Thermal Spraying in Japan*

C.C. Berndt

The two volumes of the proceedings of the 14th International National Thermal Spray Conference (22-26 May 1995, Kobe, Japan) contain 208 papers of which 78 were from Japanese authors. The proceedings (ISSN **1241-3074),** entitled ***Thermal Spraying: Current Status and Future Trends,*** with Akira Ohmori as the editor, total 1226 pages and are available from the High Temperature Society of Japan, **c/o** Welding Research Institute of Osaka University, **11-1** Mihogaoka, Ibaraki, Osaka 567, Japan.

These abstracts present a unique snapshot of thermal spray research and development in Japan towards the end of the 20th century. The thirteen sections of the proceedings and corresponding breakdown of the Japanese contributors into these sections are presented in the table below.

Keywords applications in Japan. Japanese abstracts, modeling

Section	Section heading	Total papers	Abstract No.	Number of Japanese papers	Fraction of Japanese papers (%)
Volume 1 of Proceedings					
1	Automobile industry	6	1-3	3	50
2	Steel-making industry	5	4-6	3	60
3	Energy industry	8	7-12	6	75
4	Applications	25	13-22	10	40
5	New thermal spraying devices and processes	15	23-32	10	67
6	Explanation and evaluation of thermal spraying processes	20	33-36	4	20
7	Microstructure of coatings	19	37-41	5	26
Volume 2 of Proceedings					
8	Coating properties	51	42-62	21	41
9	Methods of evaluating coating properties	17	63-68	6	35
10	Improving coatings by combining processes	11	69-75	7	64
11	Design and coating properties of thermal spraying materials	13	76-77	2	15
12	Powders and powder metallurgy	6	78	1	17
13	Thermal spraying processing and quality control	12	nil	0	0
		208		78	38

#1 Current Conditions and Future Trends of Thermal Spray Technology in the Japanese Automobile Industry

Keywords automobile, cost reduction, environment, Japan

T. Miyamoro and S. Sugimoto
Toyota Motor Corporation

Improvement of vehicle fuel consumption for global environmental protection and cost reduction for coping with the high yen rate are two challenges that the Japanese automobile industry is facing. Thermal spray technology will play an important role in the surface coating of aluminum alloys to reduce car weight and friction loss. But for further progress of application to automotive parts, thermal spray processes must be changed to be better suited for automobile production. Higher performance coatings, cost reduction, and improvement of productivity are required.

#2 Development of Brazing Method with Thermal Spray

Keywords arc spraying, copper, porosity, torque converter brazing

T. Nakano, R. Uchino, and T. Kusano
Aisen Seiki Co., Ltd.

Non-oxidation copper brazing is widely used because no flux is required. Wire or paste brazing filler metals are used; however, there are various problems, such as difficulty in automation, high material cost, and high rejection rate. To solve the

C.C. Berndt, The Thermal Spray Laboratory, SUNY at Stony Brook. Stony Brook, NY 11794-2275

*The editor acknowledges Jeffery Brogan, Karlis Gross, and Sang-Ha Leigh, former graduate students at Stony Brook, for their assistance in the preparation of this document. The abstracts have been edited for both form and content to suit the requirements of an archived document.

above problems, we have developed a new brazing method with "arc spray." An outline of the method is described.

#3 The Application of Cermet Coatings on Piston Rings by HVOF

Keywords Cr_3C_2-NiCr, HVOF, oxygen-fuel ratio, piston ring, wear

*H. Fukutome, H. Shimizu, N. Yamashita, and Y. Shimizu**
Teikoku Piston Ring Co., Ltd.
**Shinshu University*

The increasingly harsh sliding conditions of piston rings for internal combustion engines demand higher wear resistance. We have investigated the relationship between the oxygen-fuel ratio and wear resistance in a study of HVOF Cr_3C_2-NiCr cermet coatings. The best wear resistance can be achieved when $k=1.0$; that is, the oxygen-fuel ratio is at the perfect combustion condition.

#4 Application of Thermal Spraying Technology at Steelworks

Keywords detonation spraying, roll mark, steel making plants, wear resistant spraying

M. Sawa and J. Oohori
Nagoya Works Nippon Steel Corporation

Nagoya Works, one of the central steelworks of Nippon Steel, has applied thermal spraying to process rolls and many other items of mechanical equipment with excellent results. Clarification of wear phenomena and causes, development of optimum thermal spray materials, and establishment of optimum thermal spraying conditions and thermal spray machine operating conditions are three important requirements for the successful application of thermal spray technology. To increase the application of thermal spray technology, it is necessary to (i) make thermal spray general-purpose technology, (ii) take a comprehensive approach, (iii) develop techniques peripheral to thermal spray, and (iv) establish techniques for designing thermal spray coatings. This paper introduces examples of thermal spraying at Nagoya Works and discusses the future outlook.

#5 Development of Self-cleaning Coatings on Hearth Rolls in High Temperature Annealing Line

Keywords cermet coating, continuous annealing line, hearth roll, pick-up

S. Midorikawa, Y. Sato, S. Matumoto, and M. Ito
Kawasaki Steel Corp.

Ceramics rolls are used in the high temperature hearth to anneal stainless steel strips. However, the lifetime of these rolls is short due to pick-up defects from buildup on the roll surface. Once these defects occur, it is necessary to replace the roll to maintain product quality. In order to prevent pick-up defects, several materials, including abradable coatings, were investigated with the aim of having a self-cleaning function. ABN-base cermet abradable coating has superior characteristics in preventing buildup and was applied for a field test. The pickup of materials was solved by the self-cleaning function of abradable coatings, and therefore, the roll life was extended.

#6 Effect of Manganese Oxides on the Durability of a Cobalt Based Coating on Furnace Rolls in Continuous Annealing Lines

Keywords alumina, chromia, coating, furnace roll, manganese oxide

*Y. Gao, H. Nitta, and R.C. Tucker; Jr.**
Praxair Surface Technologies K.K.
**Praxair Surface Technologies, Inc.*

The premature degradation of $CoCrTaAlY+Al_2O_3$ coatings used on furnace rolls to prevent pickup and wear in continuous annealing lines (CAL) has been studied. Investigation of prematurely degraded coatings and laboratory experiments showed that a solid state reaction of manganese oxide (formed on the steel sheet in some CAL) with alumina and chromia (formed on the coating or the alumina dispersion within the coating) produced complex manganese oxides of $MnAl_2O_3$ and $Cr_{1.5}Mn_{1.5}O_4$. These reactions destroy the thin, adherent alumina protective scale that reduces wear and pickup and that is normally present on the coatings. The resulting complex oxides are brittle, do not prevent pickup, and lead to premature degradation of the coating. Based on these results, new coatings are being developed.

#7 Application of Plasma Spraying for Gas Turbine Engine Components

Keywords corrosion resistant coating, LPPS, oxidation resistant coating, TBC

N. Akikawa and T. Okamoto
Kawasaki Heavy Industries Ltd.

Kawasaki Heavy Industries has been applying thermal spray to modify the surface properties of gas turbine engine components for more than 30 years. This study describes the application of LPPS coatings to gas turbine engine components and a part of our research and development effort using burner rig test and seal test facilities.

#8 1kW Module of Solid Oxide Fuel Cell Produced by Plasma Spray Process

Keywords density, plasma spray, resistivity, SOFC

A. Notomi and N. Hisatome
Mitsubishi Heavy Industries Ltd.

New technology for electricity generation is required to be efficient, environmentally benign, and able to handle a variety of fuels. The solid oxide fuel cell (SOFC) power system could be a promising technology that satisfies all these requirements. Plasma spray technology has become a practical process to produce coatings for SOFC components, especially LPPS to form a dense electrolyte coating of yttria stabilized zirconia. The advantages of plasma spray technology increase the fuel utilization to 87.1% and the efficiency to 38% in SOFC electric power conversion. On the basis of the ability of cell characteristics

achieved by the plasma spray process, a 1 kW module has been developed and successfully operated for 3,000 hours.

#9 Thermal Barrier Coatings Design for Gas Turbines

Keywords *durability, gas turbine, multilayered coating, oxidation, TBC, thermal stress*

M. Takahashi, Y. Itoh, and M. Miyazaki
Toshiba Corporation

Thermal barrier coatings applied to hot section components of land-based gas turbines were investigated by attending to coating design. A concept of multilayered TBCs which showed high thermal barrier durability was investigated. A computer-aided interactive system that enabled thermal stress analysis for the multilayered TBC was developed to optimize the coating materials and their thickness. Next, the thermal barrier durability of coatings were confirmed by experiments. The variation of the thermal barrier ability was examined during thermal cycling tests and confirmed that the effective thermal conductivity of TBCs tended to decrease for microcracking and/or oxidation of the coating during thermal cycling. As well, the durability of TBCs was evaluated by the thermal cycling test and indicated a dependence on oxidation at the interface between the bond and top coating. The multilayered TBCs, which had an oxidation resistant layer between the bond and top coating formed by a pre-oxidation or prealuminizing treatment, increased durability.

#10 Failure Analysis of Some Plasma Spray Coated Superalloy Systems Subjected to the Synergistic High Temperature Damage in Actual Gas Turbine or in the Laboratory

Keywords *advanced gas turbine, corrosion-creep, corrosion-fatigue, failure analysis, TBC*

M. Yoshida, T. Aranami, H. Taira, and Y. Harada***
Tokyo Metropolitan University
**Nippon Steel Corporation*
***Tocalo Co., Ltd.*

In order to establish reasonable property evaluation methods for advanced plasma spray coating systems for heavy duty high temperature applications, failure analysis was conducted for two kinds of thermal barrier coating (TBC) systems. One is a conventional YSZ system, and the other is a $CaO\text{-}SiO_2\text{-}ZrO_2$ (C_2S-CZ) system. The laboratory tests were composed of high temperature oxidation, hot corrosion, and corrosion-stress (creep) rupture tests. The degradation behavior of the YSZ and C_2S-CZ systems was characterized. The former system was more sensitive to spalling of the ceramic topcoat layer, which was attributed to a preferential oxidation and/or corrosion along the topcoat/metallic (MCrAlY) undercoat interface. The topcoat of the latter system was more reactive with molten salt and resulted in compositional and structural changes with new phase formation. On the basis of the failure mode analogy between the laboratory tests and in gas turbine practice, a relative importance of various factors affecting the degradation of TBC systems is discussed. In particular, the importance of considering the simultaneous stress-corrosion effect will be emphasized.

