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Industrial and Research Activities in Thermal Spray Technology in the Nordic Region of Europe

Introduction

The Nordic countries comprise a region in Northern Europe consisting of Finland, Sweden, Norway, Denmark, Iceland, and their associated territories (in particular the Faroe Islands, Greenland, and Åland), see Fig. 1. In English usage, Scandinavia is a term that is generally regarded to be synonymous with the Nordic region, and both terms are frequently used interchangeably. The countries in the Nordic region are situated on the same latitude as Canada and, when combined, have almost the same number of inhabitants (the Nordic countries have a population of approximately 24 million), although the total land area is just 10% of that of Canada. Due largely to effect of the Gulf Stream, the Nordic Countries have four very distinct seasons, including warm summers and cold winters. The landscape is densely forested, and some areas are rich in petroleum and mineral resources. Mechanical engineering and high levels of general education are both traditional characteristics for this part of the world. In recent years, the electronics industry, particularly telecommunications industries such as Nokia and Ericsson, has been extremely important in the economic growth of both Finland and Sweden. The level of economic expansion in Norway has been strongly influenced by its offshore oil reserves. In addition to the telecommunications and oil industries, pulp and paper production have played a significant role for the economy in Finland, while the automotive and aerospace industries have had a similar function in Sweden.

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Thermal Spraying in Finland, Sweden, Norway, Denmark, and Iceland

Thermal spraying is used widely in many industrial sectors in the Nordic Countries. Important areas where thermal spraying is used are in the manufacture of products for the petroleum, paper, metals, transport, defense, and high-tech machinery industries. Thermal spraying is particularly important in Finland, Sweden, Norway, and Denmark. It is, however, still fairly limited in Iceland, and therefore will not be described to the same extent as is the case for the other countries. In Finland, thermal spray technology has wide areas of application in the pulp and paper industries. In Sweden, thermal spray technology is of great importance in the manufacture of aero engines and in industrial gas turbine applications. In Norway, thermal spraying is widely used in various offshore applications, including subsea oil drilling enterprises. Development and innovation in thermal spray technology in the Nordic countries is dominated by research conducted in Finland and Sweden, followed by Denmark and Norway. In particular, research groups from Sweden and Finland, as well as from Norway, have routinely presented their research results at international conferences and in international journals. In the following section, thermal spray activities in each of the Nordic Countries are presented in more detail. Some general information about each country, together with a description of industries using thermal spray applications, current research, education, and other activities is provided. Although the information presented here cannot be regarded as exhaustive, it does however provide a good overall picture of thermal spraying in the Nordic Countries and its relative importance in each.

Finland

Finland is a highly industrialized nation, and its key economic sectors are the manufacture of wood, metals, telecommunications, and electronics. Finland was first among the Nordic countries to join the European Economic and Monetary Union and is very active in promoting research and education. Finland's main export markets are Sweden, Germany, Russia, the United Kingdom, the United States, and the Netherlands. The main application areas for thermal spraying are in the pulp and paper industries, aero engine repair, energy generation, and mechanical engineering in general. It is noteworthy that the most widespread use of thermal spraying technology is in pulp and paper applications. This industrial sector in Finland has meant that the use of thermal spraying has become very important, and the number of companies, use of thermal spray materials, and indeed the level of international collaboration is greater in Finland than in any of the other Nordic Countries. Companies

Fig. 1 Map of the countries in the Nordic region of Europe

such as Metso Paper Inc. (a major paper machine manufacturer), Pikoteknik Oy (a subsidiary of Voith Paper), and AK-Tehdas Oy (part of the Vaahto Group) are the most important players in this industrial sector. Thermally sprayed coatings are used in various applications on the rolls and cylinders of paper machines. All of the major spray processes, from flame and arc spraying, to plasma, HVOF, and HVAF, are currently used, depending on the application and type of coating applied. Spraying of rolls and cylinders is carried out variously in workshops at the manufacturers, at designated service centers, or on-site in the paper factories themselves. Figure 2 presents typical thermal spray booths used for coatings of paper machine rolls, and Fig. 3 presents the coating of dryer cylinders on-site.

