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Commentary

The Current Status of Thermal Spraying in Asia

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The Asian Thermal Spray Conference (ATSC) has been organized for the exchange of information on the engineering and scientific aspects of thermal spraying in Asia. A report from the first conference, held in Nagoya, Japan, in November 2005, was given in *JTST* 15(1), March 2006, p 2-3. ATSC-2006 was held in Gyeongju, Korea, in November 2006. A report on the second conference was given in *JTST* 16(1) March 2007, p 18, with a preface authored by Chairperson Dr. Hwang.

In planning for ATSC-2006 in Korea, I received a request from the Korean Executive Committee to review the history, current status, and future prospects of the thermal spray industry in Japan as a keynote lecture at ATSC-2006. I asked Dr. Tani at Tocalo Co. Ltd., a well-qualified leading thermal spray company in Japan, to give this lecture. Corporate thermal spray research, development, and application in Asia are on a level equivalent to academic and government research laboratory work.

In addition to Japan, many other Asian countries have great potential in the thermal spray field. I proposed an idea to the representatives from each country to review the current status of thermal spraying in their country at ATSC-2006. In particular, China is currently undergoing a significant transition and is holding the Olympic Games (Beijing, 2008) and the next International Exposition (Shanghai World Expo 2010).

By such a process, the current status of thermal spraying in Asian countries was presented at ATSC-2006. These lectures were well done and won a favorable reception from the conference participants. In order to share this information with a broader audience, I proposed that this information be included in *JTST*. I thank the people of the *JTST* editorial committee who supported this plan.

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Status of Thermal Spraying in Korea

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Thermal spraying in Korea began about 40 years ago during an industrialization period in the 1970s. A few small companies started spraying zinc and aluminum during this initial industrialization period. Major developments in thermal spraying technology were initiated by companies related to aerospace and steel production in 1980s. Korean Air started flame spraying for commercial airplane repair. Samsung Aerospace Company (now Sermatech Korea) started OEM coating for military aircraft related repair and maintenance. Union Carbide Coating Service (now Praxair Surface Technologies) and Daeshin Metallizing Company initiated industrial applications of thermal spraying such as hearth roll coatings.

During a growth period in the 1990s, numerous new thermal spraying companies were established related to steel industries, textile industries, paper industries, and power generation plants. Saewon Hardfacing Company, New-Tech Company, and Shinwha Metal Company were the new companies founded during this time. Also, a number of information technology (IT)-related thermal spraying companies, such as KoMiKo, Entropy, and so forth, were founded. Taekwang Tech Company is currently marketing cold spraying equipment with a powder heating unit. The general thermal spray market increase has been steady, except that IT-related items have increased during the past five years. Aerospace applications in Korea have not grown because only a few companies have been involved, and growth of thermal spraying in these companies has not been significant.

As an organization of thermal spraying, the Korea Thermal Spray Society (KOTSS) was founded in 1995 by people who were interested in academic and industrial applications of thermal spraying. About 150 members have been involved in this society. Major activities have centered on workshop periods, which usually are held during spring and fall. The first thermal spray workshop was held in 1995. Since then, a number of presentations of academic and industrial applications have been made during the workshops. These workshops have provided a unique environment for professors, researchers, and engineers to converse. Recently, the 22nd Thermal Spray Workshop was held in Gangrung, in June 2006. Usually, two thermal spray workshops are held every year except for years when ITSC is held in Asia. As an international collaboration with Japan, the first joint conference between Korea and Japan was held in Osaka in 1997 as a full-day conference. Later, ATSC (Asian Thermal Spray Conference) 2006 was held in November 2006, in Korea with participants from Korea, Japan, China, Singapore, and the United States. The first ATSC conference was held in Nagoya, Japan, in 2005.

Since the 1990s, active research on thermal spraying has been performed at the Research Institute of Industrial Science and Technology (RIST). The research topics at RIST have been: the development of coatings for steel plants such as hearth roll coatings and sink roll coatings; nanostructured thermal-sprayed coatings such as nano-WC coatings; rapid tooling by arc thermal spraying; and cold spraying of copper, aluminum-silicon, aluminum-tin, and metal-diamond composites.

At Hanyang University, various thermal spray studies have been performed using plasma spraying, cold spraying, and high-velocity oxyfuel (HVOF). Academic research has been performed on the scientific background of cold spraying such as materials design and manufacturing, gas dynamics, in-flight particle behaviors, impacting phenomena, macro/microcoating structures, and characterizations of coating properties. Also, researchers have been involved in the development of cold-sprayed coatings for condensers in automobiles (Al-Si, Zn), heat sinks of electric devices, and abrasive wheels. In addition, solid lubricant nanocoatings for foil-air bearings and porous anode layers for solid oxide fuel cell have been developed.

The Korea Institute of Science and Technology (KIST) is currently engaged in thermal spray research. Recent thermal spray research topics have included nanostructured thermal spray powders, spraying forming of wear-resistant, high Young's modulus Al alloy, magnetic coatings, electromagnetic shielding coatings, coatings for the semiconductor industry, and biomaterials.

Thermal spray research is also conducted at Chungnam National University. Recent research has shown various fundamental results for thermal spray coatings such as nanostructured coatings, coatings for electrostatic chucks, rapid tooling, coatings for nuclear fuel, and plasma spray forming for armor applications.

Most thermal spray equipment and supplies are imported from abroad. The major thermal spray equipment and material suppliers in Korea are IWS (Sulzer Metco), Eutectic Korea (Eutectic Castolin), Praxair Surface Technologies, and Bayer Korea (H.C. Starck). Currently, some coating equipments are imported from China.