#11 Highly Durable Thermal Barrier Coating for Heavy Duty Gas Turbines

Keywords *ceramics, gas turbine, plasma spray, TBC*

Y. Kojima, K. Wada, T. Teramae**, and Y. Furuse***
Hitachi Research Lab.
**Hitachi Works, Hitachi Ltd.*
***Tokyo Electric Power Company*

Studies were made of four-layer TBCs for gas turbines that had the capability to relax thermal stress. The four-layer TBC consists of a ceramic layer, a corrosion/oxidation resistant metal layer, a thermal stress relaxing metal-ceramic mixed layer, and a bond layer. Thermal cycling tests showed that the lifetimes of the four-layer TBCs are about twice those of two-layer TBCs consisting of a ceramic layer and a bond layer. These four-layer coatings on turbine nozzles were not damaged under service conditions. The temperatures of the substrates coated with the four-layer TBC were about 95 °C lower than those of the uncoated substrates.

#12 Application of High Velocity Flame Spraying for the Heat Exchanger Tubes in Coal Fired Boilers

Keywords *chromium carbide, coal fired boiler, erosion, flame spraying, high velocity*

Y. Fukuda and M. Kumon
Babcock-Hitachi K.K.

One successful method for preventing the erosion of boiler tubes is high velocity flame spray (HVFS) coatings, such as those formed by the D-gun, Jet Kote, and DJ-gun processes. HVFS coatings produce virtually pore-free, high quality coatings with strong adherence to the base material. The quality of coatings depends on the powder properties, such as morphology and size distribution. We improved the coating properties and tested them under laboratory and plant conditions. Various HVFS coatings have been successfully applied to many components of coal fired boilers.

#13 Improvement of the Anode Assembly of Fluorine Cell by Plasma Sprayed Nickel Coating

Keywords *anode assembly, contact resistance, fluorine cell, nickel spraying*

M. Dohi, J. Hiraiwa, T. Tojo, J. Takeuchi, and Y. Harada**
Toyo Tanso Co., Ltd.
**Tocalo Co., Ltd.*

An improved electrical connection was developed by spraying nickel on the contacting area to the bus-bar of a LiF-impregnated carbon electrode using atmospheric plasma spraying. The electrolytic production of fluorine was performed with this electrode at high current density, such as 15 A/dm^2 for nearly 40 days. The cell voltage was about 11 V throughout the operation. Deterioration of contact between the carbon anode block and the metal bus-bar can be prevented by this method.

14 A Microstructural Study of Fatigue Damage in Stainless Steel Coated with Plasma Sprayed Alumina

Keywords Al_2O_3 deposit, corrosion environment, fatigue damage, implant, microstructure

M. Sugano, H. Masaki, J. Kishimoto, Y. Nasu, and T. Satake
Yamagata University

To evaluate the potential of a prosthetic application, a SUS3I6L stainless steel rod coated with plasma sprayed Al_2O_3 has been fatigue tested in a physiological saline solution. Fatigue tests were conducted under push-pull loading at a stress ratio of R = –1 and 2 and 30 Hz. In the S-N curve, the plasma sprayed Al_2O_3 coating improved the fatigue properties of the substrate metal. Plasma spraying was effective in the initial stages of crack propagation. The effect was more pronounced at 30 Hz than at 2 Hz. The improvement in fatigue properties resulted from (i) the residual compressive stresses due to the grit blasting, which was carried out prior to plasma spraying and (ii) the corrosion-resistance of the Al_2O_3 deposit. The Al_2O_3 plasma sprayed stainless steel is a promising material for implant application if the plasma spraying parameters are optimized.

15 Development of an Automated Polishing System for Spray Coatings Deposited on Three-Dimensionally Curved Substrate Surface

Keywords automated NC polishing system, fixed point linkage mechanism, turbine blade, 3-D curved surface, ZrO_2-22%MgO

Y. Shimizu, K. Sakaki, K. Yaejima, Y. Tezuka, and S. Tamai
Shinshu University

A personal computer aided manufacturing system was developed for polishing thermal spray coatings deposited on 3-dimensionally curved substrate surfaces. The original 3-dimensional surface profile of the object to be polished was measured using a contact linear gauge sensor, and the detected profile was converted to NC machining data by the automatic programming functions installed in the system prior to the thermal spray processing. The thermally sprayed article was polished by the NC polishing machine. The original fixed point linkage mechanism that enables control of the polishing tool axis normal to the coating surfaces was adopted. This system polished a ZrO_2-22%MgO ceramic coating sprayed on a turbine blade having a typical 3-dimensional curved surface. The surface roughness of the ZrO_2-22%MgO coating, being 36 μm R_{max} in the as-deposited state, improved to better than 7 μm R_{max} via the present polishing process.

16 Study on the Bonding Characteristics of Self-Fluxing Alloys in Spray and Cast Composite Materials

Keywords bonding characteristics, casting method, clad steel. composite material, self-fluxing alloy

*H. Yara, K. Miyagi, and A. Ikuta**
The University of the Ryukyus
**Kawasaki Heavy Industries, Ltd.*

Thermally sprayed self-fluxing alloys can be used to bond dissimilar materials in the production of composite materials. These materials are useful in various production processes due to their technological simplicity and economic advantage. Cast iron is superior in compressive strength, castability, machinability, and corrosion resistance, but inferior in tensile strength and ductility. Therefore, a composite material incorporating cast iron can improve its characteristics. A composite material consisting of cast iron, sprayed self-fluxing alloy, and a carbon steel plate has been produced, and the mechanical and metallurgical properties have been studied. In particular, experimental data was compared with those of the base metal. It was found that the strength of the composite material is higher than that of cast iron. The bonded part had a slightly higher hardness than the carbon steel and the cast iron. Furthermore, white pig iron was observed on the cast iron.

17 Energy Absorption Capacity of Thermally Sprayed Aluminum Friction Damper

Keywords aluminum spraying, friction damper. initial clamping force (contact pressure), static and dynamic hysteresis characteristics

S. Ono, K. Nakahira, S. Tsujioka, and N. Uno
Osaka University

When an earthquake acts on buildings, dampers are effective in decreasing building failure by absorbing the input energy. An objective of this study is to develop a new type of friction damper, on whose faying surface aluminum is sprayed, and the double friction joint is tightened with a high-strength bolt. When slip occurs on this friction damper, the slip coefficient is high and comparatively stable. Specimens of the friction damper were tested under static and dynamic cyclic loading conditions to investigate the effect of the faying surface on the hysteresis characteristics. The parameters of the test are thickness of sprayed aluminum, initial clamping force (contact pressure), loading program, kind of sprayed metal, and sprayed side of the plate. Results show that a relationship exists between the thickness of sprayed aluminum and the clamping force to obtain stable slip load.

18 Artificial Tooth Roots with Plasma Spraying

Keywords artificial tooth roots, clinical case, dental, implant, plasma spraying

*K. Sano, K. Hara, K. Tsutsumi, and M. Magome**
Japan Institute for Advanced Dentistry
**Osaka Sangyo University*

Today, people over 40 or 50 years of age in Japan lose about eight teeth. The bony defects have been substituted with dentures, but recently, artificial implants have been chosen and used in daily clinical practice. This paper examines the use of artificial implants in place of dentures and the technology of plasma spraying titanium for this end. Some clinical work with these implants will be shown.

19 Characteristics of a Radio-Frequency Thermal Plasma Spraying Method for the Coating of Hydroxyapatite

Keywords ceramic substrates. hydroxyapatite coatings, impurities, orientation factor. radio-frequency plasma spraying

T. Kameyama, M. Ueda, K. Onuma, A. Motoe, K. Ohsaki, H. Tanizaki*, and K. Iwasaki**
National Institute of Materials and Chemical Research
**Nisshin Steel Co., Ltd.*

Radio-frequency plasma spraying has been developed for coating hydroxyapatite on ceramic substrates of zirconia and alumina for use in artificial joints and dental roots. Characteristics of coatings manufactured with the new spraying process were examined in terms of impurities, orientation factors, phases, and structures in coated films and of bond strength to the substrates.

#20 Joining of Ceramics and Metals by Thermal Spray Coatings Using Mixed Powders

Keywords joining, mixed powder, reaction layer, thermal stress

*T. Kuwashima, I. Takahashi, M. Kawahara, S. Tachibana, and A. Ohmori**
Iwate Industrial Research Institute
**The Advanced Materials Processing Institute*

Relaxation of thermal stress caused by the expansion coefficient difference between ceramics and metals and the reaction at the interface are necessary for ceramic joining to metals. Thus, soft metals are inserted for relaxation of thermal stress, and brazing alloys containing active metals are used for reaction between ceramics and metals. In this study, thermal spray coatings formed by LPPS are used to join ceramics and metals. Mixed powders of Ag-Cu-Ti alloy and Al_2O_3 are sprayed on a carbon substrate, peeled from the substrate, and used as an insert layer. Ceramic substrates of Al_2O_3, ZrO_2, Si_3N_4, and SiC are used and S45C is used as the metal substrate. Test pieces were joined at reduced pressure of 10^{-3} to 10^{-4} Pa and analyzed by SEM/EPMA and DSC.

21 Development of HVOF Sprayed WC-Co Coating for Sink Rolls in Galvanizing Bath

Keywords Al concentration, continuous hot-dip galvanizing, durability, HVOF, tungsten carbide

Y. Kobayashi, K. Tani, Y. Harada, A. Nakahira, T. Tomita, and Y. Takatani**
Tocalo Co., Ltd.
**Hyogo Prefectural Institute of Industrial Research*

Sprayed WC-Co cermet coatings were formed on mild steel by HVOF to protect sink rolls used in continuous hot-dip galvanizing. The durability in a molten zinc bath (mainly 753 K) containing 0-3wt%Al was investigated on the basis of the constitutional change measured by SEM and EDS. A diffusion layer is grown under the surface of the sprayed coatings that depends on the interdiffusion of Co and Zn atoms. This diffusion is suppressed with Al in the bath, and the relationship between the thickness of the diffusion layer and the immersion period is discussed.

