Selected Abstracts of Thermal Spray Literature

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Application

Automotive Industry

The Applications of Wear-Resisting and Hot-Resisting Spraying and Hardfacing for Automobiles. The spraying and hardfacing can overcome the limit of traditional materials by different functional designs. Automobile pistons processed with spraying spinel materials by arc and plasma are described. The inside walls of engine block and cylinders are sprayed with inner gun. The thermal barrier coatings on piston head can reduce the emissions from automobiles. The face and top of the exhaust valves are sprayed with stellite by oxyfuel and plasma transfer arc process. Molybdenum and aluminum coatings are also discussed.

C.S. Wu. Cited: *Met. Ind. (China),* Vol 30 (No. 2), March 1996, p 45-47 [in Chinese]. ISSN 0977-0379. PHOTOCOPY ORDER NUMBER: 199702-57-0282.

Boiling Heat Transfer

Boiling Heat Transfer on Thermal Spray Coating Surface in High-Temperature Generator of Absorption Chiller/Heater. Improvement of heat transfer performance on the rear furnace wall of a high-temperature generator of an absorption chiller/heater was investigated. Heat transfer coefficients on a plain surface and a thermal spray coating surface were measured and compared. These two surfaces were located symmetrically with a vertical centerline of the wall. Surface wall temperatures of both the combustion gas and liquid sides were measured at three vertical positions of each heated surface, then the heat flux and the heat transfer coefficient were calculated. Nickel-chromium alloy and alumina were employed as spray coating materials. The experimental results reveal that the Ni-Cr spray coating surface can yield a remarkable improvement in heat transfer performance. Therefore, the thermal spray coating treatment is greatly effective to reduce the heated surface temperature for an anticorrosive countermeasure.

M. Kaji, M. Furukawa, K. Sekoguchi, and E. Enomoto. Cited: *Technol. Rep. Osaka Univ.,* Vol 45, (No. 2217-2232), 15 Oct 1995, p 191-200 [in English]. ISSN 0030-6177. PHOTOCOPY ORDER NUMBER: 199701-32-0007.

Corrosion and Erosion

High-Velocity Continuous Combustion (HVCC) Spraying System for "On-Site" Spraying of Metals and Carbides, Solving Corrosion or Corrosion/Erosion-Related Failure Mechanisms. The new high-velocity continuous combustion (HVCC) thermal spraying system has been developed to address industries on-site corrosion and corrosion/erosion-related problems. This system is capable of spraying metals and carbides to a density of better than 99%. Being portable, it is suitable for coating large surface areas of nonmovable plant equipment. Furthermore, with a deposition rate of up to 9 kg/h, thick coatings can be sprayed with reasonable ease. The HVCC system is unique in that it is capable of spraying wire and powder consumables, through a continuous combusting supersonic flame. The spray gun is air cooled to minimize maintenance and operating difficulties during on-site spraying. The versatility of the equipment design allows simple spray parameter adjustments to be made to vary the coating properties. In this way, a basic 316L type stainless steel can be sprayed with varying oxide and delta ferrite levels. These properties enable optimization of coating characteristics when used in different corrosion and erosion/corrosion environments.

C.K. Stapelberg and M.W. Seitz. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 633-638 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0012.

Corrosion Control

New Methods, Specifications and Standards in Offshore Corrosion Protection. In recent years there has been a rapid growth in the application of thermally sprayed aluminum and its alloys for corrosion protection for offshore structures. Whole production platform jackets are now being sprayed where ten years ago thermal spraying was almost completely restricted to flare booms. Furthermore, the method of application has changed largely from combustion flame spraying to arc spraying and the material sprayed is now more commonly Al with 5% Mg rather than the pure metal. At the same time quality standards have become ever more rigorous and demanding. The paper details the changes that have taken place, the applications, methods, and specifications. Also, operator qualification is now a critical issue in the placing of such large contracts and the paper describes new European and ISO standards that form a basis for proper quality control of the spraying contract by setting standards for material, equipment, methods, and, for the first time, the skill of the operator.

T.P. Lester and B. Fitzsimons. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1185-1190 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0035.

High-Friction Coatings

Plasma Sprayed High Friction WC + Co Coating. Four kinds of WC + Co powder with different sizes were selected to prepare WC + Co coating to obtain different surface roughness. The coefficient of friction of the coating sliding on itself and on titanium alloy was measured. The results obtained showed that surface roughness has an important effect on the coefficient of friction when no load was applied. The coefficient of friction as high as 1.42 was obtained. When the load was applied, the sliding friction between the coatings was higher than that between the coating and Ti alloy, while the friction was the smallest between Ti alloy itself. Meanwhile, the relationship between cohesion strength and friction was discussed.

Z.H. Tong, C.X. Ding, K.W. Huang, and B. Qiao. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 713-717 [in English]. PHOTOCOPY ORDER NUMBER: 199701-31-0040.

High-Nitrogen Steels

Thermal Spraying of High-Nitrogen Steels. High nitrogen austenitic steels have the highest product value of tensile strength and fracture toughness of all materials available today. In addition, these high N cold-worked austenitic stainless steels are the only ultra-high-strength steels that are not susceptible to stress-corrosion cracking in water at ambient temperature. In these steels 1% N is more effective than 30% Cr with respect to an increase in the critical corrosion pitting temperature. In addition, the resistance against general corrosion and crevice corrosion is high in high N steels. Nitrogen can effectively stabilize the austenitic, cubic-face-centered microstructure substituting the expensive alloying element nickel. High N steels show good wear resistance. The yield and ultimate tensile strength increase linearly with increasing N content. It is the goal of this project to transfer these good properties of bulk high N steels to coatings produced by the various thermal spraying techniques. It is outlined how high N levels can be introduced to coatings. First results of corrosion and wear testing of high N coatings (on low carbon steel) are presented.

K. Ebert, C. Karsten, and C.M. Verpoort. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1069-1074 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0027.

HVOF for Turbomachinery

A Review of HVOF System Process Considerations for Optimized Coatings in Turbomachinery. In environments of extreme wear and corrosion, coatings applied by the high velocity oxyfuel (HVOF) process successfully prolong the useful service life of turbomachinery components. The powder particles achieve extremely high impact velocity during the coating process, resulting in solid durable coatings with high resistance to wear and corrosion. Coating materials are cemented carbides, Ni_2Co, and Cu alloys and Al composites. Applications include aircraft components, marine rotors, and turbine components.

R. Clarke, A.R. Nicoll, G. Barbezat, and S. Keller. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1173-1178 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0034.

Rapid Prototyping

The Application of Arc Spray Process in Rapid Molding. The procedure of arc spray process in rapid molding is described. Zinc-base alloy spraying materials and aluminum base alloy or iron frames are used. The applications of molds in FRP (e.g., glass fiber reinforced nylon 6) and plastic (styrene) injection molding, metal injection molding, casting, and foundry pattern are discussed. Arc spray process is also applied in rapid molding of stamping molds for high strength steel and in automotive industry, spraying materials are 420J2 and copper base alloys. The temperature, deformation, surface roughness, and surface strengthening methods of molds are studied.

Filling materials for molds are low melting point alloy (e.g., TAFALOY 4328), epoxy resin, and resins with aluminum powders and particles. The combination of arc spray process in rapid molding and SLD technique is illustrated.

H. Chang. Cited: *Met. Ind. (China),* Vol 30 (No. 3), May 1996, p 84-88 [in Chinese]. ISSN 0977-0379. PHOTOCOPY ORDER NUMBER: 199703-52-0555.

Rapid Molding Technique by Arc Spraying. Molding technique by arc spraying is a rapid, simple, and economic way to form a mold. The mechanism of arc spraying and the melting and atomizing process of metal wires for molding technique are described. The procedures of molding process are presented. The mold made from the technique for RIM process is about half the cost of aluminum cast mold. The mold for vacuum forming process is sprayed with TAFLOY204M zinc-base alloy and has the hardness of Al, but low cost. The applications of the molds made by arc spraying for blow molding process and plastic injection molding process are discussed. The development of molding technique by arc spraying includes the use of stereolithography and steel as for spraying. SUS410 is discussed.

Z.N. Dong. Cited: *Met. Ind. (China),* Vol 30 (No. 1), Jan 1996, p 26-30 [in Japanese]. ISSN 0977-0379. PHOTOCOPY ORDER NUMBER: 199703-58-0339.

