oerlikon
metco

An Introduction to Thermal Spray

Issue 6 – July 2016

Contents

1 Introduction

In all sectors of industry today, the catch phrase “better, faster, cheaper” is common and valid, as it seems that production demands are ever-increasing. Highly demanding requirements and aggressive service conditions often lead to the premature loss of component or system function.

Shown in Figure 1a is a completely worn pelton turbine nozzle needle after some thousand hours of actual service. If this service life is deemed unacceptable, either the entire component must be made of a more wear resistant material, or the area where the wear occurs must be protected. For cost reasons, the usual decision is the latter. This leads to the use of surface coatings. Either the entire component can be coated or just the area prone to attack, whichever best fulfills the requirements.

1.1 Surface Properties

The necessary surface requirements for a component vary considerably depending on its service environment.

The range of surface requirements include sufficient protection against wear, corrosion resistance, thermal insulation, electrical insulation, and even improved aesthetic appearance.

In practice, it is quite rare that components are only exposed to a single service condition. Usually a combination is present; for example, abrasive wear combined with high thermal stress. Various types of wear and corrosion are the most frequent conditions the surface coating must withstand.

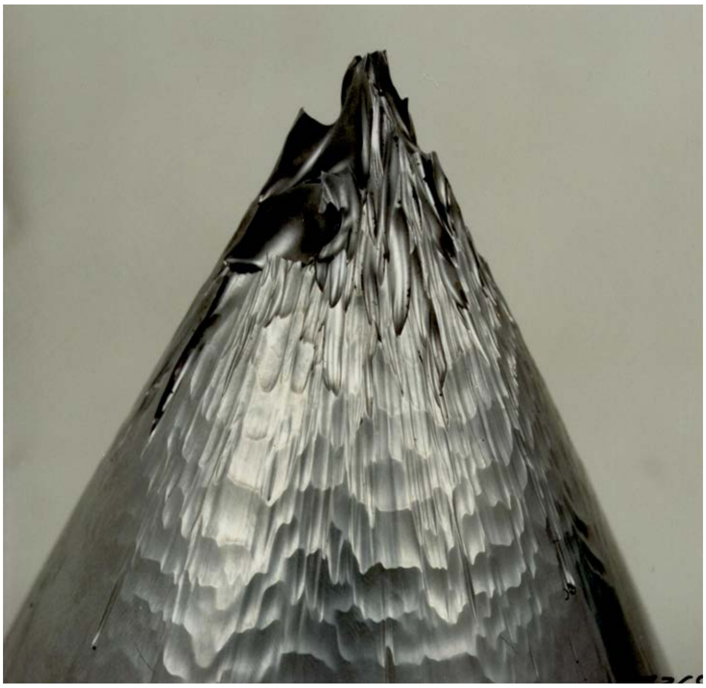

Figure 1a – Chrome plated, 13/4 steel pelton turbine nozzle needle after service.

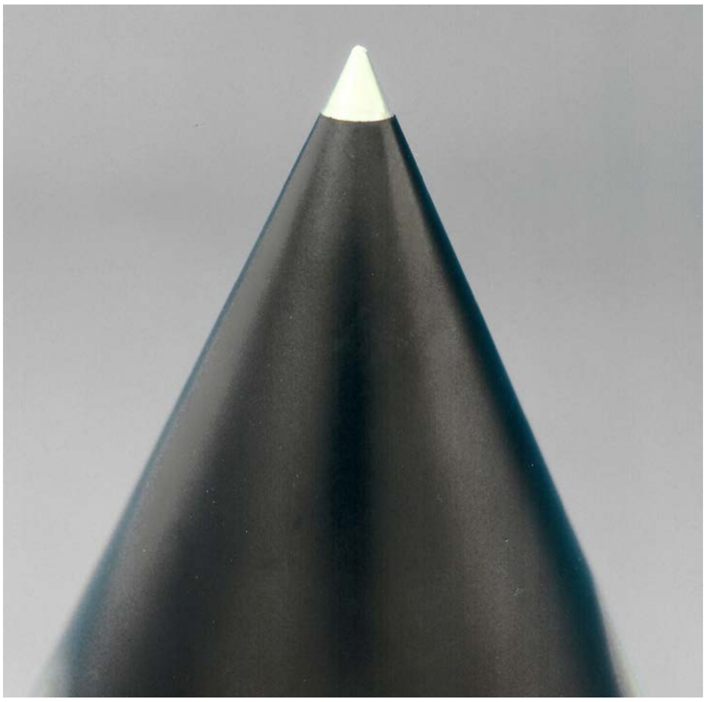

Figure 1b – Nozzle needle with a chrome oxide coating to prevent wear.

1.2 Coating processes

There are quite a number of processes to apply coatings, as well as a nearly unlimited number of coating materials. To select the correct combination for the respective application, the knowledge of specialists is usually required.

Table 1 lists principal coating processes, the typical coating thicknesses attainable, common coating materials, and sample applications. Some processes are not suitable for certain coating materials; also, the necessary coating thicknesses are not attainable with all methods. Beyond that, the equipment necessary for some processes can be quite complex and, therefore, costly. The use of cost analysis can determine whether a coating is a practical solution. Today's regulations require that ecological criteria of the respective coating processes must also be examined, as not all methods are environmentally equal.

Coating process	Typical coating thickness	Coating material	Characteristics	Examples
PVD	1 – 5 µm (40 – 200 µin)	Ti(C,N)	Wear resistance	Machine tools
CVD	1 – 50 µm (40 – 2000 µin)	SiC	Wear resistance	Fiber coatings
Baked polymers	1 – 10 µm (40 – 400 µin)	Polymers	Corrosion resistance, aesthetics	Automobile
Thermal spray	0.04 – 3 mm (0.0015 – 0.12 in)	Ceramics and metallic alloys	Wear resistance, corrosion resistance	Bearings
Hard chromium plate	10 – 100 µm (40 – 4000 µin)	Chrome	Wear resistance	Rolls
Weld overlay	0.5 – 5 mm (0.02 – 0.2 in)	Steel, stellite	Wear resistance	Valves
Galvanize	1 – 5 µm (40 – 200 µin)	Zinc	Corrosion resistance	Steel sheet
Braze overlay	10 – 100 µm (40 – 4000 µin)	Ni-Cr-B-Si alloys	Very hard, dense surface	Shafts

Table 1a – Principal coating processes and characteristics

The coating process having the greatest range of coating materials, coating thicknesses and possible coating characteristics is thermal spray.