22 Application of Thermal Spray Coating to Boiler Tubes in Refuse Incineration Plants

Keywords boiler tubes, corrosion resistant detonation spray, Ni-Cr

K. Yamada, M. Koyama, T. Ohtsuka, M. Ohsawa, K. Tohyama, and K. Kakeda
Hitachizosen Ltd.

We are developing a spray coating method to obtain higher corrosion resistance for boiler tubes used in refuse incineration plants. A detonation spray method has been developed to achieve high corrosion resistance and to save the production cost for spray coating of boiler tubes. The main results are as follows:

1. The plasma sprayed coating method with self-fluxing alloy material has sufficient corrosion resistance in the plant. However, this coat needs a post-processing fusing treatment.
2. A two-layer coat with 50Ni-50Cr material for the base coat and Cr material for the surface coat, applied by the detonation spray method, is more corrosion resistant in our laboratory test. This coat can be used without a fusing treatment.
3. The two-layer coating system described above has been tested under plant conditions. This plant has operated for ~2 years without any problems, and the coated tubes are expected to have a longer useful life.

23 Three-Dimensional Device Fabrication Using the Laser Spray Process Technique

Keywords C02 laser, laser spray, microfeeder. maskless, three-dimensional body

F. Uchiyama, K. Tsukamoto, and P. Fons
Electrotechnical Laboratory

This paper introduces the laser spray process as a means for creating a three-dimensional object on a substrate by directing raw material from a microfeeder toward a substrate in such a way to pass through the focus of a CW-CO_2 laser. Upon intersecting the laser beam path, the source material is instantaneously melted and is deposited on the substrate. Using this process, a three-dimensional object may be constructed directly on a substrate without masking. Initial three-dimensional prototypes in the form of a rod and a pipe have been fabricated.

24 A Micro Laser Spray Technique for Depositing Extremely Fine Patterns

Keywords C02 laser, fine line, laser spray, microfeeder, spiral

K. Tsukamoto, F. Uchiyama, P. Fons, T. Yanagisawa, Y. Kaga, and T Okuo
Electrotechnical Laboratory

In the current experiments, the laser spray method was used to draw fine lines. A thin film of YSZ was drawn in a spiral shape

on the surface of a porous alumina cylindrical tube. The width of the spiral line was about 0.3 mm.

#25 Laser Assisted Plasma Spray Coating Method for Surface Modification of Tribo-Materials

Keywords friction, laser, surface modification, wear

S. Sasaki, H. Shimura, Y. Kawakami, and A. Shahzad
Mechanical Engineering Laboratory

This paper describes a new surface modification technique that couples high-power CO_2 laser processing with the LPPS process. In order to clarify the laser beam irradiation effect on the tribological properties, metal alloy films were synthesized using a laser and plasma hybrid spraying system. The tribological characterization of the sprayed films was evaluated by a sliding tester under oil lubrication. Results show that it is possible to produce a high performance tribo-material possessing better adhesiveness and a low percentage of microporosity. Analytical results by XRD suggest that a metastable phase is formed by laser irradiation during the spraying process, and this phase is closely related to the antiwear and low friction mechanisms.

#26 Plasma Spraying under Controlled Atmosphere up to 300 kPa

Keywords CAPS. high pressure plasma spraying, LPPS, powder velocity, zirconia

S. Sodeoka, M. Suzuki, T. Inoue, Y. Ono, and K. Ueno
Osaka National Research Institute

In order to understand the pressure effect on the arc of a plasma jet and to reveal the effectiveness of high pressure plasma spraying (HPPS) as a coating tool, plasma spraying of yttria-stabilized zirconia was carried out by changing the chamber pressure from low (30 kPa) to high (300 kPa) in specially designed equipment. The plasma flame length and the velocity of the particles were measured in situ, and the coating characteristics including its microstructure, density, and hardness were studied. The temperature rise accompanied with the plasma flame shrinkage under high pressure caused heating of the zirconia particles, resulting in high deposition efficiency and a densified coating with improved hardness, in spite of reduced particle velocity. HPPS was found to be suitable for thermal spraying of materials, such as zirconia, which have a high melting point.

#27 Machining-Assisted Plasma Spraying (MAPS) and Its Performance

Keywords ceramic coating, coating properties, combined technology, machining

K. Maekawa, H. Shiina, and I. Ohshima*
Ibaraki University
**Hitachi Chemical Co., Ltd.*

The present paper describes the principle, apparatus, and performance of machining-assisted plasma spraying (MAPS). MAPS has been proposed not only to raise the adhesion strength of ceramic coatings over metal substrates but also to combine thermal spraying with pretreatments and posttreatments. Making use of a clean and active substrate surface that has just been machined is a key point. An alumina coating made by MAPS over a steel bar is evaluated by scratch, thermal shock, and thermal cycling tests. The effect of various bond coats on thermal resistance is also investigated. The coating formed by the combined method gives higher adhesion strength and larger resistance to heat than that made by conventional spraying. A suitable bond coat, such as Ni-Cr alloy, contributes to the rise of adhesion strength at high temperatures. This tendency is more apparent in coatings formed by MAPS. Finally, mechanisms for improvements of the interfacial characteristics in the MAPS process are discussed, and the role of a clean and chemically active surface is stressed.

#28 Development of a Magneto-Plasma-Dynamic Arc Jet Generator for Ceramic Coatings

Keywords ceramic coating, electromagnetic acceleration, hardness, magneto-plasma-dynamic arc jet. x-ray photoelectron spectroscopy

H. Tahara, Y. Kagaya, and T. Yoshikawa
Osaka University

A quasi-steady magneto-plasma-dynamic (MPD) arc jet with a cathode covered with a ceramic material was developed for spray coating ceramic materials. The velocities of ablated Al atoms measured with a streak camera were much higher than the velocities of 200-500 m/s reported for conventional plasma torches. This is effective for deposition of strong adherent films. The MPD spraying showed that a dense uniform ceramic film with above 1200 Vickers hardness could be deposited. Furthermore, from the XPS spectra, the peak area ratio of Si/Al of the coating almost equaled that of the raw ceramic material, and the valence numbers of Al and Si did not change.

#29 Factors of Blocking Phenomenon on the Internal Surface of Jet Kote Gun Nozzles

Keywords blocking phenomenon of gun nozzle, deposits of spray powder, HVOF thermal spray, Jet Kote system. spray materials

K. Sakaki, Y. Shimizu, and N. Saito
Shinshu University

An unsolved problem for the Jet Kote system is that some spray powder deposits on the internal surface of the gun nozzle. The goal of the present study is to solve this problem. As the first step, the effect of variations in the key spraying conditions, such as the melting point of spray powders, particle size, internal surface roughness of the gun nozzle, nozzle length, and fuel/oxygen flow rate, upon the deposition of spray powder was examined. The spray powders used were Sn-7.5%Sb-3.5%Cu, Al, Cu-10%Al, Ni-17%Cr-5%Al-0.5%Y, WC-12%Co, Al_2O_3, and Mo. The state of the deposits is influenced by the melting point of the spray powder, particle size, internal surface roughness of gun nozzle, and fuel flow rate. Spraying with a shorter (76.2 mm) nozzle is prone to form more deposits than with a longer (152.4 or 304.8 mm)

nozzle. The deposition tends to occur on the internal surface near the tip region at the nozzle exit. The blocking in the Jet Kote spraying of NiCrAlY can be controlled by fine finishing the internal surface of the nozzle and by selecting coarser size powder (particle size of 38 to 45 μm).

#30 Study of HVAF WC-Cermet Coatings

Keywords air-fuel, HVAF, HVOF, oxy-fuel, WC-cermet

*K. Akimoto, K. Akimoto, and Y. Horie**
Yosha Giken Co., Ltd.
Shimane International Industrial Science & Technology

The hypersonic velocity air fuel system (HVAF) was developed as high velocity flame spraying equipment requiring no oxygen and possessing quite different features than the HVOF system. WC-cermet coatings produced by the HVAF process were investigated in view of physical and mechanical properties. As a result of the study, WC-cermet coatings produced by HVAF were found to be unchanged by the spraying process, and negligible decarburization or dilution occurred.

#31 Hollow Cathode Plasma Spray Stabilized by an Applied Magnetic Field

Keywords deposition efficiency, hollow cathode, magnetic field, YSZ

A. Notomi and I: Takeda
Mitsubishi Heavy Industries, Ltd.

It is necessary to homogenize the energies of sprayed particles to improve the quality and performance of coatings. The conventional DC plasma torch with radial injection of powders tends to cause heterogeneous distribution of velocity, temperature, and particle size because of the irregularity of the particle trajectory. On the other hand, the hollow cathode DC plasma torch has potential to homogenize the distribution of particle energies, where the particle trajectory has the tendency to be the same as the plasma jet axis. This article deals with the stability of a hollow cathode DC plasma jet with an applied magnetic field. Although there are some problems, such as the instability of hollow cathode DC plasma jets and the shortness of electrode life, it has been found that rotation of the plasma arc around the electrode is effective in solving such problems. The plasma arc can be rotated around the electrode by a Lorenz force generated by an interaction of the plasma arc current and the applied magnetic flux. Stabilization of such plasma jets has led to the formation of coatings with axial injection of powders. Yttria stabilized zirconia powder has been sprayed onto a steel substrate under atmospheric and low pressure conditions. A high value of deposition efficiency has been obtained in the case of the LPPS process. The qualities of both coatings are the same as those formed by conventional processes. The hollow cathode DC plasma spray stabilized by an applied magnetic field is available for the practical use of high efficient and high quality plasma spray coatings.