There are more than 40 thermal spraying companies in Korea. A few spraying companies that provided information about their companies to me before the conference were Daeshin Metallizing Company, Sermatech Korea, Shinhwa Metal Company, Hankook Coating, Cosmos Metallizing Company, Entropy, KIC, and Taekwang Tech Company. Most of the companies are involved in flame, plasma, and HVOF spraying. Their extensive experience in special plants, such as steel plants and semiconductor plants, has led to a significant improvement in the quality of their products.

In my opinion, the following are growth areas of thermal spraying in Korea as a result of market growth information and recent R&D efforts in these areas:

- IT-related components—Y_2O_3, Al_2O_3, etc.
- Nanostructured coatings
- Cold spray coatings
- Electromagnetic shielding (EMS) coatings
- Gas turbine—licensed coatings
- Steel plant—highly functional coatings
- Power plants—boiler coatings, etc.

The Current State of Thermal Spray Activities in China

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General Thermal Spray Market State. It is well known that in the last three decades China's economy has experienced sustainable fast growth at an average annual growth rate of about 10%. Such fast growth has led to many industries in China to become worldwide top producers, for example the steelmaking and the energy industries. Such fast growth has provided the opportunity for China's thermal spray industry to grow the fastest worldwide. The statistical data from the China Surface Engineering Association show that the total output of the thermal spray industry in China increased from about 1.2 billion RMB (US $0.14 billion) in 2002 to 2.1 billion RMB (US $0.24 billion) in 2005 (Ref 1). This amounts to an annual growth rate of about 20%, which is significantly higher than the growth rate of 6.1% in North America (Ref 2). However, the thermal spray industry output in China is only 4% and 20% of the thermal spray markets of North American and Japan, respectively. On the other hand, the ratio of Chinese thermal spray industry output to the country's GDP is about 0.56:10,000, which is much less than the ratio of 3.6:10,000 in the United States. These data indicate that the potential for growth of the thermal spray market in China is large. This potential attracts many foreign companies involved in thermal spray to invest in China through establishing joint ventures and branches.

Current Thermal Spray Applications. The thermal spray industry in China includes all aspects of the field such as feedstock materials production, spray system manufacturing, and job shop contracts. Thermal spray technology has been applied to different industrial fields including steelmaking, textiles, paper and pulp, energy, petroleum and chemicals, aeronautics, and others (Fig. 1).

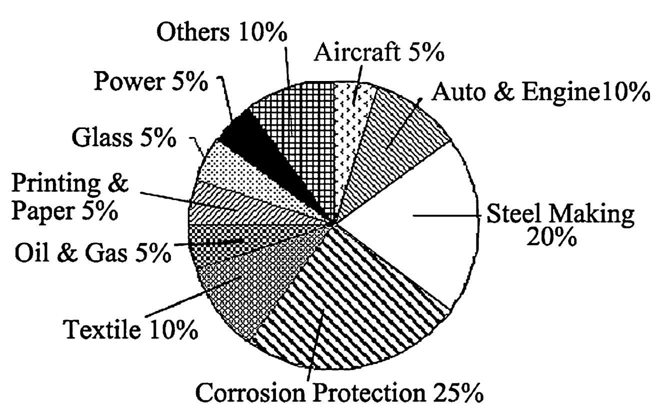

Fig. 1 Estimated share of different thermal spray application fields in China. Source: Ref 1

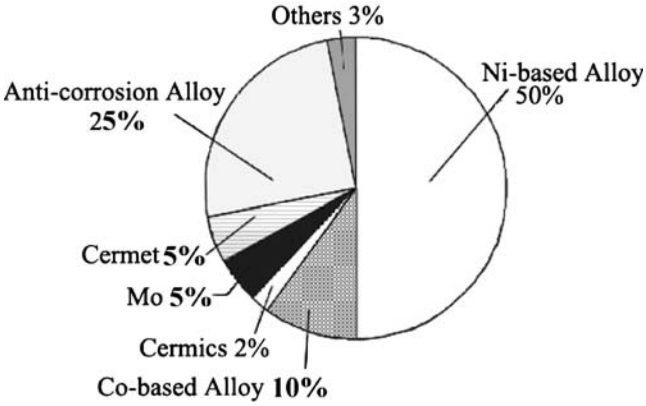

Fig. 2 Chinese thermal spray feedstock production market share distribution. Source: Ref 1

The feedstock producers can provide various kinds of spray materials including different powders of metal alloy, ceramics, cermets, and wires. As shown in Fig. 2, more than 85% of feedstock material production in China is metal alloys. Among those metal alloys, nickel-base alloys, which are widely employed through the spray-fusing process, constitute half of the materials market, and aluminum, zinc, and iron-base alloys for corrosion protection constitute an additional one-fourth of the market. On the other hand, the production output of highly value-added materials such as ceramics, cermets, and superalloys is much more limited. These high-grade materials are primarily imported into China. Moreover, the relatively low cost of spray material feedstock produced in China makes Chinese feedstock producers competitive with outside suppliers.

In the area of application of coatings, flame spraying and spray fusing are still the most popular processes employed in China because of their low capital and running cost and flexibility of operation. Moreover, wide application of the spray fusing process is attributed to its easy fulfillment of coating adhesion requirements. Arc spraying is also widely employed because of its economic advantages when applied to corrosion protection and machine part repair.