Repair Castings

The Study of Powder Spray Melting Substitute for Cast Iron Hot Welding. A new technology with gas flame spraying melt of nickel-base alloy powder to repair castpiece defect on the machining surface was studied, and the spraying material, binding strength, and the machinability of the deposit were also studied. The testing result proved the method is probably a suitable substitute for cast iron hot welding and is fairly advantageous.

X.-Z. Hua, X.-B. Wei, H.-L. Yue, C.-S. Jia. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1215-1220 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0039.

Thermal Barrier Coatings

Effects of Yttria Doping on the Properties of Plasma Sprayed Ceria-Stabilized Zirconia Coatings. Thermal barrier coating of yttria-doped ceria-stabilized zirconia (atomic ratio Zr:Ce:Y = 5:5:0, 5:4:1, 5:3:2, 5:2:3) was prepared and the thermal and physical properties were measured. A lot of cracks and open pores (~10 vol%), observed in as-sprayed coating, changed to spherical closed pores after the heat treatment at 1773 K for 86 ks in air. Cerium content decreased by the spraying, while yttrium and zirconium contents did not change. CeO_2-ZrO_2 coating had the smaller thermal conductivity than that of yttria-stabilized zirconia coating. Vickers hardness and thermal expansion coefficient increased with increasing doping amount of Y. The highest thermal shock resistance was observed for the coating with the nominal composition of $Zr_5Ce_3Y_2O_{20}$ as compared with other kinds of the coating. SS400 and SUS304 steels are used as substrates.

Y. Ono, H. Kawashima, S. Sodeoka, M. Suzuki, and K. Ueno. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.),* Vol 32 (No. 2), June 1995, p 15-24 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199701-57-0076.

Feedstocks

Composite Flux-Cored Wires

Composite Flux-Cored Wires for Thermal Spraying. The paper considers various methods for making flux-cored wires for thermal spraying of wear- and corrosion-resistant coatings. In order to form the amorphized structure of the coatings, the iron-boron base compositions are used to produce the wear-resistant coatings and the Al-Zn or aluminum-oxide compositions to produce the corrosion-resistant ones. Properties of the sprayed coatings are studied, and the fields of their practical application are defined.

Y. Borisov, V. Korzhyk, I. Kozyakov, I. Netesa, and N. Voropaj. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1115-1118 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0032.

Nickel-Base Coatings

Differences in Material Properties of Sprayed Ni-Base Alloy Coatings by HVOF and Plasma Spray Processes. The material properties of HVOF and plasma sprayed coatings of nickel-base alloy powder (on low-carbon steel) are compared. The differences in chemical composition, microstructure, hardness, corrosion behavior, and residual strains of the two sprayed coatings are investigated. The reasons for differences in material properties of the two sprayed coatings are discussed.

M. Sasaki, T. Hattori, and Y. Wakashima. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 603-608 [in English]. PHOTOCOPY ORDER NUMBER: 199701-35-0016.

WC Particle Size Effects

Effect of WC Particle Size on the Formation of HVOF Sprayed WC-Co Coatings. Deposition process of WC-Co coatings in HVOF spraying process is examined by investigating the effect of WC particle size on the thickness of flattened particles and the change of the carbide size after spraying. WC-Co coatings are sprayed (on mild steel) by Jet-Kote process using four types of powders of different carbide size. It has been found that the size of WC particles in a sprayed coating depends greatly on the size of those in starting powder. The results show that the most WC particles remain at solid state after passing through the flame and the deposition of a WC-Co coating involves lateral flattening of solid-liquid two-phase droplet rather than single liquid droplet as in spraying of metallic and ceramic materials under optimized conditions. It is clear that the size of WC particles in WC-Co powder influences greatly the formation of a WC-Co coating. It is evident that the larger WC particles in a two-phase droplet tend to rebound off easily under HVOF spraying conditions when the droplet impacts on the surface of formed coating. A model is proposed to estimate the thickness of flattened particles when a two phase droplet with liquid agglomerated solid particles impacts on a surface.

C.J. Li, A. Ohmori, and Y. Harada. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 869-875 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0023.

Modeling

Heuristic Character

Heuristic Modeling of Some Characteristics of Vacuum Plasma Sprayed Nickel-Base Alloy Deposit. The analysis of the variance (i.e., "ANOVA") approach allows definition of the significant parameters of a given process with a given interval of confidence. In some cases, such an analysis permits one to establish basic relationships, so-called heuristic models. Such an approach does not describe real behaviors; however, it makes it possible to study general trends in the examined ranges. The purpose of this study was to define heuristic models linking some characteristics of vacuum plasma sprayed Ni-base alloy deposits (i.e., macroporosity level and thickness) and some processing (i.e., controllable) spray parameters. It clearly appeared that the plasma gas flow rates and the chamber pressure, which infer different particle dwelling times, dramatically influence the considered characteristics.

G. Montavon and C. Coddet. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1109-1114 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0031.

Large-Scale Turbulence

New Modeling Approach for Calculating Particle Trajectories in a Turbulent Plasma Spray Jet. A novel modeling approach has been used to describe the large-scale turbulence and entrainment in plasma spray jets. In this approach, the jet is described by a two-fluid model in which the turbulent stream is treated as a two-phase mixture. Heat, mass, and momentum transfer between the two fluids is allowed, but no immediate mixing takes place. Particles injected into this jet can have quite different trajectories depending on which fluid they encounter during their flight. A stochastic model of the particle trajectories shows the dispersion of the particles due to different exposures during their trajectories in spite of identical initial conditions. Comparison with experimentally determined gas velocity and temperature profiles show good agreement. This new model approaches a realistic description of the physical phenomena in an atmospheric plasma spray jet.

P.C. Huang, J. Heberlein, and E. Pfender. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1159-1163 [in English]. PHOTOCOPY ORDER NUMBER: 199701-54-0014.

Parameterization

HVOF Fuel Gas Effects

The Influence of Fuel Gas on the Microstructure and Wear Performance of Alumina Coatings Produced by the High-Velocity Oxyfuel (HVOF) Thermal Spray Process. The high-velocity oxyfuel (HVOF) thermal spray process has been used to prepare coatings of alumina on a steel (low-carbon) substrate. Two fuel gas types have been examined: acetylene and hydrogen. The coating microstructure and wear performance have been found to be very dependent on the choice of fuel gas.

A.J. Sturgeon, M.D.F. Harvey, F.J. Blunt, and S.B. Dunkerton. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 669-673 [in English]. PHOTOCOPY ORDER NUMBER: 199701-57-0014.

Post-Processing

Boronizing

Boronizing of the Flame Sprayed Stainless Steel Coatings. After performing boronizing treatment on the flame sprayed stainless steel coatings formed on SM45C substrate, mechanical properties and corrosion resistance were investigated. The mechanical properties were measured by microhardness test, abrasion test, and bond strength test. The corrosion resistance was examined by potentiodynamic in 2*M* H_2SO_4, 2*M* HCl, 2*M* H_3PO_4, and 2*M* HNO_3 solutions. The thickness of boride layers formed on stainless steel coatings increased with boronizing temperature and time, but fairly thin layers formed on stainless steel coatings compared with low-alloy steels. The microhardness of boronized stainless steel coatings was about seven times higher than that of as-sprayed stainless steel coatings because of the formation of boride such as FeB and Fe_2B. The wear resistance was also improved about five times by boronizing treatment. The corrosion resistance of boronized stainless steel coatings was superior to that of as-sprayed stainless steel coatings in acid solutions as 2*M* HCl, 2*M* H_2SO_4, and 2*M* H_3PO_4. The bond strength between the substrate and stainless steel coatings was increased about two times by boronizing.

H.-S. Kim, S.-K. Kim, and S.-M. Lee. Cited: *J. Korean Inst. Met. Mater.,* Vol 34 (No. 5), May 1996, p 629-637 [in Korean]. ISSN 0253-3847. PHOTOCOPY ORDER NUMBER: 199703-58-0332.