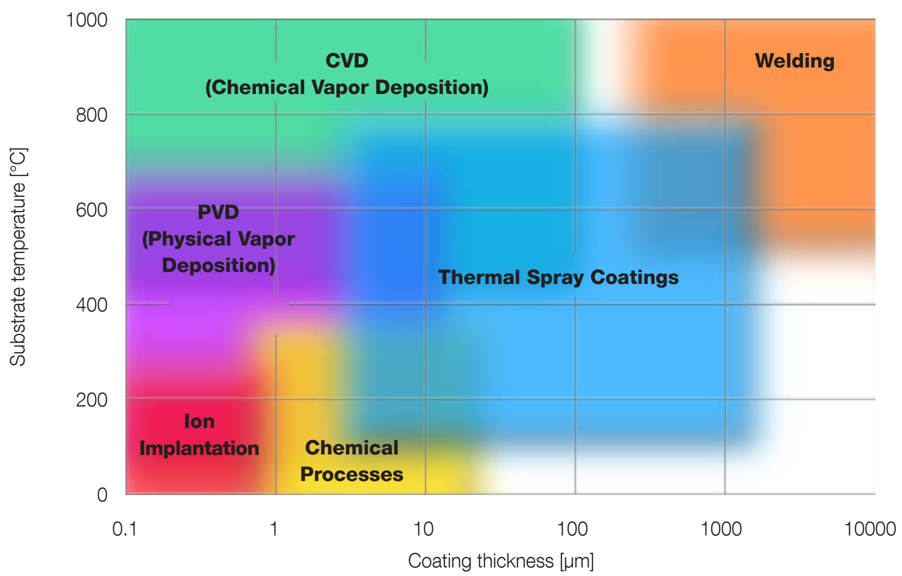

Table 1b – Coating process comparison

2 Thermal sprayed coatings

2.1 Definition

Thermal spray is defined as [1]* "…applying these coatings takes place by means of special devices/systems through which melted or molten spray material is propelled at high speed onto a cleaned and prepared component surface..." This definition does not sufficiently describe the thermal spray process.

Figure. 2 is a diagram showing the principle of thermal spray. The coating feedstock material is melted by a heat source. This liquid or molten material is then propelled by process gases and sprayed onto a base material, where it solidifies and forms a solid layer. The individual aspects of a thermal sprayed coating follows.

* Translated from German.

2.2 Substrate materials

Suitable substrate materials are those that can withstand blasting procedures to roughen the surface, generally having a surface hardness of about 55 HRC or lower. Special processing techniques are required to prepare substrates with higher hardnesses. Because the adhesion of the coating to the substrate predominantly consists of mechanical bonding, careful cleaning and pretreatment of the surface to be coated is extremely important.

After the removal of surface impurities by chemical or mechanical methods, the surface is usually roughened using a blasting procedure. This activates the surface by increasing the free surface energy and also offers the benefit of increased surface area for bonding of the sprayed particles.

The liquid or molten coating particles impact the surface at high speed. This causes the particles to deform and spread like "pancakes" on the substrate.

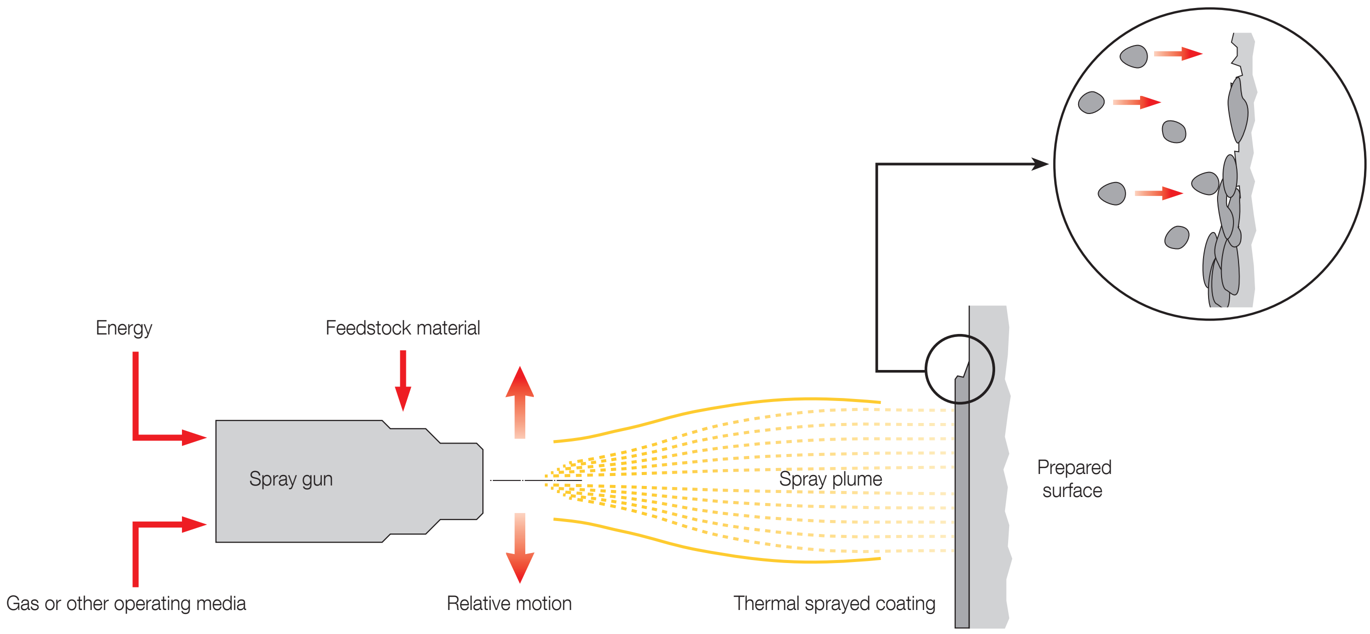

Figure 2 – Principle of thermal spraying

Heat from the hot particles is transferred to the cooler base material. As the particles shrink and solidify, they bond to the roughened base material. Adhesion of the coating is therefore based on mechanical "hooking". This procedure is represented schematically in Figures 2 and 3. The amount of metallurgical bond caused by diffusion between the coating particles and base material is small and can be neglected for discussions about bonding mechanisms (exception: Molybdenum).

Surface roughening usually takes place via grit blasting with dry corundum. In addition, other media, such as chilled iron, steel grit or SiC are used for some applications. Besides the type of grit, other important factors include particle size, particle shape, blast angle, pressure and purity of the grit media.

2.3 Coating material

In principle, any material that does not decompose as it is melted can be used as a thermal spray coating material. Depending on the thermal spray process, the coating material can be in wire or powder form.

In Table 2, some of the most frequently used classes of materials are listed, along with a typical example, characteristics and sample applications. Choosing a coating material that is suitable for a specific application requires special knowledge about the service environment as well as knowledge about the materials.

Apart from the physical characteristics, such as coefficient of expansion, density, heat conductivity and melting point, additional factors, such as particle shape, particle size distribution and manufacturing process of powder material (i.e., agglomerated, sintered, composited) will influence coating performance. As most spraying materials are available as alloys or blends, this leads to a nearly unlimited number of combination options, and only through many years of experience and broad know-how can a proper selection be made.