The application of thermal spray coatings in the steel industry has been the fastest growing field in the last several years. The annual quantity of steel produced in China was more than 340 million tons in 2005, remaining the worldwide leader as it has been over the past 10 years. Corrosion protection of many large steel structures, such as bridges, steel architectures, and ships, expands the conventional applications of flame spraying and arc spraying. Moreover, high-quality steel products are required in the rapidly expanding automobile industry. The top priority is to improve the quality of steel production and processing equipment. The need for high-quality, cost-effective production of steel sheet, especially for car bodies, drives fast expansion of thermal spray applications. In particular, coating of processing rolls by HVOF, plasma spraying, spray fusing, and plasma-transferred arc overlaying welding are used.

The fast and continuous growth of the Chinese economy leads to the increased need for energy. The applications of thermal spray to the energy industry mainly include those for coal-fired power plants and hydroelectric power plants. The capacity of Chinese coal-fired power plants reached 4.84×10^8 kW by the end of 2006, comprising about 80% of national power generation. Wire arc spraying is used to coat boiler tubes to reduce hot corrosion and erosion. Hydroelectric power plant capacity reached 1.17×10^8 kW in 2005, becoming the largest in the world. It will be expanded greatly in the coming decade. Turbine blade erosion can be severe because of high sand content in rivers such as the Yangtze and Yellow caused by soil erosion. HVOF tungsten carbide (WC) cermet coatings are being field tested for the protection of blades from erosion. Moreover, the requirements for diverse, highly efficient power sources open new fields for thermal spray coating applications. The national program for development of gas turbine power generation systems and establishment of about 13 nuclear power plants provides the opportunities for not only thermal spray coating application industries but also R&D activities.

Applications of thermal spray technology to the aeronautics industry in China are mainly performed in five large job shops that share ~5% of the total thermal spray output in China. It is expected to expand at an annual rate greater than 30% including domestic and foreign job shop contracts. The national program to develop different types of aircraft will promote further fast expansion of R&D and thermal spraying applications in this field.

The statistical data show that Chinese applications of plasma spraying are only about 10% of the total thermal spray market compared with about 50% in developed countries. Although no public data are available, it is believed that the market share of HVOF has increased markedly in the last three years, surpassing the 6% figure shown in Fig. 3 based on 2003 data. These spray technology usage figures, compared with developed countries, imply the potential for growth in the thermal spray industry in China in the coming decade.

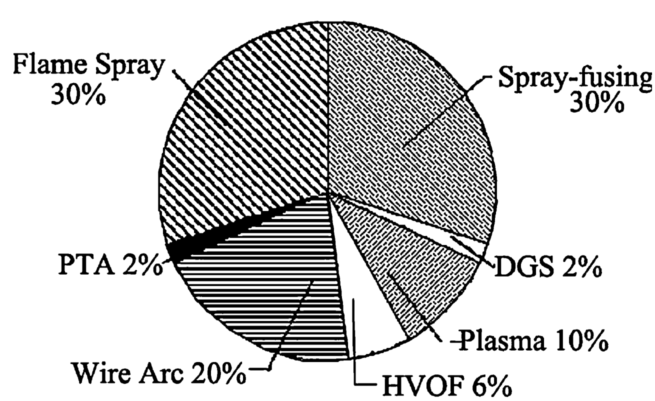

Fig. 3 Estimated share by different spray processes in China. Source: Ref 1

Current Thermal Spray R&D Activities. R&D activities on thermal spray coatings are carried out in many universities and national research institutions. These activities are mainly supported by government departments such as the National Natural Science Foundation of China (CNSF), the Ministry of Education (MOE), the Ministry of Defense (MOD), and the Ministry of Science and Technology. Most fundamental studies on thermal spray coating development are supported by the CNSF, which encourages researchers to carry out creative activities. Tables 1 and 2 show the articles published in Chinese journals and international journals, respectively, in the last several years. The processes involved in the articles published in Chinese journals reflect more application concerns than R&D activities. The processes associated with the papers published in the international journals reflect more the concerns of current R&D. The statistics of the articles show that plasma spraying is most widely employed for R&D, although the industry output of plasma spraying is only about 10%. The significant difference of the processes in Table 2 from Table 1 is that many articles in domestic journal are associated with arc spraying. This is due to the development of the arc spray process during the last decade by the introduction of the high-velocity arc spray concept similar to HVOF. Moreover, three requirements drive further growth of the arc spray process. One is the protection requirement of boiler tubes in many coal-fired power plants from corrosion and erosion. Second is the increasing concern of the remanufacturing industry with the 4R concept (reduce, reuse, recycle, and remanufacture) being a necessary strategy for the sustainable development of the country in the future.

Table 1 Articles published in Chinese journals involving applications and R&D of thermal spray coatings

Spray process	2002	2003	2004	2005	2006
Plasma spray	158	145	136	142	159
Arc spray	96	105	111	89	99
HVOF	20	14	22	36	33
Flame spray and others	47	46	57	77	79
Total	321	310	326	341	369

Note: Data summarized from the China Journal Data Base Net (www.cnki.net).

Table 2 Papers published in peer reviewed international journals in terms of spray process cited by the Scientific Citation Index Expanded

Spray process	2004	2005	2006
Plasma spray	66	91	71
Arc spray	2	3	4
HVOF	16	11	13
Cold spray	2	7	15
Flame spray and others	5	18	6
Total	92	129	112

Note: Data summarized from the database of ISI Science Citation Index Expanded (portal.isiknowledge.com).

Remanufacturing is usually performed by arc spraying as a cost-effective process. Third, the cost-effective rapid tooling of stamping dies for car body panels also promotes the application of arc spraying. The automobile industry is one of the fastest growing fields in China, and many local governments consider it to be a pillar industry.