HF Induction Fusing

Application of Self-Fused Alloy Coating by HF Induction Heating. Application of induction heating to the fusing process of nickel-base self-fusing alloy coating enables us to produce a harder and heavier coating, since the process directly heats the base metal. In order to improve the wear resistance of boiler tubes, a harder and heavier coating of Ni-base self-fusing alloy on low-alloy steel and stainless tubes is required. This induction heating process also brings about additional benefits to improve the quality, reliability, and productivity. The results obtained in this study are summarized as follows; high frequency induction heating as fusing process of Ni-base self-fusing alloy enables to produce a heavier layer of coating more than 1 mm in thickness. The heat-affected zone in the tube material by this process is smaller than that of the conventional process, which minimizes the sensitizing effect on the stainless steel tube. This process can easily be controlled by choosing the optimal power input and the coil traveling speed. This process can be utilized not only for coating boiler tubes, but also for coating rolls and in any other wear resistant application.

Y. Matsubara, M. Kumagawa, Y. Sochi, and A. Notomi. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1001-1004 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0024.

Process

Arc Spray

The Influence of Spray Distance on the Structure and Properties of Arc Sprayed 13% Cr Steel Coatings. During arc spraying, the coating structure and properties are affected by spray distance. An investigation of the influence of spray distance in the range of 50 to 500 mm on the structure and properties of 13% Cr steel coatings (on mild steel) has been conducted. The results indicated that the amount of oxides in the coatings was greatly increased with the increasing spray distance. The porosity and the macrohardness of the coatings were not changed apparently. When the distance is greater than 300 mm, the coating bond strength, coherent strength, and abrasive wear resistance declines apparently. The results of x-ray diffraction analysis and SEM evaluation revealed that the oxides in the coatings were composed of Fe_3O_4 and Cr_2O_3.

Z. Zhang, W. Geng, A. Liu, and J. Wen. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1197-1202 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0037.

Atomizing Gas and Arc Spray

Effect of Nitrogen Atomizing Gas on Coating Properties in Wire Arc Spraying. Normally, air is used as the atomizing gas in the wire arc spray coating process. Air as atomizing gas causes oxidation of deposited droplets, which, in turn, affects particle size, porosity, wear resistance, and adhesion strength of the coating. In this study, wire arc spraying of stainless steel on Al substrates using nitrogen as atomizing gas is investigated with the objective of establishing correlations among voltage fluctuations, droplet sizes, and coating properties such as porosity, microhardness, and oxide content. Arc fluctuations and droplet formation are observed with a laser strobe high-speed video camera. Porosities are measured with an image analysis system, and oxygen content is quantified by Auger electron spectroscopy. Microhardness is measured with a Vickers indenter, and the element losses are measured with energy dispersive x-ray analysis.

X. Wang, W. Gerberich, J. Heberlein, E. Pfender, and D. Zhuang. Cited. *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1209-1214 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0038.

Characteristics of Plasma Torch

Power Compensation to Eliminate Decrease in Coating Quality due to Erosion of Electrodes of Plasma Gun. Variation of coating quality was found to be related to the erosion of electrode and nozzle of plasma gun. Plasma power gradually drops about 15% or more, resulting in significant deterioration in coating structure and quality. A statistical method of combining experimental design and regression analysis was applied to get quantitative relation between coating properties and plasma gun parameters. Increase of current and hydrogen flow rate functions to compensate drop of plasma power and to achieve repeatable coating quality (on 4130 steel).

S.L. Chen, P. Kettunen, and P. Siitonen. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1221-1226 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0040.

Explosive Spraying

Coatings Produced by Explosive Spraying. The results of technological investigations of the steel surface coating features with a powdered mixture of VK25 (75%WC + 25%Co) are presented. The explosive spraying is executed on the steel 45 specimen by powder with the particle size of 40 to 90 mm up to the coating thickness of 0.35 to 0.50 mm. The process is elaborated to renovate and to harden the steel parts via the explosive spraying with the use of overcompressed detonation waves.

R.A. Latypov and B A. Molchanov. Cited: *Svar. Proizvod.,* Vol 9, Sept 1995, p 6-7 [in Russian]. ISSN 0491-6441. PHOTOCOPY ORDER NUMBER: 199701-58-0159.

HVOF for Chromium Replacement

Wider Application Fields for Thin Chromium Coatings by HVOF-Spraying in Addition to Galvanic Coating Techniques. In technical usage the requirements on components are of increasing complexity. So more and more tailored composite materials are developed to fulfill the demands in wear and corrosion. For a lot of components thin Cr coatings are used as wear and corrosion resistant surfaces (on steel). Normally these coatings are generated by galvanic processes that have different disadvantages. The main aspect now is the toxic behavior of solvents and reactants leading to pollution of the surrounding atmosphere. Another aspect that has to be taken into account is the loss of durability and an increase of brittleness caused by the process. Lastly, there is a great dependence of coating thickness on the geometry of the coated parts, making necessary different grinding and polishing procedures. Within the work carried out at MSI the development of thin Cr coatings obtained by HVOF-spraying was propagated. For a lot of applications advantages for HVOF-sprayed Cr coatings of ~100 μm thickness are expected. The coating thickness was varied from 50 to 150 μm. By variation of the significant spray parameters the production of coatings with very low porosity was achieved. A big influence on the process, especially the runtime of the spray process is given by the grain size distribution of the powder used. Although different oxidic phases are generated during spraying the corrosion behavior of these coatings is not significantly worse than that of the galvanic coatings. The galvanic coatings show a slightly better wear behavior because the counter body of the wear test apparatus is filled with pure Cr and the wear partners are reduced to Cr-Cr in the region of contact.

E. Legscheider, P. Remer, and H. Reymann. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 591-598 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0010.

Near-Net Shape

Near-Net-Shape Processing of Metal Ceramic Composites through Thermal Spraying. Current technological advancement has led to the resurgence of metal-ceramic composites with tailor-made mechanical properties. But the major bottleneck is the forming technology which is highly intricate, cost intensive, and complicated. Thermal spraying route of forming is the probable solution as it is highly versatile, cost effective, and relatively simple. Near-net-shape forming of composition through thermal spraying route involve in situ deposition, compaction, and sintering all in one stage. Removable mandrel technique has been followed to produce different shapes. While Al alloy in powder and wire form had been used as the matrix material, two types of particulate reinforcements (SiC and Al_2O_3) were introduced up to 50 vol%. Both two gun spraying techniques (arc-HVOF, arc-flame) and single gun spraying (HVOF, flame spray) were used. Some of the models developed using this technique were cone, nozzle, and diesel engine exhaust port liner.

D. Kumar and S.C. Modi. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1169-1172 [in English]. PHOTOCOPY ORDER NUMBER: 199701-62-0038.

Polymeric Substrates

Coatings for Wear Protection of Polymeric Substrates Deposited by High-Velocity Oxy-Fuel Flame Spraying. A triplex system consisting of a WC-Co coating, metallic bond layers (Ni/Cu/Ni), and acrylonitrile-butadiene-styrene as a substrate were investigated. The 30 μm thickness WC (88 wt%)-Co (12 wt%) were deposited by high-velocity oxyfuel flame spraying technique modified by the addition of CO_2 cooling. The microstructure and the composition of the coating and the phases present were studied by means of scanning electron microscopy combined with energy dispersive analysis and x-ray diffraction. The spraying powder was composed mainly of WC phase. In addition, it contains elemental Co and W_2C phase. It was found that during the spraying a fraction of the WC phase partially decomposes into W_2C and β-WC_{1-x}, or reacts with Co to form the ternary carbide, Co_3W_3C. The microstructure of the coating consists of tungsten carbide particles bonded by Co matrix. However, as a result of the CO_2 cooling a fraction of the Co particles solidify before their impact on the bond layer or the previously deposited layer, and consequently different interface morphologies and different fractions of binder phase were observed in the WC-Co coating. The factors that influence the WC decomposition during the spraying and the nature of the adhesion mechanism of the coating are discussed.

B. Bouaifi, I. Grimberg, K. Soifer, B.Z. Weiss, and U. Draugelates. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 627-632 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0011.