#32 Production of Compositionally Gradient Coatings by Laser Spraying Method

Keywords compositionally gradient coatings, laser spraying, thermal shock resistance, titanium, titanium nitride

*A. Utsumi, J. Matsuda, M. Yoneda, M. Katsumura, and T. Araki**
Shikoku National Industrial Research Institute
Ehime University

A laser spraying method has been developed, which produces compositionally gradient coatings. A pure titanium wire was melted using a high energy CO_2 laser beam, and the gas stream produced a fine spray of melted titanium particles that coated the mild steel substrate. The chemical composition of the sprayed layer depended on the environmental gas used. Different gases (argon, nitrogen, and their mixtures) produced coatings that comprised titanium, titanium nitride, and mixtures of these constituents. The ratio of titanium nitride to titanium in the sprayed layer was directly related to the ratio of nitrogen to argon in the environmental gas. Since the thermal expansion coefficients and melting points of titanium, titanium nitride, and their mixtures are different, the laser spraying method can produce coatings that have a gradation of thermal expansion properties. As a result, laser sprayed coatings have excellent thermal shock resistance.

#33 Deformation and Solidification of a Molten Droplet by Impact on a Planar Substrate

Keywords deformation ratio, Madejski model, solidification, splat, temperature and velocity of molten droplet

H. Maruo, I: Hirata, and I: Matsumoto
Osaka University

Time-dependent deformation and solidification of a molten droplet by impact on a substrate are theoretically and experimentally investigated. Ratios of a splat diameter "D to diameter "d" of a melted droplet prior to impact were calculated on the basis of the Madejski model, which was improved in the formulation of viscous dissipation. Calculated results were compared with the experimental results using melted tin as a model droplet. The deformation ratio D/d of the splat increases with increase of temperature and velocity of the molten droplet. It was also found that splat deformation becomes larger on the substrate with low thermal conductivity or at higher temperature.

#34 Splat Behavior of Plasma Sprayed Particles on Flat Substrate Surface

Keywords plasma sprayed particle, rapid solidification, splashing, splat, surface tension

M. Fukumoto, S. Katoh, and I. Okane
Toyohashi University of Technology

Size-restricted powder particles were plasma sprayed on the flat substrate surface in an air atmosphere, and the effects of both substrate temperature and particle material on the splat behavior of the particles were investigated. In the splatting of some materials, such as Ni, intense splashing was recognized in the lower

substrate temperature range. On the other hand, splashing did not occur in the higher substrate temperature range. The term Tt is defined as the transition temperature at which the splat pattern changed from the splashing to the non-splashing morphology; and this parameter was determined in this study. From the results of all the materials observed, splashing was caused by rapid solidification in the particles and tended to occur when the surface tension of the particle was large.

#35 Effect of Preheating on Coating Process in Low Pressure Plasma Spraying

Keywords diffusion, erosion rate, preheating, sintering

*K. Honda, I. Chida. M. Saito, Y. Itoh, and K.F. Kobayashi**
Toshiba Corporation
**Osaka University*

LPPS has recently been applied to production in various industries owing to the dense coatings with few impurities, which can be formed. Although it is known that LPPS coatings have high bonding strength, the coating mechanism has not been understood well. In this study, the effect of preheating on the coating process in LPPS has been investigated. Preheating to 1073 K coupled with plasma spraying causes diffusion adjacent to the coating interface that is equivalent to vacuum furnace heating at 1373 K. Moreover, LPPS coatings preheated at 873 K or above consist of the surface layers that exhibit a higher blast erosion rate and subsurface layers with lower blast erosion rates. The in situ sintering phenomenon caused by preheating of the substrate and the subsequent spraying improves the cohesion strength between sprayed particles.

#36 Measurement of Spraying Particle Behaviors by High Speed Video Camera System

Keywords diagnosis, particle temperature, particle velocity

*S. Oki, S. Gohda, and K. Furukubo**
Kinki University
**Kumano Technical College*

Simultaneous measurements of temperature and velocity of sprayed particles are studied by the use of a high speed video camera system to understand the formation mechanism of spray coatings. The possibility for simultaneous measurements of individual sprayed particles is examined.

#37 High Temperature Oxidation Behavior of Plasma Sprayed MCrAlY Coatings

Keywords high-temperature oxidation, MCrAlY coatings, microstructures. thermal cycling, thermal expansion coefficient

H. Taumi, Y. Harada, M. Nakamori**, and T. Narita*
Graduate School of Hokkaido University
**Tocalo Ltd.*
***Mitsubishi Heavy Industries, Ltd.*

Three MCrAlY (M = Co, Ni, and CoNi) coatings were prepared by air and vacuum plasma spray methods (APS and VPS) to measure properties, such as density, microstructure, thermal expansion coefficient, and high-temperature oxidation properties. The as-sprayed APS samples exhibited an abnormal temperature dependence on thermal expansion coefficients due to changes in microstructures accompanied by change in density. Under repeated measurements, they tended to obey a normal temperature dependence. Oxidation rates of the VPS-NiCrAlY coatings were much higher than those of the VPS-CoCrAlY and CoNiCrAlY coatings. The former exhibited an α-Al_2O_3 scale and an Al-depleted subsurface layer thicker than those formed on the latter two. Further, in the case of the VPS-NiCrAlY coating, an yttrium-rich phase appeared within the reaction zone.

#38 Microstructural Characterizations of Low Pressure Plasma Sprayed CoNiCrAlY Coating

Keywords a-Co precipitates, β-phase, γ-phase, γ′-phase, microstructure, TEM

K. Noguchi, M. Nishjda, A. Chiba, J. Takeuchi, and Y. Harada**
Kumamoto University
**Tocalo Co., Ltd.*

Transmission electron microscopy (TEM) studies of LPPS-CoNiCrAlY coatings have been carried out. A spherical γ′-phase with an L12 structure was surrounded by β-phase with the B2 structure in an as-sprayed coating. In other words, γ'-phase was a primary phase during solidification. After a homogenizing treatment at 1273 K for 4 hours, γ'-phase disappeared and γ-phase with a fcc structure coexisted with β-phase. The Vickers microhardness of as-sprayed coatings was decreased by the homogenizing treatment. The γ'-phase was reformed by aging at 873 and 973 K after the homogenizing treatment. The microhardness of as-sprayed coatings was higher than that of the as-sprayed coating. These hardness changes were attributed to the ordering from γ to γ′-phase and the α-Co precipitates in β-phase.

#39 Effects of Spray Conditions on the Pore Structure and Quenching Stress in Plasma Sprayed Coatings

Keywords mercury porosimetry, Ni-Cr alloy, oxidation, spray distance, substrate temperature

S. Kuroda and S. Kitahara
National Research Institute for Metals

Effects of spray distance and substrate temperature on the microstructure of Ni-20Cr alloy deposits plasma sprayed in air were studied. The spray distance was changed from 60 to 300 mm, and the substrate temperature ranged from 200 to 600 °C. Oxygen in the deposits increased almost linearly with the spray distance whereas it did not change significantly with the substrate temperature. Pore size distributions measured by mercury intrusion porosimetry changed with the spray distance and substrate temperature. Open porosity was almost completely diminished at a substrate temperature over 600 °C. SEM observation of samples treated by high pressure infiltration of a Bi-alloy into the open porosity revealed that the interlamellar contact was significantly enhanced on a hot substrate. A significant increase in the quenching stress in the temperature range suggests that the initial liquid/solid contact between a sprayed particle and the un-

derlying coating surface is largely responsible for the observed structural change.

#40 Preparation of Titanium Overlay Alloy with Dispersed Hard Particles by Plasma Transferred Arc Welding

Keywords carbide, composite powder, overlay alloy, plasma transferred arc welding, titanium

T. Tomita, Y. Takatanj, Y. Hayashi, and K. Okita
Hyogo Prefectural Institute of Industrial Research

In order to develop a wear-resistant Ti alloy, hard particle-dispersed overlays were formed on Ti plate by plasma transferred arc welding. A new composite powder made from fine TiC particles and pure Ti particles was used. The effect of plasma arc current on the dispersion of the TiC particles and the hardness of the overlay alloys was examined by means of metallographic and x-ray diffraction measurements. TiC particles in the composite powder were completely dissolved in the molten Ti alloy. During the solidification process, TiC_x (x = 0.42 to 0.46) particles of 10 μm to 50 μm diameter, were in situ formed and uniformly dispersed. As the plasma arc current increased from 100 to 200 A, the hardness of this overlay alloy decreased from 1000 to 600 HV; however, the hardness is much higher than that of the conventional overlay alloys made from Ti-TiC mixed powder.

41 Sealing and Strengthening of Plasma-Sprayed ZrO_2 Coating by Liquid Mn Alloy Penetration Treatment

Keywords liquid manganese alloy, penetration, sintering, zirconia

A. Ohmori, Z. Zhou, K. Inoue, K. Murakami*, and T. Sasaki***
Advanced Materials Processing Institute
**Osaka University*
***Taiyo Engineering Co., Ltd.*

The penetration phenomenon of liquid Mn alloy into porous ZrO_2 ($8wt\%Y_2O_3$) coatings, plasma sprayed on SS400 steel substrate was studied by heating in a vacuum atmosphere. The improvement in the mechanical properties of the coating by heat-treatment with liquid Mn alloys was examined. It was found that liquid Mn alloys, such as Mn-Cu, Mn-Sn, and Mn-In, rapidly penetrated the coating and formed a chemical bonding interface between the coating and the substrate. The densification of the ZrO_2 coating occurred when ZrO_2 particles were sintered with liquid Mn alloy that penetrated the porous coating. The dense coating was porosity free and exhibited a greater hardness after heat-treatment with Mn alloys, compared with as-sprayed ZrO_2 coating. Moreover, the fracture toughness of the coating reached the same levels as those of sintered PSZ (Y_2O_3).