Coating development activities, employing mostly plasma spraying, span a wide range of materials from traditional protective materials to those with added functions. Studies for the development of high-performance thermal barrier coating (TBCs) have been recently performed in many national institutes and universities. The functional coatings include different bioactive coatings (HA, Ti, etc.), photocatalytic coatings (TiO_2), electrolyte (YSZ), and catalytic coatings (LSM, YSZ-Ni) for the components used in solid oxide fuel cells (SOFCs) and dye-sensitized solar cells. Moreover, nanostructured coating development is primarily focused on nanostructured cermets (e.g., WC-Co), nanoceramics (e.g., YSZ, Al_2O_3-TiO_2, TiO_2), and nanostructured nickel-base alloys. Additionally, cold spraying is emerging in the field of thermal spray R&D.

Many national research institutes and universities are involved in fundamental R&D on thermal spraying. The data cited by the ISI Scientific Citation Index show that both Shanghai Institute of Ceramics of the Chinese Academy of Science and Xian Jiaotong University published about 60 research papers in last three years. The institutes that published more than 10 papers in the last three years include Beijing University of Aeronautics & Astronautics, National Key Laboratory for Remanufacturing, Institute for Metal Research of the Chinese Academy of Science, Harbin Institute of Technology, and Shandong University. In addition, Guangzhou Research Institute of Non-ferrous Metals, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing General Research Institute of Mining & Metallurgy, and Beijing General Research Institute for Agricultural Machinery carry out different coating development activities.

Thermal Spray Associations. Because thermal spraying is typically a multidiscipline field from both academic fundamentals and applications, many academic societies and industrial associations in China are involved in the organization of thermal spray activities. The main associations include the Thermal Spray Committee of the China Surface Engineering Association, China Thermal Spray Association, Surface Engineering Society of China Mechanical Engineering Society, Surface Engineering Committee of China Welding Society corresponding to the IC committee of IIW, and the ISO/TC 107 CSBTS/TC57 Thermal Spray committee. These associations organize various symposia and seminars on thermal spraying in China and make contact with international counterparts for the exchange of information. Both the Thermal Spray Committee of China Surface Engineering Association and the Thermal Spray Association participate in organizing the annual national thermal spray symposium. The Surface Engineering Society of China Mechanical Engineering Society organizes international and national conferences on surface engineering (in which thermal spraying is one of the topics) once each every two years. Moreover, the Surface Engineering Committee of the China Welding Society also organizes a domestic thermal spray seminar every year. ISO/TC 107-CSBTS/TC57 Thermal Spray committee is responsible for the organization and establishment of technical standards for thermal spraying technology.

Conclusion. The current state of the thermal spray industry and R&D activities in China is briefly introduced. The applications of thermal spray technology are expanding quickly to different industrial fields in China. The flame and arc spray processes are most widely employed for applications. Of the thermal spray feedstock material produced in China, approximately 85% is metal alloy. High value-added feedstock materials are primarily imported. Advanced coatings and processes such as plasma spraying are currently limited in application use, although plasma spraying is frequently used in R&D activities. Therefore, cooperation between industry and research institutes should be enhanced for promotion of high value-added processes and coatings.

References

1. X.O. Huang, The Current Situation and Future of Thermal Spraying Industry in China, *Sixth International Thermal Spraying Seminar and Seventh China National Thermal Spray Conference Proceedings*, 2003, p 256.
2. J.R. Davis, *Handbook of Thermal Spray Technology*, ASM International, Materials Park, OH, 2004, p 8.

The Current Status of Thermal Spray in Japan

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To date, a solid comprehensive overview of the thermal spray industry in Japan has not been undertaken. Almost no government statistics exist for this industrial segment, and there are only a few private research reports available. This is surprising, given the utilization of thermal spray technologies in Japan in the steel industry, industrial machinery, energy, steel structure corrosion protection, automotive industry, aero engine parts, and R&D. Table 1 summarizes the representative relationships among Japanese industry segments, components coated, coating type, and performance.

Steel Industry. The primary thermal spraying technologies used in the Japanese steel industry are plasma and high-velocity oxyfuel (HVOF) spraying for coating steel sheet processing rolls. These technologies produce spray coatings characterized by excellent wear resistance, nonadhesion or buildup performance, corrosion resistance, gripping properties, and thermal shock resistance. These spray technologies result in the surface modification of steel sheet processing or conveying rolls. An example of roll coatings is a proprietary WC-12Co HVOF coating applied to rolls in a continuous galvanizing line. These rolls are thermal spray coated to maintain the initial surface quality while conveying steel sheet in the molten zinc environment.

Currently, because of increasing productivity demand and higher client quality expectations, thermal spray applications in the steel industry are expected to increase. For example, for the production of surface-treated steel sheet, the following technologies are in high demand: (1) anti-buildup sprayed coatings for hearth rolls in continuous annealing lines that process high tensile strength steel sheet, (2) coatings supporting the service life enhancement for parts used in the molten metal bath in continuous galvanizing lines, and (3) technology to decrease the need for expensive or rare metals.