Coatings are used in several types of rolls and cylinders, including for instance, center press rolls, dryer cylinders, calender rolls, traction rolls, and yankee cylinders. Coating materials used are iron- and nickel-base alloys, carbides, oxide ceramics, and various multilayers, again depending on the application. Post-treatments, such as coating with fluoropolymers or sealing coatings against corrosive process environments, are also used. Figure 4 shows an example of one demanding product with a thermal sprayed roll cover. Such ceramic-coated center press rolls are, nowadays, used to replace conventional granite rolls. These coatings are application-specific and are tailored to perform optimally in various different types of paper production conditions. Factors such as wear and corrosion resistance, and the functionality of the roll surface in the paper manufacturing process, are key properties in these applications. Due to the size of the components (which are often very large) the production processes, including thermal spray processes, are often very specialized. Metso Paper is the world's leading manufacturer of products used in paper manufacture, both in Finland and elsewhere in their different production facilities around the world. Ceramic coatings are based on aluminum and chromium oxides with an underlying bond coat and corrosion barrier.

Other examples of products used are thermal spray coated dryer cylinders of paper machines and large yankee drying cylinders of tissue paper machines. These components are commonly coated on-site in the paper factory. Pikoteknik Oy has a worldwide reputation for coating dryer cylinders with various carbides. Flexible spray equipment technologies have been developed by the company especially for on-site coating operations. HVOF sprayed coatings are top-coated with a fluoropolymer layer to improve the release properties of the roll surfaces. Several other companies in Finland also use thermal spraying. Both Patria Aviation Oy and Finnair Oy use thermal spraying in gas turbine repair and maintenance for military and commercial aero engines, respectively. Companies using thermal spraying in various other applications are, for example, Telatek Oy (energy technology, mechanical engineering equipment), Virtasen Moottori Oy (various applications including valve parts), Kuopion Konepaja Oy (various applications), Fincoat Oy (various), and TTT Technology Oy (different mechanical processing equipment including that used in the timber industries). DiamondBlade Oy produces thermal spray coated coater blades for the paper industry. Research at Tampere University of Technology has led to the creation of two spin-off companies. One of these, Oseir Oy, is one of the few suppliers of thermal spray process monitors, whilst Millidyne Oy manufactures thermal spray powders based on ceramic materials (conventional and nanostructured materials) as well as various sealers for thermally sprayed coatings. Some of the industrial operators, e.g. Metso Paper Inc., Pikoteknik Oy, DiamondBlade Oy, Oseir Oy, and Millidyne Oy, are very active in conducting their own research and development.

Most of the primary and applied research into thermal spraying is conducted at Tampere University of Technology (TUT), The Institute of Materials Science (Tampere), and VTT Technical Research Centre of Finland (Espoo). In TUT, two professors head up various research projects related to thermal spraying, the size of their team comprising approximately 15 members. The laboratory at TUT is equipped with APS, HVOF, arc, wire flame, powder flame, polymer flame, cold spray, and suspension spray systems. Equipment for spray process diagnostics (SprayWatch), characterization of coatings (SEM, FEG-SEM, TEM, XRD, etc.), and evaluation of corrosion, wear, and other application-related properties are available. Laser surface engineering (cladding, hardening, alloying, remelting) is also studied at TUT's Laser Application Laboratory and in conjunction with TUT's strategic partner KETEK (Kokkola). Research at TUT is both applied and primary research. Industrial collaboration has been at the forefront of work carried out during the last 20 years. Recent research topics and projects include WC-Co(Cr) powders for HVOF using hardmetal scrap, structural ceramic nanocomposites for top-end functional applications, coatings for SOFC metallic

Fig. 2 Thermal spray booths for coating of paper machine rolls (AK-Tehdas Oy)

Fig. 3 HVOF spraying of paper machine dryer cylinders on-site (Pikoteknik Oy)

Fig. 4 Paper machine center press roll with a thermally sprayed ceramic coating (Metso Paper Inc.)

interconnects (in collaboration with VTT), properties of cold sprayed coatings, optimization of arc spray processes, corrosion and wear properties of thermal sprayed coatings used in pulp and paper manufacturing processes, surface properties of thermal sprayed coatings, spraying of catalytic coatings for electrowinning electrodes, suspension plasma/HVOF/flame spraying, laser-assisted hybrid coating processes, and so forth. A more detailed laboratory description was published in JTST (vol 13, issue 1). Industrial collaboration is done with companies in Finland as well as with foreign ones. TUT has wide network of collaboration with universities and institutes in other countries. TUT is the only thermal spray education and training organization in Finland (ETS). In total, 23 thermal sprayers have been certified by TUT.