Reaction Synthesis

Synthesis of Chromium Nitride in situ Composites by Reactive Plasma Spraying with Transferred Arc. Nitrides of transition metals have good wear and corrosion resistance, because of their high hardness and chemical stability. Chromium-nitride coatings can be deposited by ion plating; however, the low thickness due to the slow deposition rate must be improved for severe wear-resistant applications. In this paper, the objective is to realize a high deposition rate and good structure controllability by reactive low-pressure plasma spraying using Cr powder as a spray material. The transferred arc between the electrode of the spray gun and the low-carbon steel substrate was utilized to accelerate the nitride reaction. The sprayed coatings consist of Cr, Cr_2N, and CrN, which have a gradient of the constituents from the interface to the surface. The volume fraction of Cr_2N increases with transferred arc current. Nonreacted Cr significantly decreases, except close to the interface, by applying a transferred arc current of 25A. The CrN phase is, however, limited to appear only at a surface depth of 20 to 30 μm, since it is decomposed to Cr_2N above 1400 K. The hardness of the sprayed coatings depends on the volume fraction of Cr_2N, and it increases to 1300 HV at a Cr_2N volume fraction of 0.98. The seizure stress in the presence of lubricant also depends on the coating hardness. The maximum seizure stress of 24.9 MPa is obtained at a hardness of 1300 HV. The sprayed coatings also show a superior wear resistance. Hence, the Cr_2N in situ composite coatings synthesized by reactive plasma spraying with transferred arc are expected to be good candidates for wear resistant applications.

Y. Tsunekawa, T. Kobayashi, and M. Okumiya. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 755-760 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0017.

Reactive Plasma Spraying

In situ Carburized Coating Produced by Reactive Plasma Spraying of Low-Carbon Steel Using Methane. In the present investigation, an in situ carburized coating was produced by reactive plasma spraying of low-carbon steel using 100% methane as powder carrier gas. Microstructural and chemical analysis revealed modification of the microstructure and a significant increase in carbon content from 0.13 to >1 wt% C in the reactive plasma sprayed low carbon steel. Microhardness of the reactive plasma sprayed low carbon steel coating (707±26 HV) was about three times higher than that of the nonreactive plasma sprayed low carbon coating (245±11 HV). A Langmuir adsorption model was used to study the interactions that occur between the steel particles and the gaseous carbon environment. Accordingly, the thermal and momentum fields of a steel particle along the reactive plasma gas jet were numerically simulated. These simulations revealed a calculated particle carbon content in the range of 1 to 4 wt% C, which corresponded to an order of magnitude agreement with the measured results. The experimental and numerical results obtained in this study suggest that the physical adsorption of gaseous carbon onto the steel particles was significant during reactive plasma spraying.

X. Liang, A. Sickinger, E.J. Lavernia, and J. Wolfenstine. Cited: *Mater. Sci. Eng. A,* Vol 212 (No. 1), 15 July 1996, p 51-61 [in English]. ISSN 0921-5093. PHOTOCOPY ORDER NUMBER: 199702-58-0195.

SHS of Thermal Spray Powders

Self-Propagating High-Temperature Synthesis (SHS) of Thermal Spray Powders. Self-propagating high-temperature synthesis (SHS), a novel process for synthesizing composite materials was used to produce $MoSi_2$, SiC-reinforced $MoSi_2$, FeCr/TiC, and NiCr/TiC powders for plasma spraying. High-density deposits have been made via low-pressure plasma spraying, producing high-temperature structural and wear-resistant coatings. Powder morphologies, powder compositions, and structures have been investigated utilizing XRD and metallography (optical and SEM). Deposits have been evaluated via metallography, hardness testing, and selected mechanical properties, including pin-on-disk wear testing. Comparisons are made to materials and/or coatings made via other processing routes. The small diameter (>1 μm) reinforcing TiC or SiC phases in the matrices (FeCr, NiCr, or $MoSi_2$), leading to improved wear and/or fracture toughness. (Substrates 1040 steel and Ti-6Al-4V).

R.W. Smith, M. Mohanty, E. Stessel, and A. Verstak. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1121-1126 [in English]. PHOTOCOPY ORDER NUMBER: 199701-62-0034.

Thermal Spray and Shot Peening

Production of Corrosion-Resistant Metal Layer Compounds. Combined electric arc spraying and shot peening is discussed. The combination of the two processes of electric arc spraying and simultaneous shot peening opens new applications to the use of corrosion-resistant protective layers. Metal layer compounds obtained in a specifically developed coating plant are introduced here together with their technical and economic benefits.

W. Brandl and R. Podleschny. Cited: *Metalloberfläche,* Vol 50 (No. 7), July 1996, p 584-591 [in German]. ISSN 0026-0797. PHOTOCOPY ORDER NUMBER: 199702-58-0273.

Processing

Effect of Thermal Spray Variables

Gas-Abrasive Wear and Electrochemical Properties of Al-Si Alloy Base Thermal Sprayed Coatings. The methods of flame and plasma spraying were used to produce coatings of Al-Si alloy and compositions on its base with additions of silicon and titanium carbides, and iron titanate. The effect of spraying conditions, powder composition, and production method on microhardness and porosity of coatings was studied. Electrochemical properties of Al-Si and composite coatings, and their resistance to gas-abrasive wear were determined.

K. Yushchenko, E. Lugscheider, P. Remer, Y. Borisov, V. Golnik, and A. Vysotsky. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 803-807 [in English]. PHOTOCOPY ORDER NUMBER: 199701-62-0027.

Properties

Absorbance and Reflectance

Heat Absorption and Radiation Layer by Plasma Spraying Process. Microstructures of the plasma sprayed coatings on Fe_3O_4 and Al_2O_3-TiO_2 powders (on copper) are investigated. Especially, changes in the microstructures of the Fe_3O_4 due to plasma spraying and heat treatments are investigated. Absorbance and reflectance of Fe_3O_4 and Al_2O_3-TiO_2 coatings are investigated at the range of wavelengths from visual ray to far-infrared ray. Solar heat absorptivity of the two oxide coatings and far-infrared ray emissivity of the Fe_3O_4 coating are discussed.

T. Hattori, M. Sasaki, N. Shimabara, and K. Tunoda. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 731-736 [in English]. PHOTOCOPY ORDER NUMBER: 199701-32-0013.

Alumina Coatings

Report of the Cooperative Research Work on the Characteristics of Ceramic Thermal Spray Coating. II. Gray Alumina Spray Coating. Gray alumina (14% TiO_2-Al_2O_3) coatings on SS400 steel were prepared by three kinds of plasma spraying (20 kW-class and 30 kW-class atmospheric plasma spray, gas-shield air-plasma) and gas flame spraying, and their properties were compared in a round-robin test. Density of the flame spray coating was low, and it contained quite a lot of α-alumina. Its erosion and abrasive wear resistances were significantly lower than those of plasma sprayed coatings. Among the plasma sprayed coatings, air-plasma coating had superior wear resistance. While heat-cycle test for peeling revealed that the flame sprayed coating had superior heat resistance than 20 kW-class comparative to 30 kW-class plasma sprayed coating Air-plasma coating showed the highest resistance against heating-quenching cycles.

K. Ueno, G. Ueno, S. Gohda, S. Oki, Y. Hirato, T. Yoshioka, A. Bunya, S. Matsuno, M. Magome, and S. Sodeoka. Cited: *Nippon Yosha Kyokai Shi (J. Jpn. Therm. Spraying Soc.)*, Vol 32 (No. 2), June 1995, p 25-32 [in Japanese]. ISSN 0916-6076. PHOTOCOPY ORDER NUMBER: 199701-57-0077.

Bond Strength

Investigation on Bond Strengths of Ceramic Coatings. In this study, the microstructures, the bond strengths of the ceramic coatings prepared by using two different powder mixtures (Cr_2O_3-$5SiO_2$-$3TiO_2$ and Al_2O_3-$13TiO_2$) and spray techniques (flame spray and atmospheric plasma spray) were investigated. The effects of the intermediate bond layer, NiAl, and the coating thickness on the bonding strength were determined experimentally. It was observed that the optimal coating thickness and the relative effect of the NiAl bond layer depended on the spray technique and the powder used. Tensile tests, described in C633-ASTM standards, were conducted on the ceramic coated samples. The microstructures of the coatings were examined by scanning electron microscopy (SEM).

R. Samur, A.A. Kaya, and S. Salman. Cited: *8th International Metallurgy and Materials Congress. I* (Proc. Conf.), Istanbul, Turkey, 6-9 June 1995, Union of Chambers of Turkish Engineers and Architects, 1995, p 397-407 [in Turkman]. PHOTOCOPY ORDER NUMBER: 199703-57-0314.