Semiconductors and LCDs. One step in the integrated circuit manufacturing process is plasma dry etching of silicon wafers between two electrodes (Fig. 1). The lower electrode, or electrostatic chuck, is coated with a plasma-sprayed oxide coating to provide electrical insulation, a contaminant-free, precision morphology finished

Table 1 Relationship among the Japanese industry segments, coating types, performance, and effects

Segment	Members	Type of coating	Performance/Effect
Steel industry	Hearth roll in CAL, pot roll in CGL	APS MCrAlY, oxide, WC, Cr_3C_2 cermet	Nonadhesion/wear resistance
Semiconductor and LCD	Electrostatic chuck, parts in dry plasma etching chamber	APS alumina or yttria, APS or arc-sprayed alloy	Electrical insulation, plasma resistance
Energy	Gas turbine hot parts, heat exchanger tubes in boiler, cell container for NaS battery	APS/LPPS MCrAlY/YSZ, APS NiCr alloy, Cr_3C_2 cermet	High-temperature corrosion resistance
Industrial machinery	Sliding/rolling member	HVOF WC cermet	Wear resistance
Construction	Offshore/elevated highway/bridge/transmission line tower steel structure	Flame/arc Al alloy	Cathodic protection
Petrochemical	Distillation tower steel structure	APS/arc NiCr, FeCr alloy	Environmental barrier
Plastic and film	Die/drawing roll	APS oxide, HVOF WC cermet	Nonadhesion, wear resistance
Ceramics	Float plate glass furnace roll, firing tray	APS oxide	Nonadhesion, wear resistance
Paper	Yankee dryer roll, press center roll	Flame/arc Fe-Cr alloy, APS Al_2O_3/TiO_2	Nonadhesion, wear resistance
Aviation	Gas turbine hot parts	APS/LPPS MCrAlY/YSZ	High-temperature corrosion resistance
Automotive	Engine member, die, sensor	APS oxide, alloy, WC, Cr_3C_2 cermet	Tribology, wear resistance, sensing

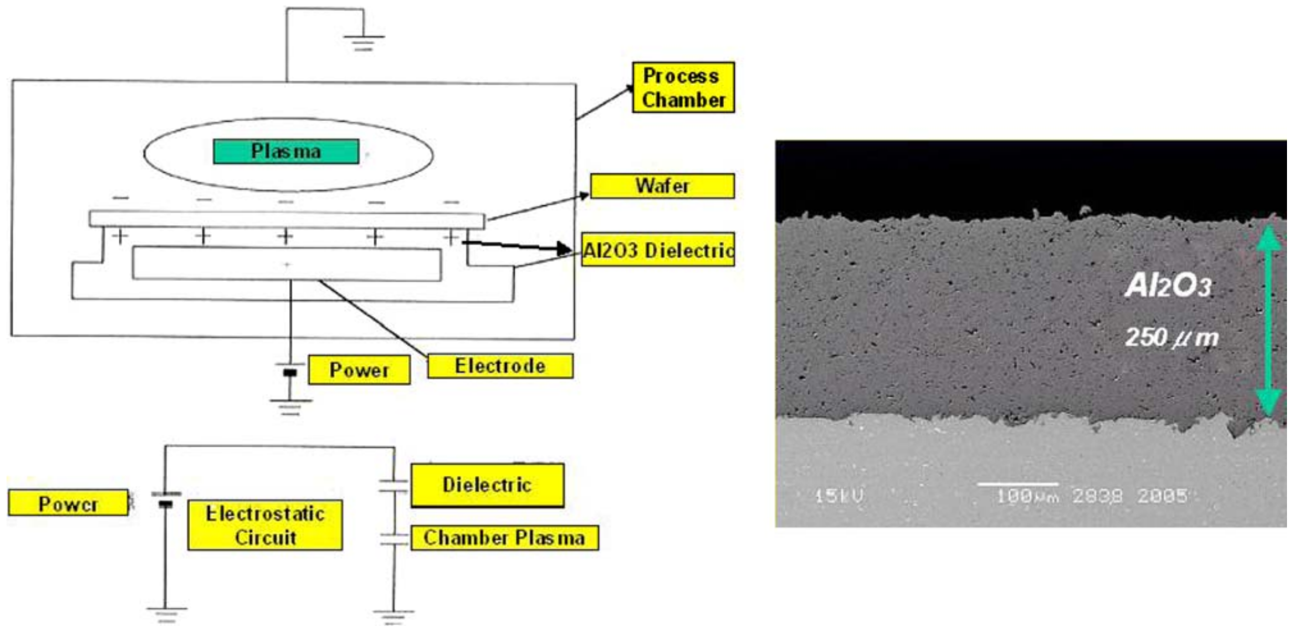

Fig. 1 Section of etching processing chamber of 300 mm diam silicon wafer and plasma-sprayed pure Al_2O_3 coating. Source: Ref 1

surface, and resistance against the low-temperature halogen plasma. The silicon wafer is held to the chuck by Coulomb force. Figure 4 also shows a cross section of a plasma-sprayed Al_2O_3 coating used on an electrostatic chuck. Chucks made of plasma-sprayed alumina aluminum alloy are also used in the industry. The flat surface of the plasma-sprayed alumina electrostatic chuck is produced by a diamond grinding. Color thin-film transistor (TFT) arrays for liquid crystal monitors and televisions are produced on a glass substrate in the same kind of etching chamber (using plasma-sprayed coatings) as that used for silicon wafers. In the semiconductor and LCD fields, future challenges involving thermal spray technologies include the following examples: the inventions of coatings applicable to the microfabrication of electronic devices involving new stacking morphologies for sprayed coatings, corrosion-resistant coatings for fluoride environments, coatings required for the production of mechanochemical properties of components used in plasma etching chambers, and the development of precision finishing technologies for thermal-sprayed coatings.