VTT Technical Research Centre of Finland is a national impartial organization that carries out technical and techno-economic research and development work. Activities of thermal spraying at VTT are part of the knowledge center Advanced Materials (approx 60 people). VTT is equipped with different HVOF, arc spray, and flame spray systems combined with process quality related equipment including on-line diagnostics, and curvature measurement unit for in situ stress stage measurements. Main strategy of research work is related on development of tailored material solutions combined with process quality evaluation and coating structure design, that is, ''process mapping'' (in cooperation with The State University of New York at Stony Brook, USA). Powder development consists of agglomeration, mechanical milling, chemical synthesis, SHS, gas atomization, and air classification). Coating performance is determined together with different application-related research teams. Examples of research areas are nanostructured ceramic and hard metal composite coatings by HVOF, self-lubricated coatings, development of microwave absorber layers, coatings for solid oxide fells (in collaboration with TUT), protective coating systems for power plants, process quality evaluation and design of coating properties, and development of functional and adaptive surfaces.

TUT and VTT, in collaboration with several industrial companies have recently started a Thermal Spray Club in Finland. The aim is to spread precommercial information within the partners and to various end-users of thermal spray coatings and to improve the general image of thermal spraying in Finland.

Sweden

Sweden, or the Kingdom of Sweden to give it its correct title, is a highly industrialized export-oriented country. Timber, hydropower, and iron constitute its major resource bases. Sweden's engineering sector accounts for 50% of output and a similar percentage of its exports. Telecommunications, the pharmaceutical industry, and the automotive and aerospace industries are of very considerable importance. For thermal spraying, the aero engine, energy and defense industries have traditionally been and still are the main drivers of production and development. The main export markets are the United States, Germany, Norway, the United Kingdom, Denmark, Finland, and France. Aero engines and industrial gas turbines are important applications for thermal spraying, with the Volvo Aero Corporation and Siemens Turbomachinery being the two major industries in which such applications are used. Thermal barriers, abradable coatings, wear protection, and dimensional buildup coatings dominate this sector, where the aim is to improve gas turbine efficiency, reduce emissions, and increase quality and efficiency in the overhaul of commercial aero engines. This sector does not involve high volumes of parts, but rather short series of a range of different component types. This means that automation has its focus on quick shifts between thermal spray processes and material and part configuration in the same spray booth. Consequently, the development and use of advanced automated and robotized spray equipment with a focus on robust processes and advanced quality control tools (such as on-line sensors) is therefore a high priority. Figure 5 shows one of the world's most advanced computerized process control tools, which is used at the Volvo Aero Corporation. This tool interacts with a large database where data (including laboratory results from destructive testing) from the totality of spray occasions over the last 10 years is stored. Using statistical procedures, this tool enables each operator (both in production and in the laboratory) to obtain a

Fig. 5 Plasma spraying of gas turbine components at Volvo Aero Corp.

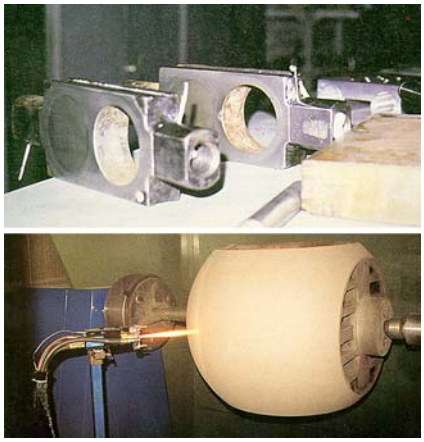

Fig. 6 Gate valves and a ball valve with HVOF sprayed carbide coatings (Bandak AS)

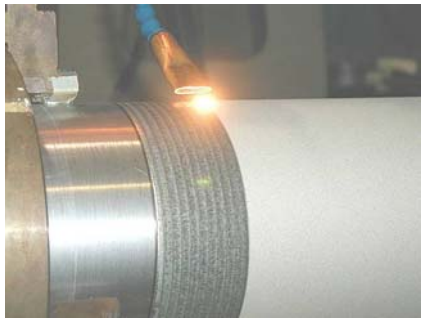

Fig. 7 Laser fusion of a thermally sprayed coating (Force Technology)

real-time control of current capabilities for each coating type. The cutting edge of high-tech thermal spraying in Sweden is found in the manufacture of components for the European Space program, with the thermal barrier on the nozzle extension of the Vulcain 2 rocket engine for the main cryogenic stage of the Ariane 5 as the most high profile application.