Cermet Coatings

Characterization of Thermally Sprayed WC-Cr_3C_2 Cermet Coating with Ni bonding. Thermally sprayed cobalt-bonded tungsten carbide coatings have been widely used as various wear-resistant materials in dry environment. However, generally they have poor corrosion resistance against aqueous solution. The WC-20 mass% Cr_3C_2-7 mass% Ni(WC-Cr_3C_2-Ni) spray material, which is a typical WC cermet with noncobalt binding phase, is sprayed by means of the high-velocity oxygen-fuel flame process. Substantial factors that control the coating properties, such as microstructure, electrochemical characteristics, and abrasive wear resistance are evaluated compared with WC-12 mass% Co(WC-12Co) sprayed coatings. The diameter of the carbide particle, 2.80 μm, and the length of the mean free path, 4.01 μm, determined for WC-Cr_3C_2-Ni sprayed coatings on SS400 are almost comparable to those for WC-12Co coatings. This suggests that both coatings are almost the same in mechanical properties. The passive current density for sprayed WC-Cr_3C_2-Ni coating is about ten times less than that for WC-12Co coatings. The corrosion resistance of WC-Cr_3C_2-Ni sprayed coating in aqueous solution is superior to that of WC-12Co coatings. Microhardness and abrasive wear resistance of sprayed WC-Cr_3C_2-Ni coatings are comparable to those of WC-12Co sprayed coatings.

K. Tani, Y. Takatani, and Y. Harada. *J. Jpn. Inst. Met.*, Vol 59 (No. 11), Nov 1995, p 1136-1142 [in Japanese]. ISSN 0021-4876. PHOTOCOPY ORDER NUMBER: 199701-58-0065.

Comparison of Processes

A Comparison of Properties of NiCrBSi-WC Coatings Deposited by HVOF and Flame-Fused Processes. NiCrBSi and NiCrBSi-WC powders have been deposited using high-velocity oxygen-fuel (HVOF) and flame-fused processes. Metallographic techniques, SEM, x-ray diffraction, and hardness test are used to study the composition, metallurgy, carbon-loss, microstructure of coatings, and difference of the HVOF and flame-fused processes on coatings. Coatings were evaluated to understand the abrasive wear, friction wear properties of each coating system relative to its physical properties, chemistry, microstructure, and phase composition. A primary objective was to determine which process is superior for depositing wear resistance for same group of powders. Conclusions drawn from this study show that for NiCrBSi and NiCrBSi-WC powders, the coatings using the HVOF processes exhibit a high hardness and high wear resistance similar to flame-fused coatings, but for NiCrB-WC powder, coatings using the HVOF or flame-fused process have a lower wear resistance than NiCrBSi powder. The phenomena of wear resistance of the HVOF coatings show potential applications which previously used the flame-fused process, meanwhile the HVOF coatings show minimum deformation, less heat-affected zone to base-metals and easier machinability than flame-fused coatings.

J. Yongchang and Y. Feng. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 827-832 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0020.

Control of Porosity

Manufacturing Methods of Porosity Controlled Metallic Porous Coatings. Porous metallic sprayed coatings were successfully low-pressure plasma sprayed using powders of various particle sizes. Tested were Ti, W, and Ni-Cr-Mo stainless steel. It was difficult to control the open porosity of metals with low melting points using only spray conditions. However, by altering the chamber pressure, it was easier to control the open porosity of powders with high melting points, such as tungsten. A new technique for manufacturing a porous titanium coating with 40% porosity and high strength for implant applications has been developed.

J. Takeuchi, H. Kawatani, and A. Nakahira. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 2 (Proc Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1103-1108 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0030.

Corrosion

Corrosion Properties of Shrouded Plasma Sprayed Titanium Coatings. Thermal spraying of Ti in air atmosphere results in severely oxidized, unhomogeneous coatings, which are brittle and porous. To overcome this problem, Ti coatings were made by shrouded plasma spraying (APS/S). Microstructural studies showed that the use of shroud in plasma spraying produces Ti coatings, which contain about the same level of oxygen, nitrogen, and hydrogen gases as the corresponding LPPS-Ti coatings. The coating materials themselves, APS-Ti and APS/S-Ti, have very good corrosion resistance in salt water and in 1 *N* S acid. But because of the moderate porosity of both of the coating types, their ability to protect the substrate is insufficient. The density of these coatings can, however, be enhanced by post treatments, such as fusion and shot peening. Homogeneous APS/S-Ti coating gives a better response to these post treatments than the corresponding APS-Ti coating and results in a corrosion resistance almost the same as a bulk Ti.

T. Kinos, S.L. Chen, P. Kettunen, and P. Siitonen. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 573-576 [in English]. PHOTOCOPY ORDER NUMBER: 199701-35-0014.

Erosion-Corrosion of Boilers

Erosion-Corrosion of Thermal Sprayed Coatings in FBC Coilers. Varieties of bed ash and fly ash were retrieved from operating fluidized bed combustor (FBC) boilers firing different fuels in North America and Europe. Using these ashes, the relative erosion-corrosion resistances of HVOF Cr_3C_2-NiCr coating and several other thermal sprayed coatings were determined in an elevated temperature blast nozzle erosion tester. Test conditions attempted to simulate erosive conditions found at the refractory-waterwall interface and in the convection pass region in tubular heat exchangers of FBC boilers. Erosion-corrosion (E-C) wastage mechanisms of the structural metals (AISI 1018, ASTM SA213-T22) were discussed and compared with the E-C wastage of HVOF Cr_3C_2-NiCr cermet coatings. The relatively different erosivities of ashes retrieved from North America and from Europe were also discussed.

B. Wang. Cited: *Wear*, Vol 199 (No. 1), 1 Nov 1996, p 24-32 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199703-57-0322.

Erosion-Corrosion Studies

The Erosion and Corrosion Properties of Thermal Spray and Other Coatings. A large number of materials and coatings have been studied with respect to erosion, corrosion, and other properties. A major task was to measure the relative and absolute importance of erosion, corrosion, and synergistic effect of erosion and corrosion in slurries under different conditions. The specimens were fixed to a rotating disk. Corrosion rate (C) was measured electrochemically during the erosion-corrosion tests. Total material loss rate (T) under free corrosion and (for some of the materials) erosion rate under cathodic protection (E) were determined by weighing the specimens before and after the experiments. Possible synergistic effect can be determined as the difference $T - (C + E)$. The degradation mechanisms are discussed. For selected coatings effects of time, water composition, sand concentration, and velocity were investigated. The relative importance of corrosion depends strongly on the erosivity of the environment, that is, on factors like sand concentration and velocity. Clear relationships between the various testing conditions and material loss rate have been established. Therefore, it is possible to transfer the results to other conditions than those used in the experiments. Base material was 22Cr5Ni3M. Coatings were WC-Co, CrC-CrNo, St37, and Ti.

E. Bardall, T.G. Eggen, T. Rogen, and T. Solem. Cited: *Thermal Spraying—Current Status and Future Trends*, Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 645-650 [in English]. PHOTOCOPY ORDER NUMBER: 199701-35-0020.

Fatigue Behavior

Rolling Contact Fatigue of Thermal Spray Coated Cones. The use of advanced materials for rolling element bearings showed some practical advantages. It may be possible to reach the full potential of ceramic hybrid bearings and increase the performance of bearing steels by using thermal spray coatings. Thermal spray tungsten carbide coating on a steel substrate is considered as a suitable material for this purpose. HVOF and detonation spray processes are employed to produce the coatings on the surface of the cone (M50 steel). Residual stresses of the coating due to rolling contact, and change in surface configuration due to partial delamination are measured. Fatigue failure modes are observed using a scanning electron microscope. The results show the requirement for significant optimization of the coating before use in rolling element bearing applications. The coating is fractured by delamination between the coating and substrate. A combination of ceramic balls and races coated with WC-Co may, however, provide a maintenance-free bearing, under the operating condition of light load and poor lubrication such as in a vacuum.

M. Hadfield, S. Tobe, and R. Ahmed. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1097-1102 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0029.