Energy. HVOF and plasma spraying are used to produce protective coatings for boiler tubes in power generation plants. The water-cooled tubes and superheater tubes are coated with Ni-50Cr alloy or carbide cermet coatings. Coatings are useful for high-temperature corrosion resistance (against vanadium salt or sulfate compounds) and environmental barrier performance and also allow on-site application. These performance enhancements contribute positively to the life-cycle enhancement of heat-exchange tubes. Figure 2 shows the corrosion-resistance effect of Ni-50Cr alloy plasma-sprayed coatings applied to superheater tubes (Ref 2). The upper photo shows an ''as-sprayed'' coating thickness of 800 mm. The lower left photo shows the coating after 20,000 h of operation. The photo on the right shows the same coating after 87,000 h of operation. Though the coating thickness has been reduced, it continues to protect the tube substrate as an environmental barrier coating. In the field of industrial machinery/energy, the future issues related to thermal spray technologies include: high corrosion-resistant coating enhancement, the design of sprayed coatings that leverage the interaction with the process environment, the development of innovative thermal barrier properties, effective formation of TGO for the undercoating required for high-temperature corrosion-resistant coatings, tough sintering/lower thermal conduction, environmental barrier properties, and coatings thinner than 100 mm characterized by lower fluid permeation.

Research. One of the methods of surveying research activity in any field is to review the publication of papers relevant to that field. Publications in the thermal spray field in the last 10 years are shown in Table 2. The publications are grouped into the five areas of thermal spray, materials, corrosion, welding, and others. Societies and their journals in these areas are also shown in Table 2. Only 11.3% of the papers referred to specific industrial case studies, suggesting that companies submitted few papers. Currently, 32 organizations are involved in publishing information about this field and a total of 306 papers were published in the past decade.

Market Size. The growth rate from 2004 to 2006 for the thermal spray industry is estimated to be more than 5%. Major contract coating job shop growth exceeded 15%. Thermal spraying output for fiscal 2004 for the three sectors of the Japanese market were: contract job shop productions—just under 40 billion Yen, in-house production by large enterprises—about 45 billion Yen, and

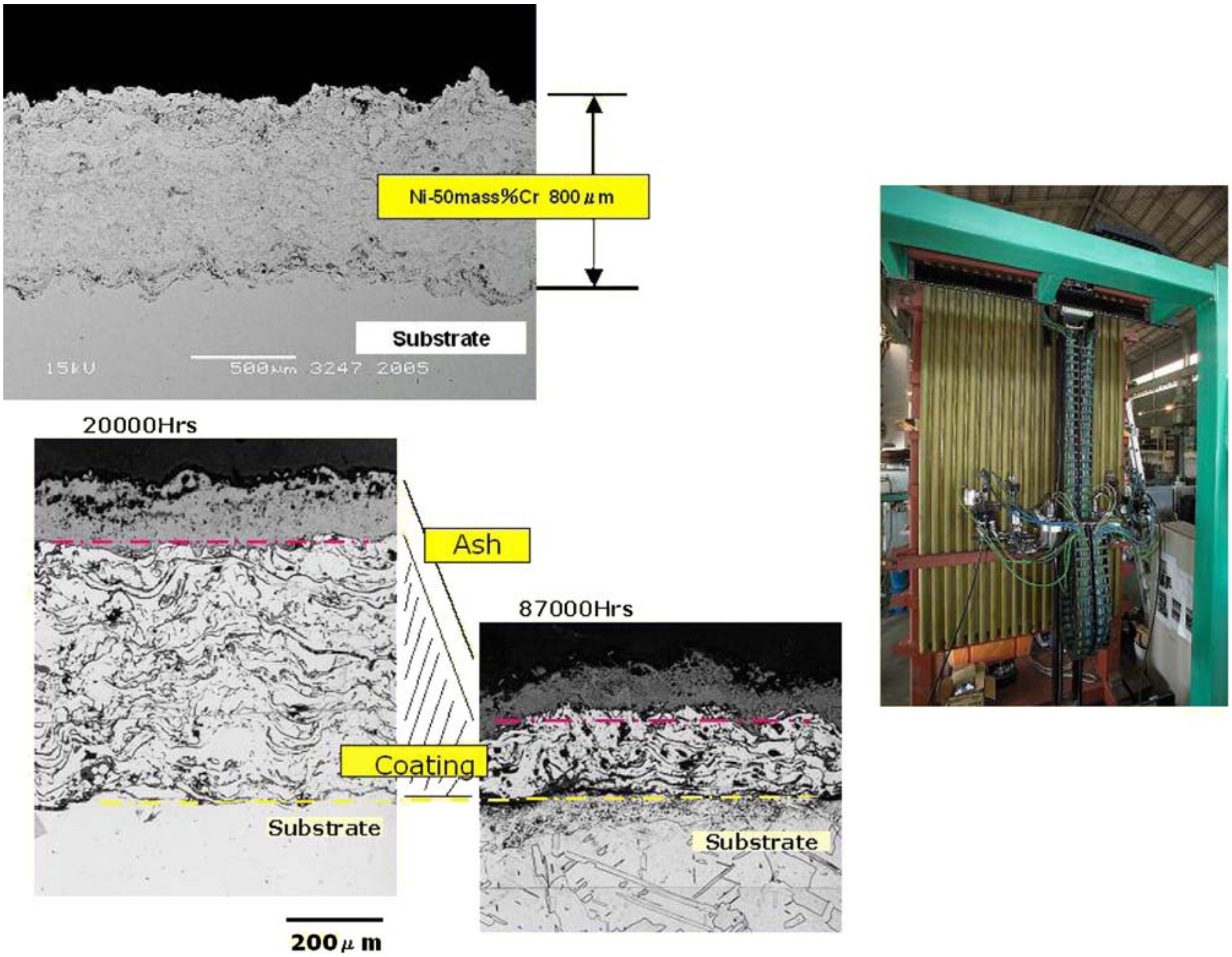

Fig. 2 Corrosion resistance of Ni-50mass%Cr alloy plasma-sprayed coatings applied to superheater tubes