Within academia in Sweden, research into thermal spraying is primarily carried out at University West in Trollhättan, where the thermal spray team consists of nine researchers. The spray shop used in the team's research, which is located at the Volvo Aero Corporation in Trollhättan, is equipped with APS and powder flame spray systems. HVOF, arc, and wire flame are also available through the close collaboration that the team has established with Volvo Aero. In addition, laser surface engineering (mainly cladding and hardening) is studied by a separate team of eight researchers. The main objective of the research conducted by this team is to develop simulation and control models, as well as to study relationships between process parameters, coating microstructures, splat morphology, and mechanical properties. Examples of ongoing research projects include TOPPCOAT within the EU's Sixth Framework Program and the implementation of low-conductivity thermal barrier coating (TBC) systems in industrial production. Both these projects are aimed toward the implementation of new materials for thermal barrier systems. Another example of ongoing research is to explore properties of MAX-Phase materials, that is, functional nanolaminate metallo-ceramics that have applications in stationary turbines and are used as bonding layers to superalloys in TBC systems. Research on thermal spraying also focuses on the development of three-dimensional simulation models of flame spraying and plasma spraying with full coupling between the particles and chemically reactive gas flow. Recently, modeling of single and multiple splats has commenced, as well as the modeling of residual stresses in HVOF spraying. Several techniques are used to monitor properties of individual particles in-flight and to study particle flattening and cooling during impact. Advanced material characterization methods, such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and photoelectron spectrometry (XPS) are, in collaboration with Chalmers University in Gothenburg, also used, as well as energy-dispersive X-ray spectrometry (EDX), to obtain information on the chemical composition, crystallinity, and homogeneity of splats.

The Swedish Welding Commission has established a working group for thermal spraying that includes 25 company members and which meets twice a year. Not infrequently, interested parties from Denmark, Finland, and Norway are invited to join this group. Conferences are held regularly, such as, for example, the Nordic Conferences in Thermal Spraying, which are held every third year, the most recent being in Trollhättan, Sweden in September 2006. Education within thermal spray are provided by Sulzer Metco (HVOF, arc spraying, APS, FS), Castolin (FS, wire arc) and on-site at companies such as the training at VAC, which has its own certification levels. Postgraduate courses are provided at University West.

Norway

In Norway, while petroleum and petroleum-related products dominate the export market, other areas, such as machinery and equipment for the offshore industry, paper production, metals, chemicals, ship manufacture, and fishery products all form valuable export sectors. In the offshore industry, fish and other food-processing industries, as well as pulp and paper manufacture and hydro power plants, all require the use of thermal spraying for improved resistance against corrosion. Consequently, a significant body of knowledge and product capacity has been developed at the various spray workshops in Norway. Main export markets include the United Kingdom, Germany, the Netherlands, France, and Sweden.

Applications for thermal spraying in Norway are largely found in the offshore industry. Examples of companies using thermal spraying are, to name but a few, Scana Offshore Vestby AS, Trio AF Teknikk AS, Bandak AS, LHK Norwegian Defence Laboratories, Volvo Aero Norge, Grenland Beleggservice AS, and METS AS. Major processes in use are flame spraying, HVOF, arc spraying, and plasma spraying (aero applications). Scana Offshore Vestby AS is active in the repair and maintenance of offshore and subsea components. Examples of production are gate and ball valves for oil-drilling companies, both in Norway and internationally, and the spraying of switches for railways. Typical coating materials used are tungsten- and chromium-base carbides, self-fluxing alloys, and corrosion-resistant alloys. Bandak AS is also active in coating components for the offshore industry, such as water-injection pumps, wear parts, and valves. The LHK Norwegian Defence Laboratories are active in spraying aero engine parts used in military applications. METS AS has provided education for thermal spray operators in Norway.