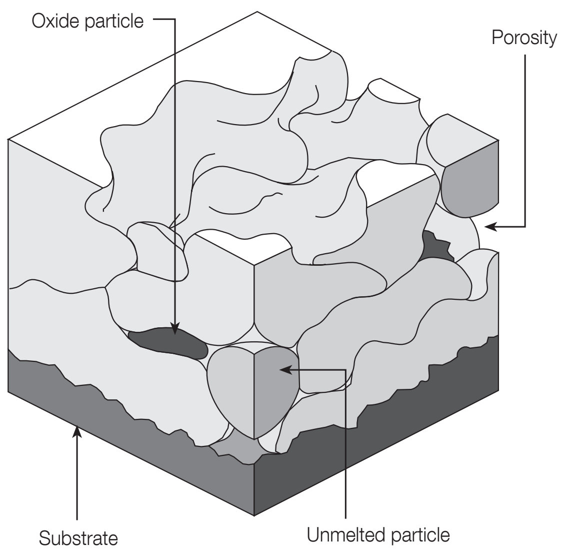

Figure 3 – Schematic diagram of a thermal sprayed coating

Material class	Example composition	Characteristics	Example application
Pure metals	Zn	Corrosion protection	Bridge construction
Self-fluxing alloys	FeNiBSi	High hardness, fused, minimal porosity	Shafts, bearings
Steel	Fe 13Cr	Economical, wear resistance	Repair
MCrAlY	NiCrAlY	High temperature, corrosion resistance	Gas turbine blades
Nickel-graphite	Ni 25C	Anti-fretting	Compressor inlet ducts
Oxides	Al_2O_3	Oxidation resistance, high hardness	Textile industry
Carbides	WC 12Co	Wear resistance	Shafts

Table 2 – Common classes of thermal spray powder materials

2.4 Thermal Spray coating processes

There are several different processes used to apply a thermal sprayed coating [2]. They are:

- Conventional flame spray,
- Electric arc wire spray,
  Plasma spray and
- High velocity oxy-fuel spray (HVOF).

2.4.1 Conventional flame spray process

2.4.1.1 Combustion wire spray

With the combustion wire spray process, the wire spray material is melted in a gaseous oxygen-fuel flame. The fuel gas can be acetylene, propane or hydrogen. The wire is fed concentrically into the flame, where it is melted and atomized by the addition of compressed air that also directs the melted material towards the workpiece surface.

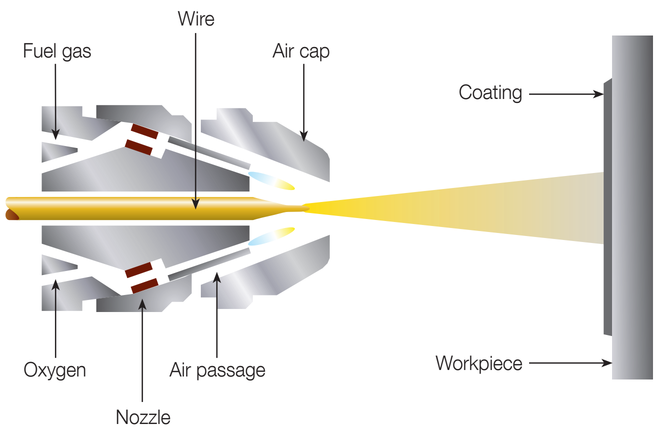

Figure 4a – Schematic diagram of the combustion wire spray process

2.4.1.2 Combustion powder spray

This coating process is based on the same operational principle as the wire flame spray process, with the difference that the coating material is a spray powder. Thus, a larger selection of spray materials is available, as not all spray materials can be manufactured in wire form.

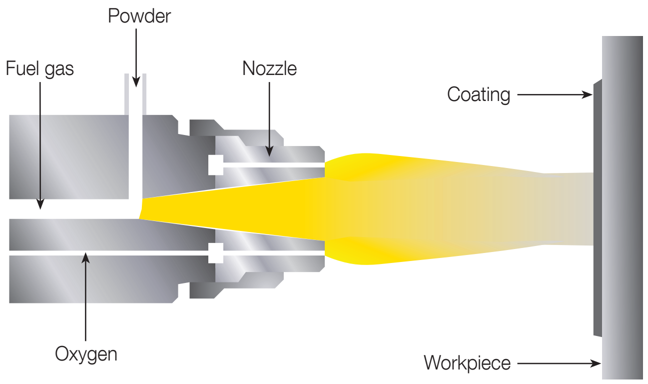

Figure 4b – Schematic diagram of the combustion powder spray process

2.4.2 Electric Arc Wire Spray

With electric arc wire spray, an arc is formed by contact of two oppositely charged metallic wires, usually of the same composition. This leads to melting at the tip of the wire material.

Air atomizes the melted spray material and accelerates onto the substrate. The rate of spray is adjusted by appropriate regulation of the wire feed as it is melted, so a constant arc can be maintained.

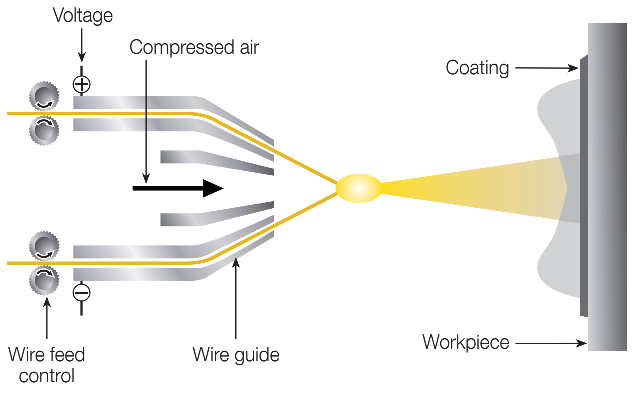

Figure 5 – Schematic diagram of the electric arc wire spray process

2.4.3 Plasma Spray

The principle of plasma spraying is shown schematically in Figure 6a. A high frequency arc is ignited between an anode and a tungsten cathode. The gas flowing through between the electrodes (i.e., He, H_2, N_2 or mixtures) is ionized such that a plasma plume several centimeters in length develops. The temperature within the plume can reach as high as 16000 K. The spray material is injected as a powder outside of the gun nozzle into the plasma plume, where it is melted, and hurled by the gas onto the substrate surface.