Table 2 Relationship among various technical fields, major academic societies, journals, and number of original papers published in journals for the past decade

Segment	Society	Journal	Number of papers published
Thermal spray	Japan Thermal Spray Society	*J. Jpn. Thermal Spray Soc.*	89
	High Temperature Society of Japan/ Thermal Spray Division	*J. High Temp. Soc.*	66
Material	Japan Institute of Metals	*J. Jpn. Inst. Met.*	24
		Mater. Trans.	44
	The Society of Materials Science, Japan	*J. Soc. Mater. Sci, Jpn.*	45
	The Iron and Steel Institute of Japan	*Tetsu-To-Hagane*	2
		ISIJ International	3
Corrosion	Japan Society of Corrosion Engineering	*Zairyo-to-Kankyo*	7
Welding	Japan Welding Society	*Q. J. Jpn. Weld. Soc.*	26
Composition	Properties, characterization, and testing: 26%, applications: 11.3%, ceramic/TBC: 9.3%, pre/posttreatment: 7%, misc.: 46.4%		

consumables and spray equipment manufacturing—10 to 15 billion Yen. Total amount of Japanese thermal spray output in fiscal 2004 was estimated to be 95-100 billion Yen. According to a source in the United States, the entire thermal spray market in Japan for 2004 was estimated to be 0.8 billion U.S. dollars (Ref 3). The segmentation of

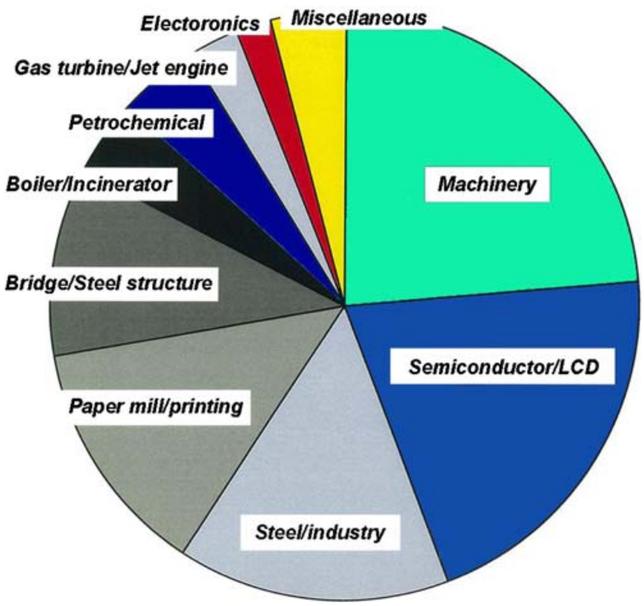

Fig. 3 Segmentation of application field/turnover of contract job shops in fiscal 2004

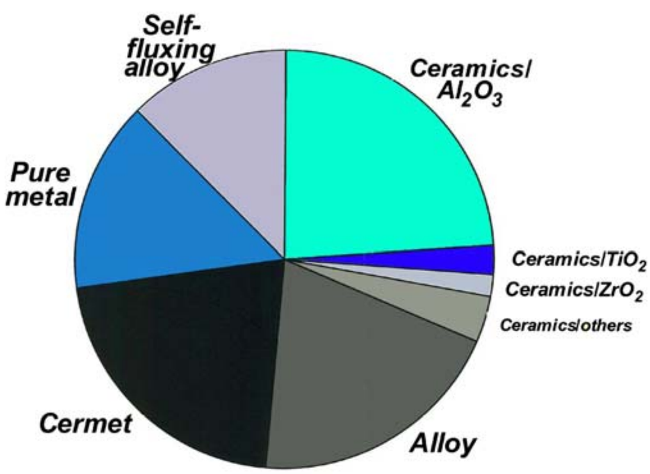

Fig. 4 Segmentation of spray material/turnover of contract job shops in fiscal 2004

application fields and materials for contract coating job shops in fiscal 2004 is shown in Fig. 3 (Ref 4). The growth rate in the semiconductor/LCD field is very high. Figure 4 shows the segmentation of spray material used (Ref 4). Spray process segmentation is shown in Fig. 5 (Ref 4).

Conclusions. The current situation and challenges for thermal spray technologies and the industries related to these technologies in Japan are summarized. According to the coating contract job shop turnover, the thermal spray industry market size is expanding at an annual rate of 5%. The development of new applications is an essential factor for further growth in this field.