#42 Properties of Iron-Based Amorphous Coatings

Keywords amorphous, corrosion resistance, crystallization, iron alloy

F. Otsubo, H. Era, and K. Kishitake
Kyushu Institute of Technology

Fe-Cr-Mo alloys containing carbon and/or boron were plasma sprayed under reduced pressure. All the sprayed coatings are amorphous and show a high hardness of 800 to 1000 DPN. The amorphous coatings crystallize above 773 K. Very fine carbides, borocarbides, or borides precipitate in the matrix of χ phase and/or femte after crystallization of the amorphous phase bringing about a hardness of 1300 to 1450 DPN. The anodic polarization behavior of the as-sprayed amorphous coatings exhibits the activation-passivationtransition in $1N\ H_2SO_4$ solution. The active and passive current densities of the coatings increase with increasing boron content of the alloy. The corrosion resistance of the coating containing no boron is superior to SUS316L stainless steel coating.

#43 Differences in Material Properties of Sprayed Ni-Base Alloy Coatings by HVOF and Plasma Spray Processes

Keywords corrosion behavior, hardness, HVOF, Ni-based alloy

M. Sasaki, Y. Wakashima, and T. Hattori
Daiichi Metco Co., Ltd.

The material properties of HVOF and plasma sprayed coatings of Ni-base alloy powder are compared. The differences in chemical composition, microstructure, hardness, corrosion behavior, and residual strains of two sprayed coatings are investigated.

#44 Hot Corrosion Resistance of a Chromium-Based Alloy Coating

Keywords chromium-based alloy, incinerator

K. Hidaka, K. Tanaka, S. Nishimura, and K. Kawarada
Fukuda Metal Foil & Powder Co., Ltd.

The hot corrosion resistance of a chromium-based alloy (CNX-2) sprayed coating was investigated by carrying out tests in molten ash and in a waste incinerator. The sprayed coatings of 80Ni-20Cr, 50Ni-50Cr, and nickel-based self-fluxing alloy were also tested as comparison materials. The results indicate that the sprayed coating of CNX-2 exhibited better hot corrosion resistance than the comparison alloys.

#45 Corrosion Behavior of Nickel-Chromium Alloy HVOF Spray Coatings

Keywords corrosion behavior, corrosion resistance current density, nickel chromium HVOF spray coating, scanning vibrating electrode technique

J. Oka, M. Magome, K. Hidaka, K. Tanaka*, and T. Tajiri***
Osaka Sangyo University
**Fukuda Metal & Powder Co., Ltd.*
***Kurasiki Boring Co., Ltd.*

The different chemical and mechanical properties of spray coatings depend on the material. Corrosion resistance is significantly changed by the spraying method since the solidification velocity of particles and plastic deformation behavior of the coating change. The scanning vibrating electrode technique (SVET) can be used to determine the potential gradient caused

by corrosion currents occurring near the surface of spray coatings and the separation of the anodic and cathodic reactions by using the scanning vibrating electrode. Test specimens were HVOF-prepared from mixed powder of nickel and chromium in ratios of 80:20 and 50:50. The corrosion testing was determined using a 5% aqueous solution of sulfuric acid. The current density in the 50Ni:50Cr sprayed coating showed a lower value than the 80Ni:20Cr coating. Variation of the local surface current density was determined with the SVET. The same phenomenon can be also found in the case of crevice corrosion.

#46 Degradation Characteristics of Plasma-Spray Ceramic Coatings under Cyclic Heating Conditions

Keywords APS, cyclic heating, LPPS. micropores and microcracks, oxidation

*H. Yajima, Y. Kimura, and T. Yoshioka**
Kogakuin University
Nippon Coating Industry Co., Ltd.

LPPS coatings exhibit higher adhesive strength and a more refined microstructure. Thus, LPPS coatings are expected to exhibit better high temperature oxidation resistance compared with APS coatings. Therefore, in this paper, cyclic and continuous heating tests of APS and LPPS coatings were conducted, and the degradation characteristics of these coatings under cyclic heating conditions were investigated. As a result, a few cracks were generated in the top coated ZrO_2-8wt%Y_2O_3 layer of the APS coating after several heating cycles to 1000 °C. Therefore, oxidation of the APS coating has been suppressed. On the contrary, in the case of LPPS coatings many microcracks were generated after several cycles to 1000 °C. Oxidation of LPPS coatings preferentially occurred due to oxygen coming into coated layers through these cracks. The governing factor of microcrack generation in the cyclic heating process was understood from the viewpoint of larger thermal stress generation in the top coated ZrO_2-8wt%Y_2O_3 layer in the case of LPPS coating due to a larger Young's modulus. The thermal cycle life was related to a change in mechanical properties due to porosity changes.

#47 Durability and Tribological Properties of Thermally Sprayed WC Cermet Coating in Rolling/Sliding Contact

Keywords HVOF, surface durability, tribology, two-roller test. WC cermet

M. Yoshida, K. Tani, A. Nakahira, A. Nakajima, and T. Mawatari**
Tocalo Co., Ltd.
Saga University

Two-roller tests under lubricated line contact or point contact conditions were conducted to examine the durability and tribological properties of HVOF-sprayed WC-Cr-Ni cermet coating in rolling/sliding contact. The coatings of –25 μm, 40 μm, and 90 μm thickness, were sprayed onto carburized steel rollers, and the contact surfaces were finished to a mirror-like condition. The WC cermet coated roller and the carburized steel roller without a coating (R_{max} –0.1 m) were placed in contact, and a maximum Hertzian stress in the range of P_H = 1.2 to –1.4 GPa in line contact or P_H = 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 a 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%). Generally, the resistance to flaking tended to increase as the thickness of coating increases, though significant differences in the friction and wear behavior were not distinguished.

#48 Development of Dry Process for Heavy Thickness Coating Layer

Keywords coating, deposit 1 mm thickness, friction, personal computer

T. Shinoda, S. Takemoto, Y. Kato, T. Shimizu*, and T. Yashiro**
Nagoya University
Daido Steel Co., Ltd.

There is a strong industrial need to obtain hard coatings of 1 mm thickness. This paper deals with the approach to establish friction surfacing techniques. We established the process parameters of friction surfacing and developed a large surfacing machine with a 50 ton loading capacity. We clarified the effect of operating parameters on surface quality using a conventional friction welding machine equipped with a sliding stage. Martensitic stainless steel with 1C-17Cr was selected as the coating material, and a low carbon structural steel was the substrate. A stable hardened coated layer can be obtained with dimensions of 20 mm width and 1 mm thickness with fine dispersed chromium carbides. No dilution was observed in this process. Hardness values reached around 700 to 800 HV in the as-coated condition. Coated dimensions depend on the friction speed of the coated material with the lower friction speed forming thicker and wider deposits. Deposition speed is nearly the same or greater than conventional arc welding processes.

#49 Developments of PPW Process for Water Gate Valve

Keywords cast iron, coating, copper alloy, powder

Y. Kato, T. Shimizu, T. Yashiro, H. Xiaoou, and W. Taixing***
Daido Steel Co., Ltd.
Chinese Academy of Agricultural Mechanization Sciences, China
****Tielin Valve Works, China***

Newly developed surface modification technology, the plasma powder welding (PPW) process, was adopted to copper deposition on cast iron to improve corrosion resistance. In experiments with small gage test pieces, no cracking was observed in the surface layer and substrate while a little dilution was detected in the substrate. These results showed that this surface modification technology was able to form a stable and sound surface layer efficiently. This technology was adopted to a large-sized cast iron gate valve for a water supply system in China. The copper alloy surface layer consisted of α and δ phases while a little Sn and Zn were observed at the weld bond. Tension test

specimens cut from a cast iron gate valve surfaced with a copper alloy by the PPW process did not fail at the weld bond but in the copper alloy surface layers and indicated good mechanical properties.

#50 Heat Absorption and Radiation Layer by Plasma Spraying Process

Keywords absorptivity, alumina-titania. emissivity, magnetite

T. Hattori, M. Sasaki, K. Tunoda, and N. Shimabara
Daiichi Metco Co., Ltd.

Microstructures of plasma sprayed coatings of Fe_3O_4 and Al_2O_3-TiO_2 powders are investigated. Changes in the microstructures of Fe_3O_4 due to plasma spraying and heat treatment are investigated. Absorbance and reflectance of Fe_3O_4 and Al_2O_3-TiO_2 coatings are investigated at visual to far-infrared wavelengths. The solar heat absorptivity of the two oxide coatings and far-infrared ray emissivity of the Fe_3O_4 coating are discussed.

#51 Aluminum Diffusion in a Plasma Sprayed Ni_3Al/Ni Substrate Coating System

Keywords activation energy, Boltzman-Matano method, diffusion coefficient, error function, joined couple

K. Wada, S. Arai, S. Suenaga, K. Yasuda, M. Nakahashi, and H. Takeda
Toshiba Corporation

The main purpose of this paper is to clarify the diffusion mechanism in a plasma sprayed metallic coating system. The Al interdiffusion coefficient and the activation energy for the Ni_3Al coating layer are compared with those for the Ni_3Al plate in a joined couple. A new analytical method is proposed to obtain the interdiffusion coefficient in the layer. It is suggested that defects in the layer, such as grain boundaries and voids, provide a high-velocity diffusion path.

#52 Synthesis of Chromium Nitride in situ Composites by Reactive Plasma Spraying with Transferred Arc

Keywords Cr-nitride, Cr powder, in situ composites. reactive low pressure plasma spraying, transferred arc

Y. Tsunekawa, M. Okumiya, and T. Kobayashi
Toyota Technological Institute

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 achieve a high deposition rate and good structure control in Cr-nitride composite coatings. These were synthesized by reactive LPPS using Cr powder as the spray material. The transferred arc between the electrode of the spray gun and the low carbon steel substrate was used to accelerate the nitride reaction. The sprayed coatings consist of Cr, Cr_2N, and CrN, which have a compositional gradient from the interface to the surface. The volume fraction of Cr_2N increases with the transferred arc current. Nonreacted Cr significantly decreases, except close to the interface, by applying a transferred arc current of 25 A. 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 increases to HV 1300 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 HV 1300. 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.