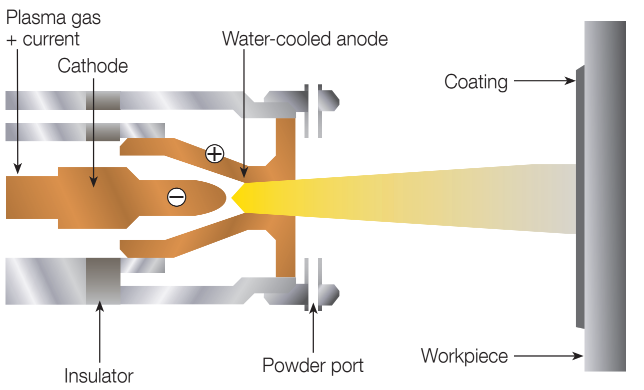

Figure 6a – Schematic diagram of the plasma spray process

For specialized applications, a variant of the process is to plasma spray in a controlled, low pressure atmosphere. In contrast to coating in air (atmospheric plasma spraying, or APS), the melted particles oxidize far less with vacuum plasma spraying (VPS), resulting in coatings of considerably higher quality [3].

Figure 6b – Controlled atmosphere plasma spraying

2.4.4 High Velocity Oxy-Fuel Spray (HVOF)

The high velocity oxy-fuel spray (HVOF) process is a relatively recent addition to the family of thermal spray processes. As it uses a supersonic jet, setting it apart from conventional flame spray, the speed of particle impact on the substrate is much higher, resulting in improved coating characteristics. The mechanism differs from flame spraying by an expansion of the jet at the exit of the gun (Figure 7). Fuel gases of propane, propylene, acetylene, hydrogen and natural gas can be used, as well as liquid fuels such as kerosene.

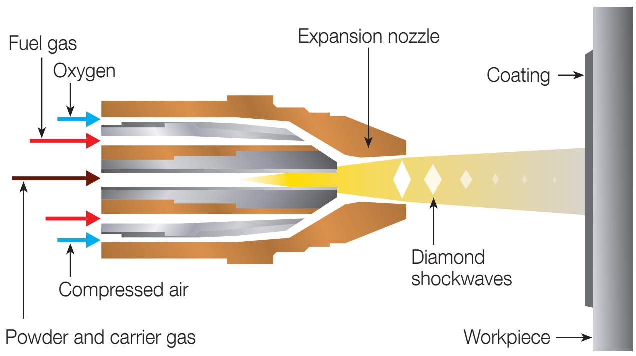

Figure 7 – Schematic diagram of the high velocity oxy-fuel spray process (HVOF)

2.4.5 Process comparison

The processes previously discussed differ fundamentally by the thermal and kinetic energy imparted to the spray particles by each process. The thermal energy is determined by the attainable flame temperature and the kinetic energy of the spray particle is a function of gas velocity. An energy comparison of the spray processes is represented in Figure 8. The high temperature of plasma spraying is particularly suitable for materials with a high melting point, such as ceramics.

The HVOF process, having high kinetic energy and comparatively low thermal energy, results in a positive effect on the coating characteristics and is favorable for spray materials such as tungsten carbide coatings. The comparison of the processes is largely of interest in relation to the coatings that result. Table 3 lists some important coating characteristics, organized by material class.

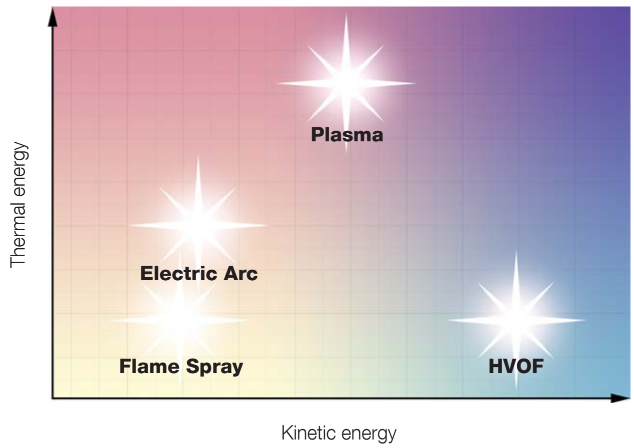

Figure 8 – Energy comparison of thermal spray processes

Characteristics		Coating type	Combustion powder	HVOF	Electric arc wire	Plasma
Gas temperature	[°C]		3000	2600 – 3000	4000 (Arc)	12000 – 16000
	[°F]		5400	4700 – 5400	7200 (Arc)	21500 – 29000
Spray rate	[kg/h]		2 – 6	1 – 9	10 – 25	2 – 10
	[lb/h]		4.5 – 13	2 – 20	22 – 55	4.5 – 22
Particle velocity	[m/s]		≤ 50	≤ 700	~ 150	≤ 450
	[ft/s]		≤ 160	≤ 2300	~ 500	≤ 1500
Bond strength	[MPa]	Ferrous alloys	14 – 21	48 – 62	28 – 41	21 – 34
	[psi]		2000 – 3000	7000 – 9000	4000 – 6000	3000 – 5000
	[MPa]	Non-ferrous alloys	7 – 34	48 – 62	14 – 48	14 – 48
	[psi]		2000 – 5000	7000 – 9000	4000 – 7000	4000 – 7000
	[MPa]	Self-fluxing alloys	83+ (fused)	70 – 80	15 – 50	---
	[psi]		12000+ (fused)	10000 – 11500	2200 – 7200	---
	[MPa]	Ceramics	14 – 34	---	---	21 – 41
	[psi]		4000 – 5000	---	---	3000 – 6000
	[MPa]	Carbides	34 – 48	83+	---	55 – 69
	[psi]		5000 – 7000	12000+	---	8000 – 10000
Coating thickness	[mm]	Ferrous alloys	0.05 – 2.0	0.05 – 2.5	0.1 – 2.5	0.4 – 2.5
	[in]		0.002 – 0.080	0.002 – 0.100	0.004 – 0.100	0.015 – 0.100
	[mm]	Non-ferrous alloys	0.05 – 5.0	0.05 – 2.5	0.1 – 5.0	0.05 – 5.0
	[in]		0.002 – 0.200	0.002 – 0.100	0.004 – 0.200	0.002 – 0.200
	[mm]	Self-fluxing alloys	0.15 – 2.5	0.05 – 2.5	---	---
	[in]		0.006 – 0.100	0.002 – 0.100	---	---
	[mm]	Ceramics	0.25 – 2.0	---	---	0.1 – 2.0
	[in]		0.010 – 0.075	---	---	0.004 – 0.080
	[mm]	Carbides	0.15 – 0.8	0.05 – 5.0	---	0.15 – 0.8
	[in]		0.006 – 0.030	0.002 – 0.200	---	0.006 – 0.030
Hardness (see Table A1 in the Appendix)	[HRC]	Ferrous alloys	35	45	40	40
		Non-ferrous alloys	20	55	35	50
		Self-fluxing alloys	30 – 60	30 – 60	---	30 – 60
		Ceramics	40 – 65	---	---	45 – 65
		Carbides	45 – 55	55 – 72	---	50 – 65
Porosity	[%]	Ferrous alloys	3 – 10	< 2	3 – 10	2 – 5
		Non-ferrous alloys	3 – 10	< 2	3 – 10	2 – 5
		Self-fluxing alloys	< 2 (fused)	< 2	---	---
		Ceramics	5 – 15	---	---	1 – 2
		Carbides	5 – 15	< 1	---	2 – 3