High-Temperature Oxidation

High-Temperature Oxidation and Hot Corrosion Behavior of Two Kinds of Thermal Barrier Coating Systems for Advanced Gas Turbines. High-temperature oxidation and hot corrosion tests were conducted at 800 to 1100 °C under isothermal and thermal-cycle conditions for two kinds of thermal barrier coating (TBC) systems with different compositions of ceramic top-coat; one is Y_2O_3-stabilized ZrO_2 (YSZ) and another is CaO-SiO_2-ZrO_2 (C_2S-CZ). Qualitative and quantitative failure analyses were carried out to clarify the failure mechanisms of the TBC systems (on Inconel X750). In a high-temperature oxidation up to 1100 °C, YSZ-TBC system was found to be subjected more easily to the peeling off of the coat layer, which is attributed to the localized oxidation along the ceramic top-coat/metallic (NiCrAlY) undercoat interface, as compared with the case of C_2S-CZ-TBC system. Thus the most significant oxidation damage resulted in the YSZ system under the thermal-cycle condition. On the other hand, in the hot corrosion in the Na_2SO_4-NaCl molten salt up to 1000 °C, C_2S-CZ system was found to be more reactive with the molten salt to form a new phase layer composed of both the metallic undercoat constituents and corrosive species at an inner region of the ceramic topcoat. Influence of the reheat-treatment, in particular of its atmosphere, after the plasma spraying also was investigated in relation to the change of coating structure and the interface adhesion.

M. Yoshiba, Y. Harada, K. Abe, and T. Aranami. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 785-790 [in English]. PHOTOCOPY ORDER NUMBER: 199701-35-0021.

High-Temperature Oxidation of MCrAlY Coatings Produced by HVOF. In the past, the application of high-integrity, low-oxygen MCrAlY coatings was only successfully done in an inert atmosphere and/or vacuum pressure chamber. Though vacuum plasma spraying(VPS) offers several advantages over conventional atmospheric plasma spraying, the major disadvantage is its high cost of application. This study explores an alternate deposition technique, namely, shrouded high velocity O fuel (HVOF) spraying. MCrAlY coatings sprayed using both VPS and HVOF methods were evaluated for structural integrity and compared for high-temperature oxidation resistance. It was concluded that with proper selection of powder size distribution and spray parameters, HVOF MCrAlY coatings would generally be considered an acceptable substitute for VPS sprayed coatings that are used in less critical applications. (Substrate was Inconel 718.)

L. Russo and M. Dorfman. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1179-1184 [in English]. PHOTOCOPY ORDER NUMBER: 199701-35-0024.

Evaluation of High-Temperature Corrosion Resistance of Al Plasma Spray Coatings in Molten Sulfates at 1073 K by Electrochemical Measurements. Measurements of polarization curves were made to evaluate the corrosion resistance of aluminum plasma spray coatings in 50 mol% Na_2SO_4-50 mol%Li_2SO_4 melt at 1073 K. The results showed that substrate materials have a great effect on the corrosion resistance of Al plasma spray coatings. Also, it is found that the corrosion resistance of Al plasma spray coatings can be improved through diffusion treatment in argon atmosphere. The effects of diffusion treatment conditions on Al plasma spray coatings were investigated in detail. The results obtained from electrochemical measurements were correlated with those of x-ray diffraction, SEM observation, and EPMA analysis. The substrate was Inconel 600.

M. Okuyama. Cited: *Mater. Trans., JIM,* Vol 37 (No. 5), May 1996, p 991-997 [in English]. ISSN 0916-1821. PHOTOCOPY ORDER NUMBER: 199701-58-0145.

Iron-Base Alloys

Properties of Iron-Base Amorphous Coatings. Fe-Cr-Mo alloys containing a large amount of carbon and/or boron were plasma sprayed (on mild steel) under reduced pressure. All the sprayed coatings are amorphous and show a high hardness of 800 to 1000 DPN. The amorphous coatings crystallize at about 773 K or more. Very fine carbides, borocarbides, or borides precipitate in the matrix of ψ-phase and/or ferrite after crystallization of the amorphous phase, bringing about a very high hardness of 1300 to 1450 DPN. The anodic polarization behavior of the as-sprayed amorphous coatings exhibits the activation-passivation transition in 1 *N* H_2SO_4 solution. The active and passive current densities of the coatings increase with increasing B content of the alloy. The corrosion resistance of the coating containing no B is superior to SUS316L stainless steel coating.

F. Otsubo, H. Era, and K. Kishitake. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 585-589 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0009.

Oxidation and Corrosion

Oxidation and Corrosion Behavior of Mild Steel Plasma Coated with Cr-Ni Followed by Laser Treatment. Mild steel samples were coated with chromium and nickel powders using atmospheric plasma coating. This was followed by laser treatment using a 5 kW carbon dioxide continuous laser. The surface alloys so formed were analyzed for surface composition, morphology, and roughness. The samples were then tested for their oxidation and corrosion resistance. Oxidation tests were carried out in air at 800 °C, while aqueous corrosion tests were conducted using anodic polarization in 1 *N* H_2SO_4 solution.

A.S. Khanna, K. Wissenbach, and A.K. Pattnaik. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 993-999 [in English]. PHOTOCOPY ORDER NUMBER: 199701-16-0008.

Plasma and D-Gun Coatings

Structure and Wear Properties of Plasma and Detonation Gun Sprayed (Ti,Mo)C-NiCo Cermet Coatings. Structure and wear resistance of coatings prepared from agglomerated and sintered (TiMo)C-NiCo type cermet powders have been investigated. Powders with different binder content and particle size were sprayed (on low-carbon steel) using atmospheric plasma spray (APS) and detonation gun spray (DGS) methods. The sprayed coatings were characterized by microstructure, phase structure, and microhardness. Wear resistance of the coatings were characterized by microstructure, phase structure, and microhardness. Wear resistance of the coatings was studied in rubber wheel abrasion and solid particle erosion wear tests. Properties of (Ti,Mo)C-NiCo cermet coatings were compared to other carbide coatings sprayed using different thermal spray methods. Depending on the properties of the powder, the spray method, and the parameters used, (Ti,Mo)C-NiCo cermet coatings can have good microstructures and properties giving them potential for wear applications.

P. Vuoristo, L.-M. Berger, W. Hermel, M. Nebelung, B. Jouve, T. Mäntylä, K. Niemi, and T. Stenberg. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 699-704 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0015.

Residual Stresses

Measurement of Residual Stress and Thermal Stress in Sprayed Coating Layers. The present paper describes thermal stress alterations in the thermal cycling process. The specimens were prepared by the laser spraying method. X-ray diffraction was used to measure residual stresses in the layer surface. An in situ thermal stress measurement was performed by using a vacuum furnace mounted of the diffractometer. The results of FEM analysis were compared with the x-ray experimental results. The hysteresis loop due to the thermal cycle process appeared in the specimens of the aluminum layer on the mild steel substrate. In the FEM analysis, the behavior of the hysteresis loop coincided qualitatively with the experimental results.

M. Nishida and T. Hanabusa. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 915-920 [in English]. PHOTOCOPY ORDER NUMBER: 199701-22-0033.

The Relationship between Residual Stress and Wear Resistance of HVOF Coatings. HVOF coatings, the newest variant in thermal spray technologies, have low density, high hardness, and good bond strength. Most of the scientific work is done to show the relation between spray parameters and coating properties. The residual stress conditions of thermal sprayed coatings can be influenced by variation of the spray parameters. The goal of this work is to show the relation between residual stress of HVOF-coatings and their wear resistance. Typical commercial carbide-powders (WC-Co) were sprayed with different parameters. The residual stress was measured in a modified "Almen" test. The wear resistance was tested and compared in different abrasion and erosion tests. (Substrate was $AlMg_3$.)

O. Bradt. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 639-643 [in English]. PHOTOCOPY ORDER NUMBER: 199701-31-0035.