The HVOF spray process is increasingly used in Norway to improve erosion and corrosion properties of gate and ball valves and pumps. Figure 6 shows HVOF coated gate and ball valves. One of the most common materials deposited in the HVOF process is WC-10Co-4Cr coating. This coating reduces fluid erosion, wear, and corrosion in harsh environments found in the offshore industry. When such coatings are used in corrosive media, the metallic binder should be homogeneous and compatible with the surrounding materials. This is of major importance for constructions where maintenance is difficult, such as, for example, in construction for oil and gas production, and for wells bored at great depths in the North Sea. Increased lifetimes for coated components will lead to improved safety conditions, fewer shutdowns, and greater reductions in maintenance costs. Although metal spray coatings have been used for many years on bridges, components, and in chimneys, it is only relatively recently that they also been used for offshore applications. Examples of platforms where arc sprayed aluminum has been specified include the Troll gas development for Norway. The metallic coatings deposited by thermal spraying are often combined with organic coatings on the top. In such applications, the metal is either zinc (Zn) or aluminum (Al) and is deposited by arc spraying. The metal provides cathodic protection while the organic coating on the top serves as an extra barrier.

Thermal spray research and development in Norway is conducted in institutions such as SINTEF and Norwegian University of Science and Technology (NTNU), both located in Trodheim, and in industries, such as LHK Norwegian Defence Laboratories. The team sizes are smaller compared with those in Finland or Sweden. An arc spray process is only available at NTNU, and thus the coatings for research and testing are often sprayed by the industrial partners. Examples of recent research topics at SINTEF include various coating studies and the post-treatment of coatings to reduce porosity. Other research activities include, for example, coating technology for cylinders used in deep water and harsh conditions, lubricant/surface treatment for system riser connections, and the replacement of electrolytic hard chromium by thermal spray coatings.

Education is provided by METS AS, and the programs that they offer have been approved by CEN and Standard Norge. About 15 operators have been certified in several spray processes and 150 in thermal spraying for corrosion protection. A forum for Surface and Coating Technology was established in 1995 and is supported by The Research Council of Norway and Norwegian industry. The forum has 16 members and holds two meetings per year.

Denmark

While agricultural products used to dominate the Danish export sector, industrial products now account for the majority of the country's export revenue. The principal export goods are industrial machinery and instruments, followed by chemical products and industrially processed agricultural products. The main export markets are Germany, Sweden, the United Kingdom, the United States, the Netherlands, Norway, and France. In Denmark, thermal spraying is used in boilers, in maritime diesel engines, and for wear-resistance coatings for machine and tool parts. A major application area is the shipyard industry where thermal spraying is used for diesel engines in industries such as MAN and B&W. Another area of application in Denmark is wear-resistant coatings for machine and tool parts. Thermal spraying is used in production, for example in Sintex, and in workshops such as Vestergaard Marin Service A/S. Major processes in use are flame spraying, plasma, arc, and HVOF spraying.

Primary research into thermal spraying is not currently conducted at any of the country's universities. However, The Force Technology Institute uses thermal spraying in certain production processes and conducts programs of applied research and development. Recently, studies on laser fusion of thermally sprayed coatings have been carried out in order to improve the bond strength, mechanical properties and non-porosity of coatings. Figure 7 shows the laser fusion of a thermally sprayed coating.

Iceland

It is apparent that the use of thermal spraying in Iceland is fairly limited compared with the other countries in the Nordic region of Europe. The application areas are mainly in repair and maintenance, especially in the fishing industry, where the aim is to reduce corrosion to components. Workshops using thermal spraying include, for example, Sandtak EHF and Zinkstödin Stekkur EHF. The authors are not aware of any current thermal

spray related research and development activities in Iceland.

Summary

Thermal spraying is used widely in many industrial sectors in the North European Countries: Finland, Sweden, Norway, and Denmark. Important areas where thermal spraying is used petroleum, paper, metals, transport, defense, and high-tech machinery industries. In Finland, thermal spray technology has widest use in the pulp and paper industries with several companies spraying various types of rolls and cylinders. In Sweden, thermal spray technology is of great importance in the manufacture of aero engines and in industrial gas turbine applications. In Norway, thermal spraying is widely used in various offshore applications, including subsea oil drilling enterprises. Development and innovation in thermal spray technology in the Nordic countries is dominated by research conducted in Finland and Sweden, followed by Denmark and Norway. In particular, research groups from Sweden and Finland, as well as from Norway, have routinely presented their research results at international conferences and in international journals.

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