#53 Adhesion between Thermal Sprayed Coatings and Aluminum Alloy Substrates

Keywords adhesion; aluminum alloys, shearing test

K. Nakanishi, H. Tachikawa, H. Harada, and K. Mori**
Toyota Central R&D Labs., Inc.
**Toyota Motor Corporation*

Thermal spray has attracted much attention as an effective method to coat aluminum alloy substrates. This paper reports on a series of experiments to investigate the adhesion between thermally sprayed coatings and aluminum alloy substrates. The influence of spray angle and substrate temperature on the adhesion of sprayed coatings is discussed. The relationship between the adhesive strength of the coating and various conditions are analyzed through investigation of shearing fracture surfaces. The difference in adhesion at each substrate temperature is also discussed through examination of the particles deposited on the substrate.

#54 Fatigue Strength and Fracture Mechanisms of Ceramic-Sprayed Steel in Air and a Corrosive Environment

Keywords ceramic-sprayed steel, crack growth, environment, fatigue, rotating bending

J.U. Hwang, 1: Ogawa, and K. Tokaji
Gifu University

Rotating bending fatigue tests have been conducted at room temperature, in air, and in 3% NaCl solution to investigate the fatigue strength and fracture mechanisms of ceramic-sprayed steel. A medium carbon steel (S45C) substrate, a sprayed layer of Ni-5%Al (bond coating), and chromia (top coating) were used as test specimens. Observation of fatigue data on specimens subjected to individual treatment during the ceramic spraying process showed that at an early stage of fatigue life, cracks were initiated at the interface between the bond and top coating layers, which then grew rapidly into the ceramic layer. However, these cracks did not propagate continuously into the substrate, and final failure was led by growth of a crack initiated at the substrate surface. Thus, the fatigue strength of the ceramic sprayed steel in air was established as a property of the substrate. Corrosion fatigue strength of the ceramic sprayed steel was improved when compared to that of the substrate steel. However,

the coating contained many pores, through which NaCl solution penetrated to the substrate. Corrosion pits were formed at the interface between the bond coating and the substrate. Subsequently, cracks initiated from the pits and grew into the substrate. Tests were also conducted on specimens where pores were sealed. In this case, NaCl solution was supplied to the substrate by cracks initiated in the top coating layer. The sealing treatment was effective at low stress levels where fatigue life was more than 10^7 cycles, while it had little effect on improving corrosion fatigue strength at higher stress levels because of many cracks initiated in the top coating layer.

#55 High Temperature Oxidation and Hot Corrosion Behavior of Two Kinds of Thermal Barrier Coating Systems for Advanced Gas Turbines

Keywords ceramic coating, failure analysis, high temperature oxidation. hot corrosion. TBC

*M. Yoshiba, K. Abe, T. Aranami, and Y. Harada**
Tokyo Metropolitan University
**Tocalo Co., Ltd.*

High temperature oxidation and hot corrosion tests were conducted at 800 to 1100 °C under isothermal and thermal cycle conditions for two TBC systems with different compositions of ceramic top coat; that is, Y_2O_3-stabilized ZrO_2 (YSZ) and 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. In high temperature oxidation up to 1100 °C, the YSZ-TBC system was more readily subjected to delamination of the top coat, which is attributed to localized oxidation along the ceramic top coat / metallic (NiCrAlY) bond coat interlace, as compared with the case of the C_2S-CZ-TBC system. Thus, the most significant oxidation damage resulted in the YSZ system under thermal cycling conditions. On the other hand, in the Na_2SO_4-NaCl molten salt up to 1000 °C, the C_2S-CZ system was more reactive with the molten salt and formed a new phase layer composed of both the metallic bond coat constituents and corrosive species at an inner region of the ceramic top coat. The influence of the heat treatment, in particular on the nature of the atmosphere, after plasma spraying was also investigated in relation to the change of coating structure and the interface adhesion.

#56 Corrosion Behavior of Carbide Cermet Sprayed Coating in Alkaline Aqueous Solution

Keywords cermet, galvanic corrosion, polarization behavior. sacrificial anode

M. Inaba, K. Tani, Y. Harada, A. Nakahira, T. Tomita, and Y. Takatani**
Tocalo Co., Ltd.
**Hyogo Prefectural Institute of Industrial Research*

The corrosion behavior of carbide cermet sprayed coatings in alkaline solutions is examined by electrochemical processes. The two-layer thermal sprayed coating (Cr_3C_2/NiCr: top coat, Ni-P: under coat, mild steel: substrate) was investigated by the following tests: corrosion potential, polarization behavior, and coupling current, in 1M NaOH at 323 K. The results are as follows:

1. Cr_3C_2/NiCr coating exhibits active dissolution.
2. The mild steel tends to be anodic on the Cr_3C_2/NiCr coating/mild steel couple.
3. The Ni-P coating tends to be anodic on the Cr_3C_2/NiCr coating, Ni-P coating, and mild steel system.
4. On the couple with Cr_3C_2/NiCr coating and Ni-P coating, Ni-P coating may be expected to be passivated, act as a sacrificial anode, and protect the Cr_3C_2/NiCr coating from corrosion.

#57 Corrosion Behavior of Aluminum Overlay Weld Alloys with Dispersed NbC Particles in Sodium Chloride Solution

Keywords aluminum alloy, electrochemical measurement, niobium carbide, overlay weld alloy, plasma transferred arc welding process, sodium chloride

Y. Takatani, T. Tomita, K. Tani, and Y. Harada**
Hyogo Prefectural Institute of Industrial Research
**Tocalo Corporation*

Aluminum overlay weld alloys with dispersed niobium carbide particles (NbCp/Al) were prepared by a plasma transferred arc welding process. The corrosion behavior of the NbCp/Al alloys was studied in sodium chloride solution by means of electrochemical techniques and scanning electron microscopy. The aluminum alloys under investigation were pure Al, Al-Mg, Al-Mg-Si, and Al-CU. The addition of NbC particles shifted the corrosion potentials in the positive direction. However, the pitting potentials were similar to that of overlay weld alloys without NbC particles. At the immersion test in quiescent 0.5M NaCl open to the air, preferential localized corrosion of all NbCp/Al alloys was observed at the matrix-NbC particles and crystalline material interfaces.

#58 Effect of Undercoating on Properties of Y_2O_3 Coating

Keywords electrical insulator, undercoating, vacuum plasma spray, Y_2O_3 coating

M. Nakamichi, H. Kawamura, R. Oyamada, K. Mjyajima, and Y. Harada*
Japan Atomic Energy Research Institute
**Tocalo Co., Ltd.*

Ceramic coatings on the surface of structural materials, such as 316SS, are being considered as an electrical insulator and tritium permeation barrier for fusion reactor applications. Y_2O_3 is a promising coating material from a point of high electrical resistivity and good compatibility with liquid lithium. However, cracking and peeling occurs from differential thermal expansion between the 316SS substrate and Y_2O_3 coating. Therefore, undercoating between the 316SS substrate and Y_2O_3 coating is indispensable to prevent delamination of the Y_2O_3 coating.

#59 Characteristics of Microcrystalline Diamond Films Synthesized by Plasma Jet CVD

Keywords cemented WC substrate, coefficient of friction, diamond film, plasma jet CVD, Raman spectra

*F. Matsumoto, S. Kato, and Y. Tomii**
Nippon Aluminium Co., Ltd.
**Kyoto University*

Chemical vapor deposited diamond films are grown by a plasma arc jet method with a mixture of Ar and H_2 as the plasma gases and a mixture of CH_4 and H_2 as the reaction gases. SiC ceramic and WC-based cemented carbide are used as substrates. Characteristics of the deposited films are investigated by SEM, TEM, Raman spectroscopy, Vickers microhardness, and tribology tests. Raman spectra showed that the film composition varies from graphite to diamond and hydrogenated carbon. SEM showed that the amorphous carbon forms amorphous hydrogenated carbon (a-C:H), including nanocrystal sized diamond particles and prevents the growth of diamond. As a result, a microcrystalline diamond film zone is produced between the graphite and polycrystalline diamond zones. TEM studies show the microcrystalline diamond film to be a a-C:H matrix material surrounding the single crystalline diamonds of 10 to 20 nm diameter. The Vickers hardness of the microcrystalline diamond film is 82 GPa with a load of 9.8 N. Coefficients of friction of a SUJ2 ball/microcrystalline diamond coated WC-Co substrate are lower than that of a SUJ2/noncoated WC-Co substrate.

#60 Wear Properties of TiC-Ni composite Coatings

Keywords HVOF, intermetallic compounds, LPPS, TiC-Ni composite coatings, wear resistance

S. Fujii, T. Tajiri, and A. Ohmori***
Industrial Technology Center of Okayama Prefecture
**Kurashiki Boring Kiko Co., Ltd.*
***The Advanced Materials Processing Institute*

LPPS and HVOF spray processes were used to prepare TiC-Ni composite coatings for steel substrates and were investigated with respect to their structure and wear properties. Ni plated TiC particles were used as the powder. The structure of the coatings was studied using optical microscopy, and the phases were determined by x-ray diffraction. The microhardness was also measured. The wear resistance of the coatings was studied with a blast erosion test (ACT-JP) and a reciprocating plane wear test (JIS H8615). In general, the hardness of the coatings sprayed with the LPPS process was greater than those of coatings sprayed using the HVOF process. Although the wear behavior of both coatings show almost the same tendency, the wear properties of the coatings with the LPPS process were superior to those of the coatings with the HVOF process. These results depend on the dispersion of intermetallic compounds in the Ni matrix of the TiC-Ni composite coatings.

#61 Effect of Thermal Sprayed Ceramic Coatings on Fatigue Behavior of Metals

Keywords ceramic coating, fatigue crack, fatigue strength, plane bending fatigue

T. Shiraishi, H. Ogiyama, and H. Tsukuda
Ehime University

Plane bending fatigue tests were performed on annealed and prestrained copper substrates coatings with ~150 μm thick alumina. Plasma sprayed coatings were produced after sand blasting without any bond coats. The fatigue strength and the behavior of fatigue crack initiation and propagation were examined. The fatigue strength of the alumina-coated specimen was similar to that of uncoated substrates. The measurements of the bending moment and the strain on the specimen surface indicated that the bending elastic modulus of the alumina coating was much lower than that of the substrate. Fatigue cracks were initiated at both the alumina layer and the copper substrate. These two factors, that is, the low elastic modulus of the layers and the crack behavior in the coated specimens, accounted for the result that the fatigue strength of copper was not appreciably affected by the plasma spraying of alumina.