Splat Behavior

Splat Formation and Stacking Behavior of Particles in High-Velocity Oxygen-Fuel Spraying of WC-Co Coatings. Lamellar structure, splat formation of molten droplets, coating microstructure, transfiguration of carbide particles and deposition yield of the powders in high- velocity oxygen-fuel flame spraying of WC-Co coating on SUS304 using powders with different morphologies were examined. The ratio of the particle diameter to the thickness of splats is 7 to 17. These values are in good agreement with the calculated values according to the splat formation model proposed by Jones et al. The formation of coating deposits is followed by the expanding flow of the molten binding phase accompanying solid WC particles. The smaller size of WC particles in the spray powder allows the fluidization and flattening together with the molten binding phase; on the contrary, the flattening behavior of particles are restrained if the size of WC particles is large. Susceptibility to flattening of the spray powder tends to result in the compactness or the high density of the coating. Consequently, spray powders composed of the smaller size of WC particles allow the formation of denser coatings. The selection of the spray powder composed of smaller-sized primary WC particles and the moderately larger size of cermet particles is effective for the higher deposition yield of WC-Co spraying.

K. Tani, Y. Harada, and C.-J. Li. Cited: *J. Jpn. Inst. Met.*, Vol 59 (No. 11), Nov 1995, p 1130-1135 [in Japanese]. ISSN 0021-4876. PHOTOCOPY ORDER NUMBER: 199701-58-0064.

Splatting and Solidification Behavior of Plasma Sprayed Metallic Powders Impinging on Flat SUS304 Substrate. The effects of both substrate temperature and particle material on the splat behavior of the plasma sprayed powders impinging on the flat SUS304 steel substrate surface were fundamentally investigated. The results obtained are summarized as follows: (1) In the splatting of Ni, Cr, Cu, and Mo powder on stainless steel substrate, typical splashing at the substrate temperature of 300 K and a drastic fraction change of the splat pattern, from the form with splashing to the one without splashing with the substrate temperature, were observed. On the other hand, those were not recognized in the case of Al and Ti. It seems that splatting strongly depends on the powder material. (2) From the observation of the bottom surface of the splat and the comparison of the latent heats of the powder materials, initial rapid solidification of the splat just after the impingement seems to be one of the remarkable reasons for splashing. (3) It was revealed that the surface tension of the powder material was one of the dominating factors for the splashing from the relation between surface tension and transition temperature of the powder. (4) The initial solidifications rates of the powder impinged were estimated by the simple splat and solidification model, and the incident of the splashing corresponded well to the relation between solidification rate and surface tension of the powder material. (5) As for the intervals between solidification and flattening, it seems that both occur simultaneously when the solidification tends to occur easier, while the flattening occurs preferentially followed by the solidification when the solidification rate is lower.

M. Fukomoto, Y. Huang, S. Kata, and M. Ohwatari Cited: *J. Jpn. Inst. Met.*, Vol 59 (No. 11), Nov 1995, p 1178-1184 [in Japanese]. ISSN 0021-4876. PHOTOCOPY ORDER NUMBER: 199701-58-0066.

Supersonic Plasma Spray Process

Structure and Properties of Coatings Deposited by Supersonic Air-Gas Plasma Spraying. The process of Al alloy and aluminum oxide powder spraying using supersonic air-gas plasma jets was studied, and the effect of powder consumption, particle, sizes, spraying conditions, and anode wear on properties of the coatings was investigated. Substrates were bronze, 0.2%C steel, AlCuMgMn alloy, and graphite/glass composite. Sprayed was Al-12Si and Al_2O_3.

Y. Borisov, S. Petrov, M. Kolomytsev, A. Murashov, and R. Novak. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 857-862 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0021.

TiC-Ni Composite Coatings

Effect of Powder Manufacturing Method, Particle Sizes, and Binder Content on the Properties of TiC-Ni Composite Coatings. The aim of this study was to develop wear-resistant coatings for high-temperature applications using TiC as a hard phase. Detonation gun spray (DGS) and atmospheric plasma spray (APS) techniques were utilized to prepare TiC-Ni composite coatings onto unalloyed steel substrates. Coated, mechanically blended, sintered, and mechanically alloyed (MA) powders were used Nickel content in powders varied from 20 to 40 wt%. Mechanical alloying was performed in a planetary mill under argon atmosphere by using Ni-lined vials and Ni balls for protecting the powders from iron contamination. The effects of Ni content, carbide size, and milling time were studied. The structure of the coatings was studied by optical and scanning electron microscopy. Phases were determined with an x-ray diffractometer. Also microhardness values of the coatings were measured. Abrasion wear resistance was studied using rubber wheel abrasion test. The plasma sprayed TiC-Ni coatings were slightly oxidized, but the detonation gun coatings deposited with the long barrel consisted only of the TiC and Ni phases. The best abrasion wear resistance of the studied coatings was obtained by using 40 wt% of Ni, and it was of the order of the values for WC-12Co coatings deposited by DGS. The hardness values of the best coatings were 950 $HV_{0.2}$.

T.H. Stenberg, and T.A. Mäntylä, K.J. Niemi, K.J. Tiainen, J E. Vuorinen, and P.M.J. Vuoristo. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1145-1150 [in English]. PHOTOCOPY ORDER NUMBER: 199701-62-0036.

Tribology of WC Cermets

Durability and Tribological Properties of Thermally Sprayed WC Cermet Coating in Rolling/Sliding Contact. In order to examine the durability and tribological properties of high-velocity oxyfuel flame sprayed WC-Cr-Ni cermet coating in rolling/sliding contact, the authors have conducted two-roller test under the lubricated line contact or point contact conditions. The coatings of about 25, 40, and 90 μm in thickness were formed onto carburized steel rollers (SCM45) and the contact surfaces were finished smooth to a mirrorlike condition. The WC cermet coated roller and the carburized steel roller without coating (R_{max} = 0.1 μm) were combined and a maximum Hertzian stress in the range of PH = 1.2 to 1.4 GPa in line contact or PH = 2.4 to 3.0 GPa in point contact was applied. In the case of pure rolling conditions, neither flaking nor surface distress occurred except for the test with thin coating. In the case of rolling/sliding conditions, flaking was apt to occur when the coated roller was placed on the slower side (slip ratio $s = -14.8\%$), while the occurrence of flaking was restrained when the coated roller was placed on the faster side ($s = -12.9\%$). On the whole, the resistance to flaking had a tendency to increase as the thickness of coating increases, though significant differences in the friction and wear behavior were not recognized.

M. Yoshida, T. Mawatari, A. Nakajima, A. Nakahira, and K. Tani. *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 663-668 [in English]. PHOTOCOPY ORDER NUMBER· 199701-31-0036.

Wear

Characteristic Features of Wear in Tools Made of High-Speed Steels with Surface Engineered Coatings. II. Study of Surface Engineered High-Speed Steel Cutting Tools by AES, SIMS, and EELFAS Methods. Changes in chemical composition and fine (at atomic level) structure characteristics of surfaces during the lifetime of cutting tools were investigated by using AES, SIMS, and EELFAS methods. High-speed steels M2 and T15 with coatings incorporating ion nitriding and (Ti,Cr) nitride CAPDP (cathode arc plasma deposition process) were used. It was found that, under the wear conditions studied (such as cutting of medium-carbon steels), some components of the protective hard coating dissociated, forming quasi-oxide amorphous films. This shows the parallel developing processes of. (1) dissociation of chemical compound in coating material (Ti,Cr)N and intensive diffusion (absorption) of nitrogen into chip and (2) creation on tool surface of stable amorphous protecting quasi-oxide Ti-O films. The discovered changes in chemical and phase composition of contact surfaces of the "tool-workpiece" tribopair improve service characteristics of the cutting tool and promote its adaptation to service conditions (names "self-organization"). The adaptation observed is expressed more on steel T15 with high heat resistance and leads to a significant increase of tool life.

G.S. Fox-Rabinovich, S.N. Afanasyev, and A.I. Kovalev Cited: *Wear,* Vol 197 (No. 1-2), Oct 1996, p 280-286 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER: 199702-31-0442.