Table 3 – Comparison of thermal spray process coating characteristics (approximate values)

2.4.6 Infrastructure (system requirements)

Besides the principal item of a coating system, that of the spray gun, there are numerous other items necessary to apply coatings in an industrial environment. Figure 9 shows a coating system. The spray cabin serves as a shield for the sound and dust produced by the spray gun during spraying. The cabin has inlet ports for the power, gas supply and the process monitoring and control equipment. Usually, the gun is mounted on a robot, with movement programmed for the specific components to be coated. The component to be sprayed is usually mounted on a manipulation unit, such as a turntable. Therefore, it is possible to apply coatings to very complex geometries. The ventilation system with its filtering unit is not to be forgotten, as the so-called "overspray", i.e. the powder material that does not stick to the component surface, can be exhausted and trapped in the filtering unit. The spray dust produced by some spray materials can ignite; hence, in these situations, the entire system must be fire and explosion proof. Figure 26 on page 21 shows a modern, automated, high productivity coating facility.

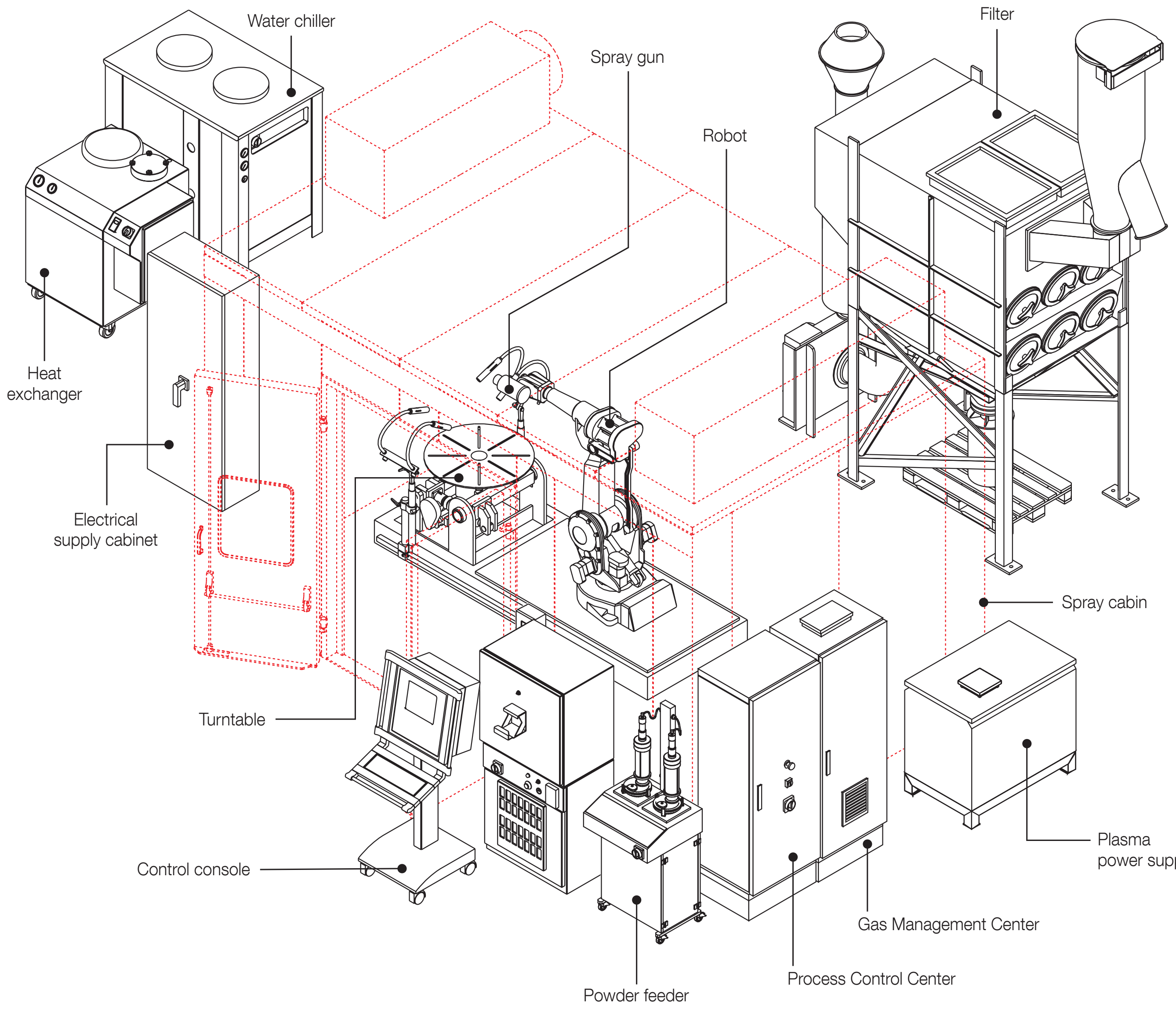

Figure 9 – Typical coating facility

2.5 Coating structure

Thermal sprayed coatings exhibit a certain amount of process-dependant porosity. The highest porosity values develop for flame and electric arc spray. HVOF coatings, however, produce very dense layers with porosity under 0.5 %. Typical plasma coatings have approximately 1 to 2 % porosity. Controlled atmosphere plasma spray can be near fully dense.

The sprayed coating develops as the spray gun traverses repeatedly over the surface and applies the coating in layers, bit by bit; with a typical layer thickness of 10 to 20 µm (400 to 800 µin) . Oxides can form during the time between passes on the outer surface of the layer. This oxidation can be minimized by spraying in a vacuum or inert atmosphere.

Fine dust from overspray and unmelted particles can become trapped in the coating. The dust is the result of coating material that does not adhere to the workpiece during spraying. Subsequent spray passes drag these particles towards the coating surface where they become trapped in the coating layer.

Figure 10 shows a photomicrograph of an arc sprayed coating of X40 CR 13. One recognizes the laminated structure and existing porosity (the black regions). The circular particles are those that did not melt completely before resolidifying. The thickness of this coating can be to up to several millimeters.

One can produce much denser coatings with the HVOF spray process. In Figure 11, a coating of WC (CoCr) is represented. There is hardly any porosity visible. The bright regions consist of WC hard phase, which is embedded in a ductile matrix of cobalt and chrome. Here the typical coating thickness is with 0.2 to 0.3 mm (0.008 to 0.012 inches).

Thermal sprayed coatings generally exhibit high internal stresses, which are attributable to the process of solidification and cooling. The hot particle contracts as it cools, which gives rise to the internal coating stress.