#62 Characteristics of Pack Aluminized VPS Sprayed MCrAlY Coatings

Keywords LPPS, MCrAlY, metallography, oxidation, pack cementation, post treatment

R. Yamasaki, J. Takeuchi, A. Nakahira, M. Saitoh, and Y. Itoh**
Tocalo Co., Ltd.
**Toshiba Corp.*

Characteristics of pack aluminized MCrAlY (where M indicates Co, Ni, or their combinations) coatings were investigated. Five types of MCrAlY alloys were sprayed onto Inconel 738LC (IN738LC) substrates using LPPS. After spraying, each test specimen was heat treated in a vacuum at 1120 °C for 2 hours and then at 845 °C for 24 hours. A subsequent pack aluminizing treatment was applied to specimens at 900, 950, and 1000 °C for 5, 10, and 20 hours, respectively. The microstructure of the aluminized layer that formed in the surface region of each coating was investigated using SEM and EPMA. The formation rate of the aluminized layer was calculated from the measured thickness of the layer, and the activation energy for formation was estimated for each MCrAlY coating and IN738LC specimen. Oxidation behavior was evaluated on the basis of the specific weight gain and the SEM cross-sectional structure after oxidation at 1050 °C for 1000 hours in an atmospheric environment, and compared with the conventional MCrAlY coatings and IN738LC.

#63 Application of Ultrasonic Testing Robot with Five Axes for Evaluating Adhesion of Thermal Sprayed Coating

Keywords adhesion of coating, delamination, robot for testing, ultrasonic testing

D. Lian, Y. Suga, and S. Kurihara
Keio University

A nondestructive method to detect delamination of thermal sprayed coating by ultrasonic testing has been proposed. However, it is relatively difficult to apply the automatic ultrasonic testing method to thermal sprayed products because of their complex shape, If the surface of the plate has a complex shape, then it is difficult to detect the ultrasonic echo returned from the specimen because the ultrasound need not be reflected back to the probe. A robot with five axes was constructed that allows (i) ultrasonic testing along Cartesian coordinates of X-Y-Z and (ii) changing the angle of a and θ. Therefore, even if the surface of the specimen is inclined to the probe, then accurate echo data

can be obtained since the robot can alter the holding angle of the probe automatically. In this paper, the effectiveness of the ultrasonic testing robot system for nondestructive testing of thermal sprayed coatings is discussed.

#64 Introduction of Fractal Dimension to Evaluation of Adhesive Strength

Keywords blasting, blasting angle, fractal dimension, surface roughness, thermal spray

S. Amada, T. Hirose, and K. Tomoyasu
Gunma University

The fractal dimension has been used to relate the grit blast angle and surface characteristics of metal substrates. It has been shown that the usual average surface roughness does not change with blasting angle. However, the fractal dimension of substrate surfaces is influenced considerably by the blasting angle. It is concluded that there is an optimum angle that influences the fractal dimension of roughened surfaces.

#65 Measurement of Residual Stress and Thermal Stress in Sprayed Coating Layers

Keywords finite element method, in situ thermal stress measurement. laser spraying, x-ray stress measurement

*M. Nishida and T. Hanabusa**
Kagawa Polytechnic College
**Tokushima University*

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

#66 Microstructure Measurement of Plasma-Sprayed Alumina Coatings

Keywords alumina, image processing, mercury intrusion porosimetry, porosity

C. Takahashi and T. Senda
Ship Research Institute, Ministry of Transport

The porosity of plasma sprayed alumina coatings prepared under various conditions was analyzed by image processing of micrographs and mercury intrusion techniques. In order to prevent possible pull-out of particles during polishing and to improve the SEM image contrast between the coating and its pores, pores were impregnated by a chromic acid process. Three types of porosity were confirmed from the back-scattered electron images of the cross sections; namely, (i) coarse pores of around 10 μm diameter located between lamellae, (ii) narrow gaps resulting from incomplete lamellae-to-lamellae contact, and (iii) 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 depend significantly on spraying conditions. This is supported by the mercury intrusion porosimetry results.

#67 Study on Non-Destructive Evaluation Method for Thermal Sprayed WC-Co Coatings Using Ultrasonic Wave

Keywords non-destructive evaluation, porosity, ultrasonic wave, WC-Co coating

*R. Kawase and R. Yasutake**
Ariake National College of Technology
**Koeiseiko Co., Ltd.*

This study established a nondestructive evaluation method for thermal spray coatings that used ultrasonic waves. The ultrasonic velocity and ultrasonic strength transmitted in WC-Co coatings have been measured, and these values were related to the coating properties.

#68 Detection of Delamination of Sprayed Ceramic Coating in Thermal Shock Test by Ultrasonic Testing Method

Keywords delamination, thermal shock. ultrasonic testing

Y. Suga, D. Lian, and S. Kurihara
Keio University

Coatings may delaminate from the substrate since the adhesion strength of the coating is relatively low. In particular, TBCs such as ZrO_2 delaminate due to thermal shock; however, it is difficult to detect and evaluate such failure. A nondestructive inspection method using ultrasound to detect the delamination of sprayed coatings has been proposed. In this study, a sprayed coating model was made from acrylic plates, and an ultrasonic test was applied to investigate the detection precision of delamination by the ultrasonic testing method. Delaminations of more than 1 mm diameter can be detected under thermal shock conditions.

#69 Laser Fusing of Sprayed WC-Co Coatings

Keywords CO_2 gas laser WC-Co, hardness, HVOF thermal spraying, microstructure

*N. Takasaki, M. Kumagawa, K. Yairo, and A. Ohmori**
Dai-ichi High Frequency Co., Ltd.
**Osaka University*

In this research, the fusing process for laser irradiation of WC-Co coatings is studied, and the properties and microstructures of fused films are investigated. The properties are also compared with the as-sprayed coatings. The film will not become dense without an alloying stage. Alloying is induced to the full thickness of the fused film, and the hardness of the fused film is a maximum of 1400 HV.

70 Application of Self-Fused Alloy Coating by HF Induction Heating

Keywords boiler tubes, induction, self-fusing, thick coatings. wear resistance

*Y. Matsubara, M. Kumagawa. Y. Sochi, and A. Notomi**
Dai-ichi High Frequency Co., Ltd.
**Mitsubishi Heavy Industries, Ltd.*

Application of induction heating to the fusing process of Ni-based, self-fusing alloy coatings for boiler tubes enables the production of harder and denser coatings. This induction heating process brings about additional benefits to improve the quality, reliability, and productivity. The results obtained in this study are summarized as follows:

1. High frequency induction heating of Ni-based, self-fusing alloy enables production of a coating more than 1 mm thick.
2. 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.
3. This process can be controlled by choosing the optimum power input and the coil traveling speed.
4. This process can also be used to coat rolls and for other wear resistant applications.

#71 High Corrosion Resistance of a Ni-Alloy Sprayed and Pd-P Plated Coating

Keywords compound coating, corrosion resistance. HVOF, microdefects. sulfur dew point corrosion

*M. Ishida, M. Sasaki, T. Hattori, and Y. Nakagishi**
Daiichi Metco Co., Ltd.
**Okuno Chemical Industries Co., Ltd.*

Expensive Ni-based alloys, such as Hastelloy-C, are used in power plants or diesel engines, which use petroleum fuel gases. From the cost viewpoint, corrosion resistant alloy coated steel parts are preferable to expensive alloys. In a previous study, a Ni-based alloy sprayed with a HVOF system (Metco DJ gun) showed high corrosion resistance. However, corrosive acid penetrated through microdefects of the coating and resulted in coating separation from the substrate. Sealing of the coating is one method to prevent this; but the dense HVOF coating precludes use of a practical sealer. In this study, we introduce a unique compound coating that prevented sulfur dew point corrosion. The coating consists of Ni-P plating, Pd-P plating, and a thermal sprayed Ni-based alloy coating.

72 Improvement of Plasma-Sprayed Ceramic Coatings Treated by Sol-Gel Process

Keywords adhesive strength, interface, SiO_2 depositions, sol-gel process. ZrO_2 coatings

K. Moriya, W. Zhao, and A. Ohmori***
Kagawa Prefectural Industrial Technology Center
**Xj'an Jiaotong University, China*
***The Advanced Materials Processing Institute*

Plasma sprayed ceramic coatings are used in various fields, such as hard coatings on soft materials. However, plasma sprayed ceramic coatings contain pores and cracks (including connected porosity) and, therefore, exhibit poor corrosion, abrasion, and adhesion properties. This research focuses on the improvement of the adhesive strength of plasma sprayed ZrO_2 ($8wt\%Y_2O_3$) coatings treated by the sol-gel process. The adhesive strength is measured according to ASTM C633-69. The adhesive strength of plasma sprayed ZrO_2 coatings on SS400 substrates, which are pretreated by the sol-gel deposition of SiO_2, increases compared with the as-sprayed material. The deposition of SiO_2 is obtained by the penetration of sol solution through the connected porosity and the evaporation of solvent. The connected porosity of plasma sprayed ZrO_2 coatings, which are pretreated with sol gel SiO_2, decreases greatly. It is found by XRD analysis that the improvement of the adhesive strength of ZrO_2 coatings treated by the sol gel process is due to the deposition of SiO_2, both at the interface between the coating and the substrate and in the porosity and gaps of the ZrO_2 particles.

73 Trial Fabrication of Y_2O_3 Coating on 316SS

Keywords densification treatment, electrical insulator, undercoating. Y_2O_3 coating

M. Nakamichi, H. Kawamura, R. Oyamada, K. Miyajima, and Y. Harada**
Japan Atomic Energy Research Institute
**Tocalo Co., Ltd.*

Ceramic coatings on the surface of structural materials such as 316SS are being considered for an electrical insulator and tritium permeation barrier in fusion reactors. Y_2O_3 is one of the most promising coating materials due to its high electrical resistivity and good compatibility with liquid lithium. In this study, trial fabrication and preliminary characterization of Y_2O_3 coatings as electrical insulators were performed to obtain a material data base of the coating.