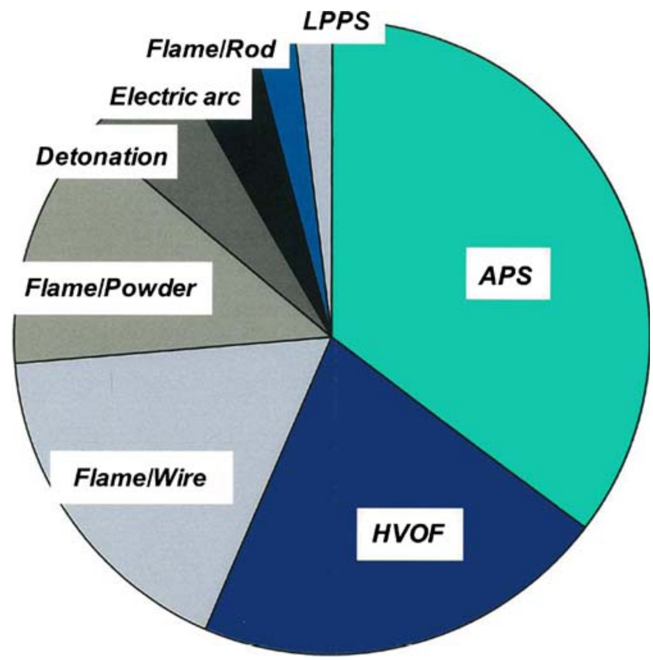

Fig. 5 Segmentation of spray process/turnover of contract job shops in fiscal 2004

References

1. T. Shimizu, Application to a Sputter Real Process of an Electrostatic Chuck, *J. Vac. Soc. Jpn.*, 2002, **45**(8), p 643-646.
2. K. Tani and Y. Harada, Enhancement of Service Life of Steam Generating Tubes in Oil-Fired Boiler for Power Generation Employing Plasma Spray Technology, *J. Thermal Spray Technol.*, 2007, **16**(1), p 111-117.
3. P. Hanneforth, *Int. Thermal Spray Surf. Eng.*, 2006, **1**(1), (2006), p 14-16.
4. Digital Research Institute Inc.: *Thermal Spray Industry Review in Japan, 2004*, (2004), Nagoya, Japan.

Thermal Spray Activities in Singapore

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Singapore took the top spot in the 2005 ranking in the Foreign Policy Globalization Index (A.T. Kearney). The key to this rise has been its proactive steps in several global engagements. For example, it boosted foreign trade by signing a bilateral free trade agreement with the United States in May 2003, the first such agreement the United States had signed with an Asian nation. More pertinent to thermal spray technology is Singapore's aspiration to be a "Global Hub" in aerospace and maritime industries. In addition, Singapore aims to be known not only for its top end manufacturing and excellent infrastructure, but also for endorsing a strong culture of innovation and entrepreneurship. In Jan 2006, the National Research Foundation (NRF) was formed to identify and invest in strategic areas of R&D. It coordinates the research of different agencies within the larger national framework to provide a coherent strategic overview and direction for the various research programs in the salient ministries. It will fund a balance of basic and applied research within strategic areas and provide resources and support to encourage private sector R&D. The strategic programs identified are: water and environmental technologies, interactive digital media, and biomedical science. There is also a Clean Energy Program.

Opportunities for growth in thermal spray in Singapore remain strong for aerospace, maritime, electronics, chemical, and power industries. For example, Singapore Technologies Engineering Ltd (ST Engineering) announced at the end of 2006 that its aerospace arm, Singapore Technologies Aerospace Ltd (ST Aerospace), has been awarded a US$635 million (approximately $1 billion Singapore) contract by Airbus to provide Total Aviation Support for a US airline. Processing of advanced materials such as composites or nanocomposites and development of nanocomposite coatings for improving the physical properties of a material are some objectives in the Aerospace Program of the Agency for Science, Technology, and Research (A*STAR) Science and Engineering Research Council (SERC). In maritime industries, there is continual demand for quality anticorrosion surface coatings. Thermal spray technology, as a chrome plating alternative, remains an active topic. The growing awareness, over the past decade, of the health, safety, and environmental hazards associated with chrome plating led to tightened regulation. Thermal spray processes such as HVOF can offer advantages in performance and long-term costs. For the defense industry, thermal spray coatings offer the advantage of weight reduction and alternatives for thermal management technologies. In environmental technologies, thermal spray-fabricated photocatalytic coatings remain an area that holds potential for commercial exploitation. This is particularly so as environmental technologies are gearing up as key research areas.

Thermal spray activities at Nanyang Technological University (NTU) remain centered on bioceramic coatings, with particular emphasis on synthesis of silicon-substituted hydroxyapatite (HA) by radiofrequency (RF) plasma, HVOF-sprayed nanostructured HA, and Taguchi design of experiments together with the analysis of variance (ANOVA) method for studying the effect of process parameters in plasma spraying of HA. The incorporation of silicate ions into the HA crystal lattice has been reported to improve its in vivo bioactivity, and silicon-substituted HA became an attractive alternative to conventional HA materials for use as bone substitute compacts. Silicate ion substitution was also reported to enhance the formation of a poorly crystalline surface apatite layer of HA after immersing in simulated body fluids (SBF). Co-spraying of SiO_2 and HA in a RF plasma has shown that there is simultaneous melting of each material that facilitates the formation of silicon-substituted HA. Subsequent consolidation by spark plasma sintering (SPS) demonstrated enhanced mechanical properties of the sintered products.

The Institute of Materials East Asia regularly organizes thermal spray short courses in Singapore as well as a regional meeting called Thermal Spray in Singapore (TSS). Attendees of these meetings are from Malaysia, Indonesia, and Thailand. There is also an Indo-ASEAN (Association of South East Asian Nations) Project on Thermal Sprayed Bioceramics and Thermal Barrier Coatings. Participants from ASEAN are from Singapore, Malaysia, and Thailand. Apart from the workshops and visits, this regional project will perform comparison of techniques used in thermal spray deposition of thermal barrier and bioceramic coatings as well as study the use of thermal spray feedstock produced from indigenous materials.

Thermal spray technology has much room for expansion and growth in the South East Asian region, and Singapore continues to play its role as a regional hub for the research and development of thermal spray applications pertinent to the needs of the industries in the region.