If the ratio of the thermal expansion coefficients for the substrate material and the coating material are taken into account, these stresses can be compensated for by producing compressive stresses. Temperature control during the coating process, therefore, plays an mportant role to determine if the substrate must be cooled or warmed.

Sometimes, the adhesion of a ceramic coating on a substrate does not meet the necessary requirement for bond strength. In order to increase the bond strength, a bond coat is applied, usually composed of a NiAl or NiCr alloy, which acts as an intermediate layer between the substrate and the ceramic coating. Such intermediate coatings can also perform another important function by providing additional corrosion protection.

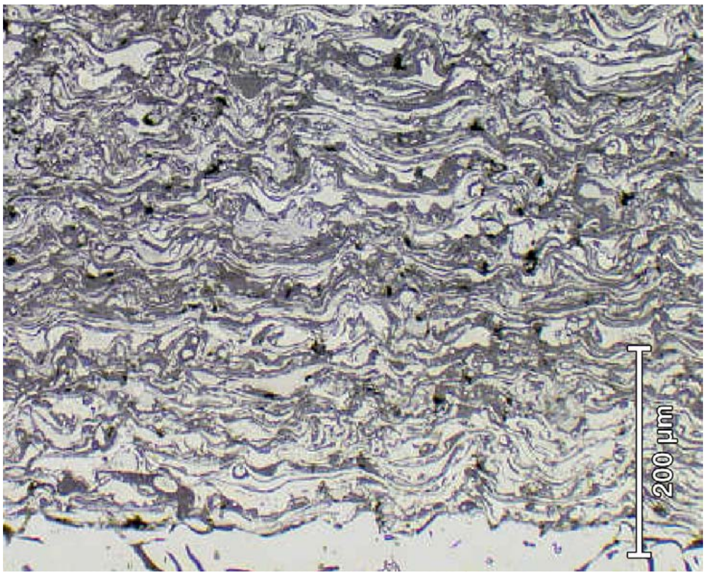

Figure 10 – Arc wire spray coating of X40 steel

Figure 11 – HVOF spray coating of WC 12(CoCr)

2.6 Coating characteristics

As previously stated, the porosity of a thermal spray coating is process-dependant, and exhibits an anisotropic, layered structure. These basic characteristics can be modified within a wide range to suit the specific application.

2.6.1 Wear protection

One of the most important uses of thermal sprayed coatings is for wear protection [4]. In these applications, ceramics, and above all, carbide materials are used. The commonly used carbide materials are WC/Co or WC/CoCr. Here, the carbide hard phases (WC) exhibit excellent resistance against abrasive and erosive wear, and are embedded in a ductile matrix of cobalt.

2.6.2 Corrosion protection

Low carbon, unalloyed steel and cast iron materials are susceptible to rust and therefore often need constant surface protection. This can be produced by flame sprayed coatings of aluminum or zinc. The main areas of application are for bridges the offshore structures. For high temperature applications, protective coatings of MCrAlY materials can be used. These are usually applied using controlled atmosphere plasma spray.

2.6.3 Insulative coatings (thermal/electrical)

Ceramic materials are excellent thermal and electrical insulators. They also possess good oxidation and wear resistance. These characteristics are quite useful on engine and turbine components as thermal barrier coatings. The thermal barrier coating lowers the skin temperature of the substrate, thereby extending the useful service life. On the other hand, efficiency is improved as a result of reduced heat loss at the same operating temperature. These coating systems consist of a bond coat, which is usually an oxidation resistant MCrAlY material (M = Fe, Ni or Co) and a ceramic top coat. A yttrium-stabilized zirconium oxide material is often used for the top coat because of its good thermal shock characteristics.

2.7 Post processing

Because many sprayed coatings have an inherently rough surface finish and porosity, it is frequently necessary to post process the surface. In addition, specification procedures can call for other methods, such as post-coating diffusion, nitrating, hot isostatic pressing or shot peening, as required.

2.7.1 Mechanical post processing

Thermal sprayed coatings possess a rough surface that is between 5 and 20 µm (see Table A2 in the Appendix). Therefore, it will often be necessary to machine many components to achieve a final dimension and surface finish. Depending on the coating applied, the surface can be worked by conventional machining or can be ground and lapped to final dimension.

2.7.2 Sealing

Sealing sprayed coatings serves primarily to fill the pores and microcracks in the coating, which provides additional protection against corrosive media that would otherwise penetrate to the base material.

When resin or wax sealants are used, those in a liquid condition penetrate into the pores and then harden (usually with heating). If the sealant is sprayed or painted on, the procedure may have to be repeated several times to insure complete coverage.

Sealants can also be used to provide surfaces with non-adhesive characteristics (PTFE based sealers).

2.7.3 Post-coat heat treatment

With thermal post-coat treatments, one differentiates between diffusion to increase the coating bond to the base material versus fusing of “self-fluxing” alloys.

Self-fluxing alloys form a special class of spray materials in that after the spray coating is applied, an additional step of fusing the coating is employed. The spray materials are generally alloys of chromium, iron and nickel that contain a substantial amount of temperature suppressants, such as boron and silicon.

During the spray process, there is some partial formation of intermetallic phases. Subsequent fusing of the coating causes a complete transformation of the materials and the formation of hard silicide and boride phases. Diffusion into the substrate also occurs, improving bonding. Porosity is nearly eliminated, with no interconnecting porosity.

These coatings exhibit extremely good corrosion resistance as well as very high hardness. The common manual method used to melt the coating is through the use of an acetylene torch. Fusing in a furnace, with laser, electron beam or with induction heating is also possible. The temperature required to effect diffusion is in the range of 1000 to 1200 °C (1800 to 2200 °F).

In Figure 12, just such a coating of a NiCrBSi alloy is shown before and after fusing of the coating. The homogenization of the coating structure is clearly recognizable, as is the reduced porosity and dense nature of the fused coating.

2.8 Coating characterization

Apart from the coating characteristics that are important with respect to the application, there are some characteristics that can be determined with relatively little effort and can be accomplished in terms of standardized quality control measurements. These are:

- Visual inspection
- Coating thickness measurement
- Surface finish measurement

If necessary, test pieces, sprayed at the same time and under the same conditions as the coating, can be examined to determine additional coating characteristics:

- Cross-sectioning for the determination of precise coating thickness, porosity, microstructure, and examination for unmelted particles and oxide inclusion
- Microhardness and / or macrohardness measurement
- Bond strength determination
- Bend tests

The test measurements use standardized sample geometries. Exact execution and interpretation is in accordance with various standards [6]. Beyond that, there are many other possibilities. The characterization of coatings in practice is quite complex, and there are many different procedures that are not common.