#74 Corrosion Characteristics of Thermal Sprayed Stainless Steel Alloy Coatings in Chloride Solution

Keywords anodic, cathodic, chloride. corrosion, stainless steel

T. Suzuki, K. Ishikawa, and Y. Kitamura***
Ajinomoto Co., Inc.,
**Tokyo Metallikon Co., Ltd.*
***Kitamura Technical Consultant Office*

The corrosion behavior of a thermal spray coating of SUS 304,316, and Hastelloy C was studied in 3.5%NaCl solution by anodic and cathodic polarization measurements, SEM, and EPMA. It was found that anodic dissolution occurs along the crevices between the deposited particles. The anodic process is essentially the same as that of crevice corrosion. A marked decrease of corrosion resistance in the sprayed alloys compared with that of the original solid wire was attributed not only to the accelerated anodic process but also to the increased activity of the cathodic reaction. The latter was suggested by the presence of a diffusion controlled cathodic current observed after the onset of cathodic polarization measurements. Such behavior does not usually appear on stainless steel in neutral solutions. Sealing of the microcrevice in the spray deposited alloy layers is essential to improve the corrosion resistance in chloride solution. The

thermal sprayed Hastelloy C, with a lower crevice corrosion susceptibility, coated with epoxy resin, exhibited the highest corrosion resistance.

#75 Characteristics of Wire Explosion Sprayed Mo, WC-6.5%Co Coatings and Their Composite Coatings

Keywords abrasive wear, composite coatings, molybdenum. WC-Co, wire explosion spraying

K. Tokumoto, R. Nakamura, and H. Ito***
Nippon Tungsten Co., Ltd.,
**Kurume College of Technology*
***Koei Seiko Co., Ltd.*

Molybdenum and WC-6.5%Co composite coatings were deposited by means of wire explosion spraying to improve the wear resistance of a WC-6.5%Co coating. Additionally, WC-6.5%Co coatings and Ni-P (P: phosphorus) alloy coatings were codeposited by means of wire explosion spraying and electroless nickel plating, respectively. The abrasive wear resistance of these composite coatings was also examined. The results are summarized as follows:

1. The most appropriate spray distances d/r, where d is spraying distance and r is radius of wire, for both molybdenum and WC-6.5%Co cemented carbide were in the range of 30 to 40 according to the evaluation of hardness and adhesion strength.
2. WC-6.5%Co-Mo composite coating having 25 vol% molybdenum exhibited better abrasive wear resistance than a WC-6.5%Co coating.
3. The abrasive wear resistance of WC-6.5%Co-Ni-P composite coating having 50 vol% Ni-P alloy was nearly the same as that of WC-6.5%Co-Mo composite coating having 25 vol% Mo.

#76 Formation of Amorphous Alloy Coatings by Wire Explosion Spraying Process

Keywords amorphous alloys, cooling rate, wire explosion process

M. Nakayama, H. Ito, R. Nakamura, and M. Toh
Kurume National College of Technology

Amorphous alloys have excellent resistance to corrosion. These structures can be obtained by rapid cooling during solidification. In the wire explosion spray process, melted particles are supercooled at very high velocity and form thin amorphous coatings. Amorphous coatings were formed when Ni-P plated SUS304 stainless steel and Inconel alloy wires were wire explosion sprayed on aluminum and SS41 carbon steel substrates.

#77 Manufacturing Methods of Porosity Controlled Metallic Porous Coatings

Keywords FGM, implant, open porosity, porous coating, titanium

*J. Takeuchi, A. Nakahira, and H. Kawatani**
Tocalo Co., Ltd.
**Kobe Steel Ltd.*

This article describes a manufacturing method for a metallic coating with controlled porosity and high bonding strength between particles. First, stainless steel and tungsten powders were used to form a porous coating with the aim of making a functionally gradient material (FGM). The influence of spraying parameters and powder particle size on the open porosity of the coating was investigated. The degree of porosity was evaluated by means of the mercury intrusion method, and the cohesion strength was studied using comparative blast erosion tests. It is difficult to control the open porosity of stainless steel coatings by changing the spray conditions. Instead, open porosity was affected by powder particle size. Also, these porous coatings were as strong as a stainless steel plate based on the results of the blast erosion test. For tungsten powder, it was difficult to change the porosity of the coating significantly by controlling powder size; however, the coating porosity was altered by varying the argon chamber pressure under LPPS conditions. Titanium powder was used to make a porous coating with the aim of using it for implant applications. Usually it is necessary to have an open pore size of approximately 250 μm and over 40% open porosity to allow bone ingrowth into the coating. In this case, 350 μm titanium powder is necessary; however the test results indicate a low coating strength. Therefore, a spray mix of 300 μm and fine (30 to 70 μm) powder at mix ratios from 10 to 50% was tested. The most suitable mixing ratio was 30%. High strength for implant applications can be obtained by post spray heat treatment of the specimens.

#78 Phase Transformation of Plasma Sprayed Zirconia-Yttria Coatings during Hydrothermal Aging

Keywords concentration, EPMA, phase transformation, yttria, Y_2O_3, zirconia

K. Yasuda, S. Suenaga, K. Wada, S. Arai, M. Itoh, and H. Takedu
Toshiba Corporation

Tetragonal to monoclinic phase transformation during hydrothermal aging has been studied for plasma sprayed 8wt% Y_2O_3 stabilized zirconia coatings. The transformation occurred in the area of the coatings where Y_2O_3 concentration was less than the critical concentration, that is, 6.5 wt%. Controlling Y_2O_3 distribution is, therefore, critical for fabrication of coatings with superior chemical durability.

ASM INTERNATIONAL®
The Materials Information Society

SEPTEMBER 1996

VOL. 5: NO. 3

JOURNAL OF

THERMAL SPRAY TECHNOLOGY

INSIDE:

Corrosion Fatigue Behavior of a Steel with Sprayed Coatings

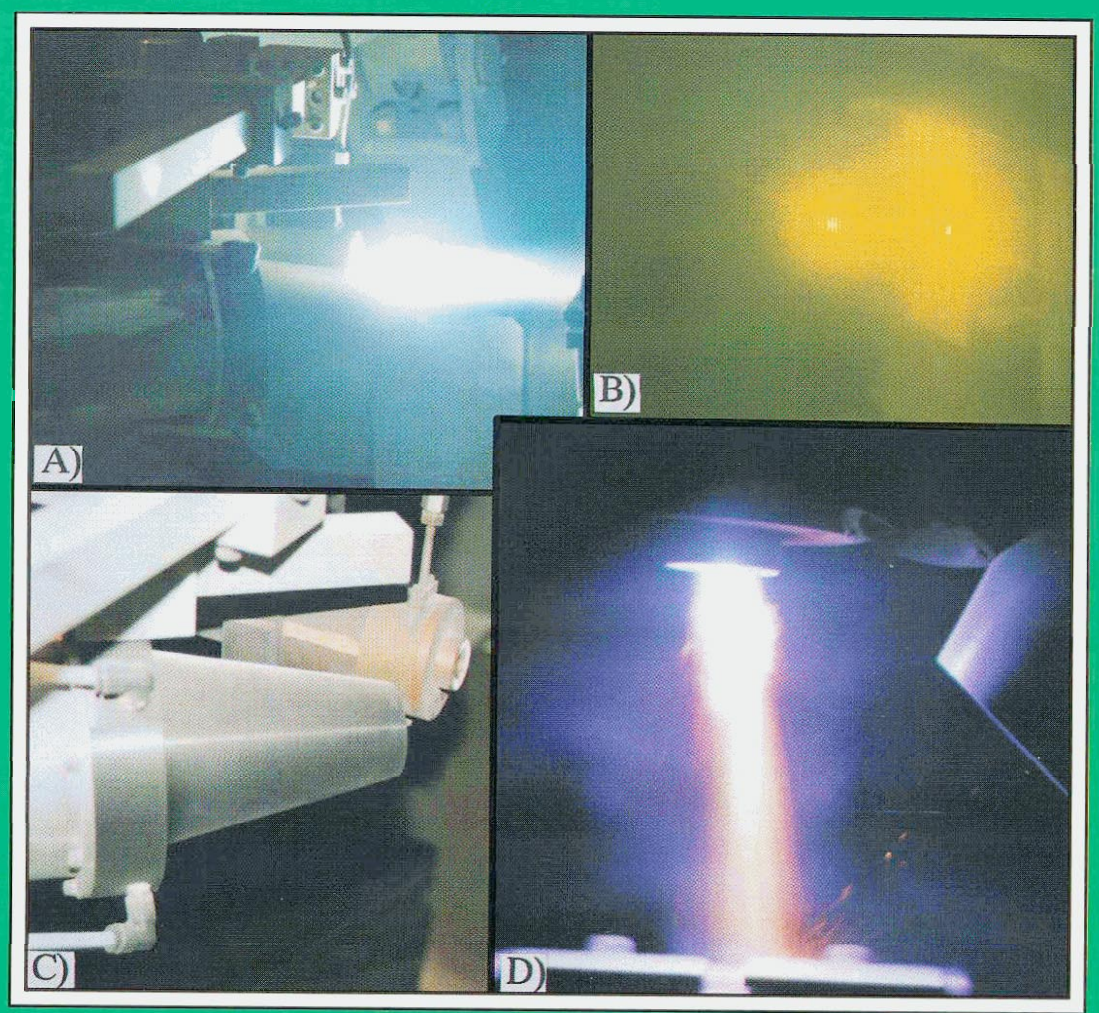
Yttria-Stabilized Zirconia Coating

Plasma Sprayed Fe-17Cr-38Mo-4C Amorphous Coatings

Influence of Powder Characteristics on Hydroxyapatite Coatings

Technology of Thermally Sprayed Anilox Rolls

and much more!



Christopher C. Berndt, Editor-in-Chief
Akira Ohmori, Guest Editor