to a stronger constraint against thermal contraction of sprayed splats after solidification due to the improved contact. Substrate: mild steel.

S. Kuroda, T. Dendo, and S. Kitahara. Cited: *J. Therm. Spray Technol.,* Vol 4 (No. 1), March 1995, p 75-84 [in English]. ISSN 1059-9630. PHOTOCOPY ORDER NUMBER· 199605-58-0807

Residual Stresses

Internal Stresses in Thermal Spray Coating and Their Generation Mechanism. Thermal spray coatings consist of stacking of lamellae; the structure is not homogeneous. The size of residual stress field of the coatings is estimated to be quite small, judging from the coating structure. Therefore, the dynamic properties of the coatings can hardly be evaluated by macrostress The purpose is to reveal the true stress state of the coatings and to investigate the generation mechanism of residual stresses. Residual macrostress and microstress were measured separately using two kinds of x-ray diffraction processes. One was $\sin^2$ phi method for macrostress measurement, and the other was integral width method for microstress measurement. The residual stress generation mechanism was also discussed. It is found that the microstress is much higher than macrostress in all of thermal spray coatings, especially in some metallic coatings, the microstress is higher >20 times of macrostress. The microstress is considered to be generated by some mechanism at a different temperature in a lamella when it is cooled rapidly after spreading on the substrate surface and the bending stresses that involve both tensile and compressive stress, by partial bonding between lamellae and complicated configuration of the lamellae. The chemical composition of powder used for spraying is $92Cr_2O_3$-$5SiO_2$-$3TiO_2$, $86TiO_2$-$14M_2O_3$, $92ZrO_2$-$8Y_2O_3$, 99.5% molybdenum, 80Ni-20Cr, 82WC-12Co. SS400 is used as substrate.

S. Tobe and K. Akita. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.),* Vol 32 (No. 3), Oct 1995, p 10-16 [in Japanese]. ISSN 0916-6076 PHOTOCOPY ORDER NUMBER: 199606-57-1020.

Wear

Wear Protection by Nitridic, Oxonitridic and Special-Oxidic Flame and Plasma Coatings. Final Report. The present project aimed at the improvement of products and process engineering in the forming of flat glasses and hollow glasses by glass surface coating and by reducing the glass adhesion in steel or ceramic forming tools. Different substrates have been coated by flame spraying or plasma spraying, and the mechanical and chemical properties of the coatings were characterized As substrate, flat glass, hollow glass, ceramics, steel, bronze, gray iron and as coating material aluminum oxide, aluminum nitride, Alon (AlON), Sialon (SiAlON), spinel ($MgAl_2O_4$), titanium dioxide, zirconium dioxide and Tialit (Al_2TiO_5) have been studied. The properties of fused silicon flat glasses are distinctly improved by spinel coating For the coating of forming tools Tialit has been introduced in the case of hollow glass fabrication, and in the case of flat glass manufacturing zirconium dioxide is proposed.

B. Grauheer, J. Decker, and W. Kollenberg. Cited: *Gov. Res. Announc. Index,* 1995, p 19 [in German] ISSN 0097-9007. PHOTOCOPY ORDER NUMBER: 199606-57-1057.

Testing

Thermal Wave Interferometry

The Accuracy of Thermal Wave Interferometry for the Evaluation of Thermophysical Properties of Plasma Sprayed Coatings. The thermal wave interferometry (TWI) technique is investigated as a means of measuring the thermal and optical properties of plasma sprayed coatings. Results obtained from a range of ceramic coatings on metallic substrates (mild steel, Nimonic, stainless steel, and titanium) are presented with a methodology for estimation of the accuracy of the technique. The factors that determine the accuracy of the technique are discussed.

A.C. Bento and D.P. Almond. Cited: *Meas. Sci. Technol.,* Vol 6 (No. 7), July 1995, p 1022-1027 [in English]. ISSN 0957-0233. PHOTOCOPY ORDER NUMBER: 199606-22-0535.

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