In addition, other tests can be included such as various methods for elemental analysis, scratch testing, tribological investigations, stress analysis, corrosion characterization and abrasion behavioral investigations. Since these are all destructive examinations, they are not especially usable for production and are rarely employed on test pieces. Many end users have developed their own specifications and test methods to characterize and judge the quality of their coatings. In particular, the aerospace and automotive industries have very strict guidelines.

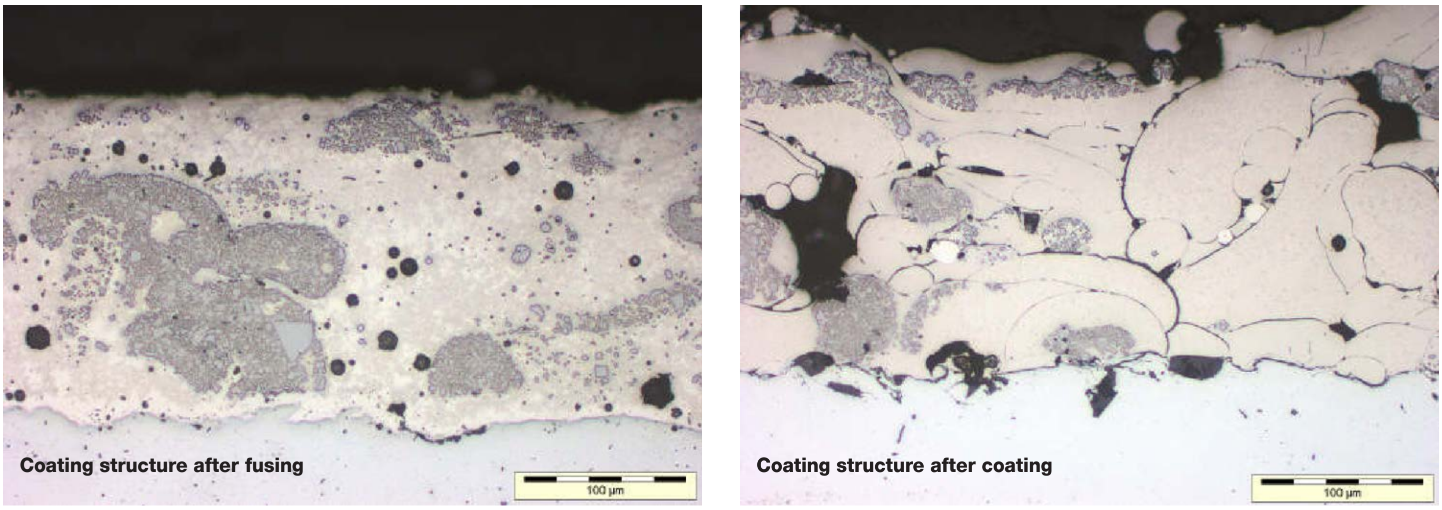

Figure 12 – Self-fluxing coating

3 Applications

In order to use thermal sprayed coatings to best advantage, the coating material has to be properly selected, the coating process has to be chosen and the process parameters developed. Also, the component to be coated has to be correctly dimensioned for coating.

The preferred geometries for coatings are disks, flat panels and rotationally symmetrical components, as illustrated in Figure 13.

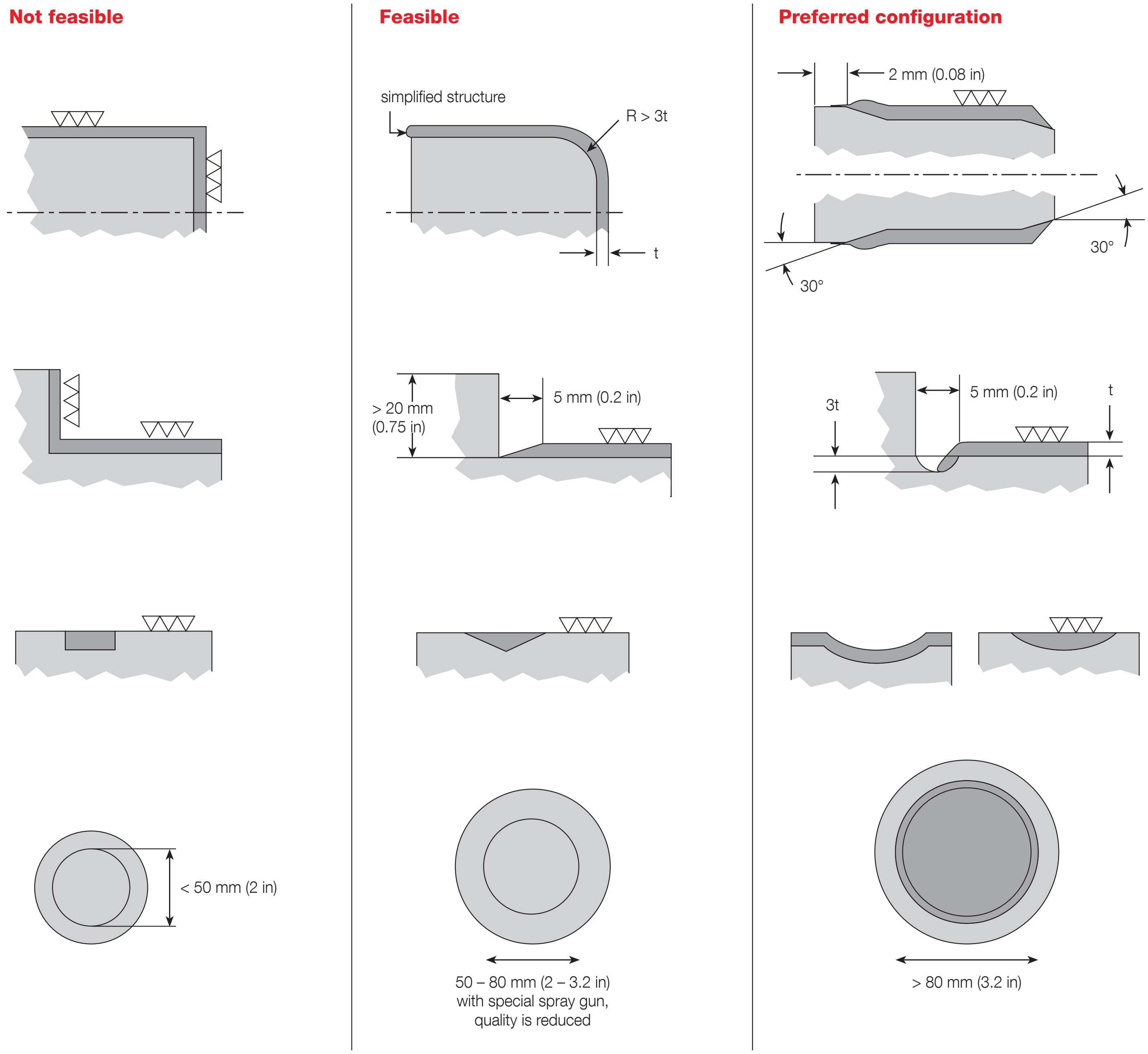

Figure 13 – Favorable coating geometries for coating

3.1 Production applications

3.1.1 Hard chromium alternative

Thermal sprayed HVOF coatings can be used as an alternative to hard chromium plating to provide wear and corrosion protection using pure chromium and various carbide coatings [5]. The characteristics of HVOF coatings, in part, exceed those of chromium plate and HVOF processing times are generally significantly shorter. The reflective surface appearance of hard chromium plating can be achieved by grinding and lapping the HVOF coating. An example application where thermal spray is used to replace hard chromium plate is that of aircraft landing gear components, as shown in Figure 14.