Wear by Pin-On-Disk

Sliding Wear Behavior of Thermally Sprayed 75/25 Cr_3C_2/NiCr Wear-Resistant Coatings. One of the foremost coating methods for combating wear is thermal spraying; however, despite its widespread industrial use, little is known about the basic friction behavior and the mechanisms by which such coatings wear. The manner of processing in thermal spraying inevitably leads to inhomogeneities, such as unmelted particles, oxide inclusions and porosity, in the sprayed deposits resulting in a structure markedly different from that of cast, wrought, or even powder metallurgy materials. It is expected that thermal spray coating behavior would be even more complicated than that of homogeneous, uncoated bulk materials. Results of an investigation to determine the effects of some wear test variables on high-velocity oxyfuel (HVOF) sprayed Cr_3C_2/NiCr coatings using a pin-on-disk tribometer are presented. Room-temperature sliding friction and wear behavior of coatings are discussed with respect to load, relative velocity, and counterbody material. The present investigation shows that the tribological behavior of HVOF sprayed Cr_3C_2/NiCr coatings is significantly affected by its microstructural constituents such as splats, porosity, and form and dispersion of second phases. It is also shown that changes in imposed sliding wear test conditions varied the friction and wear behavior of thermally sprayed coatings considerably. The break-in sliding coefficient of friction is found to be more significantly affected by load than other test parameters. Results also indicate that friction decreased with increasing velocity, but wear decreased then increased with increasing velocity. By proper control of test conditions and by selected changes of those conditions, the physical wear mechanisms involved in thermally sprayed coatings could be understood. This study showed that the pin-on-disk is a well-controlled test and can be used to understand certain basic relationships between the sliding friction and wear behavior of thermally sprayed coatings. Substrate material: 4140 steel.

M. Mohanty, R.W Smith, J.P. Celis, M. De Bonte, and E. Lugscheider. Cited: *Wear,* Vol 197 (No. 1-2), Oct 1996, p 251-266 [in English]. ISSN 0043-1648. PHOTOCOPY ORDER NUMBER· 199702-57-0137.

Wear of Carbides and Borides

Advanced Carbides and Borides for Wear Resistant Coatings—Powder and Coating Properties. The results of studies with HVOF sprayed coatings are presented in this article. Test materials are tungsten- and chromium-base powders containing borides, which are compared to standard WC/Co and standard Cr_3C_2/NiCr materials with regard to their coating properties. Test results show that coatings containing borides have properties comparable to those of coatings containing carbides.

J. Beczkowiak, J. Fischer, H. Keller, and G. Schwier. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1053-1057 [in English]. PHOTOCOPY ORDER NUMBER: 199701-62-0033.

Wear Resistance

Influence of Various Oxide Additions on the Wear Resistance of Plasma Sprayed Alumina Coatings. Alumina-based powders form a very important group of materials for plasma sprayed coatings in various applications demanding high wear resistance. Commercial alumina-based powders contain usually titania, chromia, or recently also zirconia as an alloying oxide. However, the possible synergetic effect of combining these alloying oxides for multicomponent alumina-based coatings on wear resistance is a relatively unstudied area. In this work several multicomponent alumina-based oxide powders were produced by spray drying. The oxide additions were zirconia and titania in various amounts. The coatings were then produced (or unalloyed steel) by atmospheric plasma spraying. The abrasive wear resistance of the coatings was determined with the pin-on-disk-test. The relative wear resistance of the coatings was compared to typical APS chromia coatings The obtained microstructures and microhardness were determined and related to coating materials and its processing and coating parameters.

E. Lugscheider, H. Jungklaus, J. Knuuttila, and P Remer. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 833-838 [in English]. PHOTOCOPY ORDER NUMBER: 199701-57-0018.

Quality Control

Influence of Variables

Thermal Spray Application Speeds. To ensure high quality in thermal sprayed coatings, the amount of material applied per layer (pass) must be controlled. The variables to be considered include the spray process, material, rate and pattern, and the part geometry. The deposition conditions are described for various materials sprayed by different processes, and the optimal application speed is calculated for each. (Coating materials are metals, cermets or ceramics.)

G. Irons. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1165-1168 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0033.

Quality Management

ISO 9001

Experience of a Thermal Spray Company with the Certification According to Quality Standard ISO 9001. In this paper it is outlined how a quality management system based on the ISO 9001 can be introduced into a thermal spray company. In 20 quality elements the ISO 9001 describes the requirements that have to be fulfilled. It outlines starting from management responsibility, the quality system and contract review as well as more technically oriented elements like inspection and testing and the quality records. The main emphasis of this ISO 9001 quality standard is that all quality relevant steps are described and documented. A general overview of all 20 quality elements is given in a quality management handbook, part I whereas more detailed quality instructions are given in handbook, part II. In handbook, part III, all quality-related work steps are documented. Thermal spraying is considered to be a so-called "special process," that is, a process that does not allow the quality control at the final product. Therefore, various steps of work planning, incoming inspections of spray powder, inspection, measuring and testing of the spray equipment, and the appropriate training of personnel performing specific tasks have to be specified. In addition, a planned and documented system of internal audits to determine effectiveness of the quality system has to be established. When all quality elements are established, the company can apply for a certification of the quality management system.

K. Ebert and C.M. Verpoort. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 1191-1196 [in English]. PHOTOCOPY ORDER NUMBER: 199701-58-0036.

Testing

Nondestructive Methods

Nondestructive Testing of Low Pressure Plasma Sprayed Ceramic Coating. For the application of refractory metals at temperatures above 500 °C oxidation resistant coatings are necessary. To avoid a breakdown of the component knowledge of coating thickness, coating structure, volume and surface defects are essential and nondestructive testing becomes of significant importance. In this investigation coating thickness, surface roughness, and porosity was determined by different nondestructive methods. A good agreement was obtained for coating thickness, crack appearance, and surface roughness, whereas great differences in porosity values exist. To relativize these results, image analysis was utilized to determine crack area, porosity, and portion of the second phases. A good concurrence was obtained.

K. Luebbers, J. Disam, and U. Neudert. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 909-914 [in English]. PHOTOCOPY ORDER NUMBER: 199701-22-0032.

Porosity Measurements

Microstructure Measurement of Plasma Sprayed Alumina Coatings. The porosity of plasma sprayed alumina coatings (on mild steel), prepared under various conditions, was analyzed by image processing of micrographs and mercury intrusion techniques. In order to prevent possible pullout of particles during polishing, and also to improve the SEM image contrast between the coating and its pores, the pores were impregnated by a chromic acid process. Three types of porosity were confirmed from the backscattered electron images of the cross sections; namely, coarse pores of around 10 μm diameter located between lamellae, narrow gaps resulting from incomplete lamellae-lamellae contact and vertical microcracks perpendicular to the lamellar plane of individual lamellae. The volume fraction of each type of porosity changed with changing spraying conditions such as spraying distance. Overall, the total porosity did not significantly depend on spraying conditions. This is supported by Hg intrusion porosimetry results.

C. Takahashi and T. Senda. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 921-926 [in English]. PHOTOCOPY ORDER NUMBER: 199701-21-0003.

Ultrasonic Loading

Investigation of the Structural and Phase Transformations in the Plasma Spray Powder Coatings by Powerful Ultrasound Loading and Laser Melting. High-energy action on the coatings (ultrasound, laser) is very effective to improve properties of spray coatings based on nickel. To find a more effective method of treatment of the coatings and predict the development of changes in the coatings by intensive deformation and thermal heating, it is very important to know the peculiarities of these transformations in the coatings on the different structural levels. Investigations of the structural and phase composition of the coatings (on steel) have been carried out by means of electronic microscopy and x-ray-structural analysis.

V.A Klimenov, V.P. Bezborodov, E.V. Kozlov, V.E. Panin, and O.B. Perevalova. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf.), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, Welding Research Institute, Osaka University, Japan, 1995, p 1005-1009 [in English]. PHOTOCOPY ORDER NUMBER: 199701-16-0009.

Vacuum Impregnation for Microscopy

Vacuum Impregnation of Sprayed Coatings for Microstructural Studies. Thermal spray coatings normally require vacuum impregnation with an epoxy prior to metallographic investigation. A study on the effect of different specimen impregnation techniques of sprayed coatings has been carried out. This study has shown that independent, simultaneous, and controlled evacuation of both the specimen and resin is required for the complete impregnation of all the pores, and that this impregnation procedure yields metallographic specimens with minimum abrasive loss and minimum scatter in the measured coating properties.

J. Karthikeyan. Cited: *Thermal Spraying—Current Status and Future Trends,* Vol 2 (Proc. Conf), Kobe, Japan, 22-26 May 1995, High Temperature Society of Japan, 1995, p 927-932 [in English]. PHOTOCOPY ORDER NUMBER: 199701-21-0004.

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