Figure 14 – Nose gear of an F5 Tiger with a WC/CoCr coating

3.1.2 Medical implants

For strong and durable anchoring of orthopedic implants, such as artificial hip joints, surface finish is of great importance. Oerlikon Metco's Metco™PLANT coatings, applied using the vacuum plasma process, are purposely sprayed with a very fissured surface that allows the bone to grow into it. There are Metco™PLANT coatings that act as a biocompatible titanium coating (Figure 15), or bioactive hydroxy apatite coatings, which actively accelerates the growth of the natural bone into the surface of the prosthesis.

Figure 15 – Biocompatible Metco™PLANT titanium coating on a hip implant

3.1.3 Textile machinery

Metco™TEX coating systems were developed as the result of many years of cooperation with textile machinery manufacturers. These coatings are characterized by a precise definition of the morphology produced using various handling methods and the topology of the surface. The surface texture is of particular importance for production components in contact with thread. In order to maximize fiber production, coatings of ceramic oxides are used, usually with a nickel bond coat that provides corrosion protection. Sample applications are represented in Figure 16.

Figure 16 – Various textile machinery components

3.1.4 Gas turbines

In both stationary and flight gas turbines, thermal sprayed coatings are used in many different places and for many different functions. Protective coatings for high temperature corrosion resistance, thermally insulating coatings, clearance control coatings and the repair of superalloy components with coatings of similar composition are just some examples (see Figure 17).

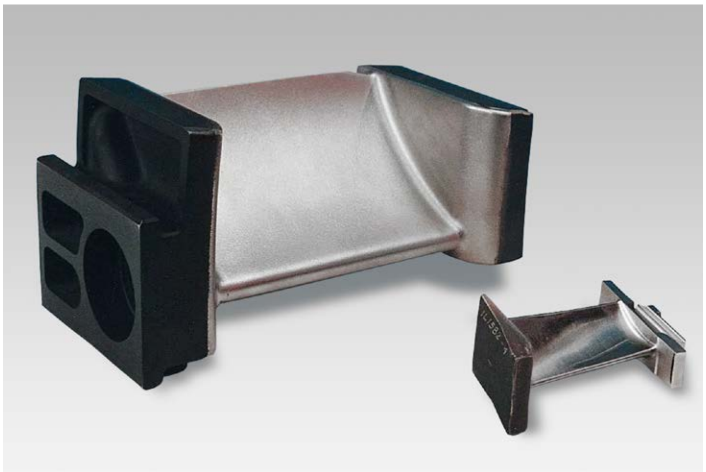

Figure 17 – Coated gas turbine vanes

3.1.5 Printing industry

Coated rollers and cylinders are used extensively for printing machinery. In partnership with customers from the paper and printing industry, several Metco™PRINT coatings were developed. Plasma sprayed chraome oxide coatings for inking rollers exhibit very fine microstructures, which can then be laser engraved with a very small and tight pattern (Figure 18).

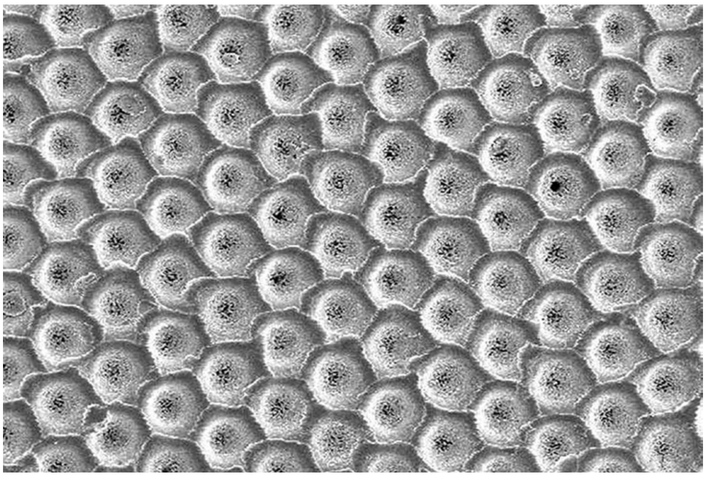

Figure 18 – Anilox printing roll with a laser engraved Metco™PRINT coating

3.1.6 General industrial uses

The largest variety of applications is for the machinery industry. Figure 19 shows a bearing shaft coated with a babbitt coating used in cement plants.

This special, particularly porous coating is designed for oil lubrication, providing a reservoir to prevent seizure.

Other examples of applications are piston rings for diesel engines, piston rods in compressors, pump bearings, valve covers, etc.

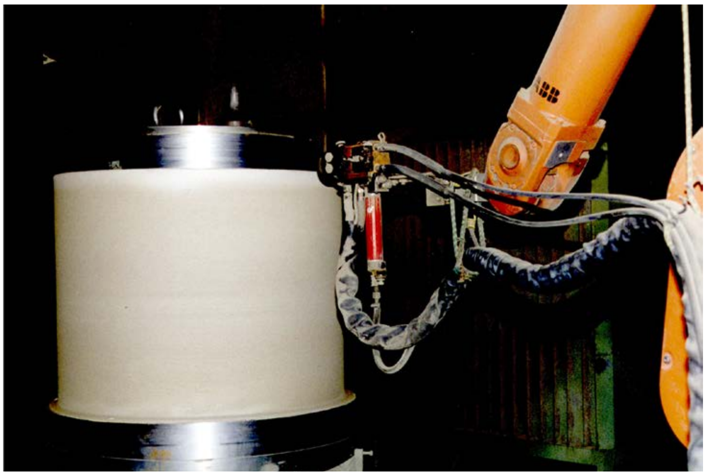

Figure 19 – Bearing shaft with a babbitt coating

3.1.7 Consumer goods

Although most uses for thermal spray coatings were developed for very specialized components, there are also applications within the consumer goods industry. An iron sole plate, on which a ceramic coating was applied as protection from wear is shown in Figure 20. A coating of an anti-stick material is subsequently applied. Similar coatings are also applied to non-stick frying pans.

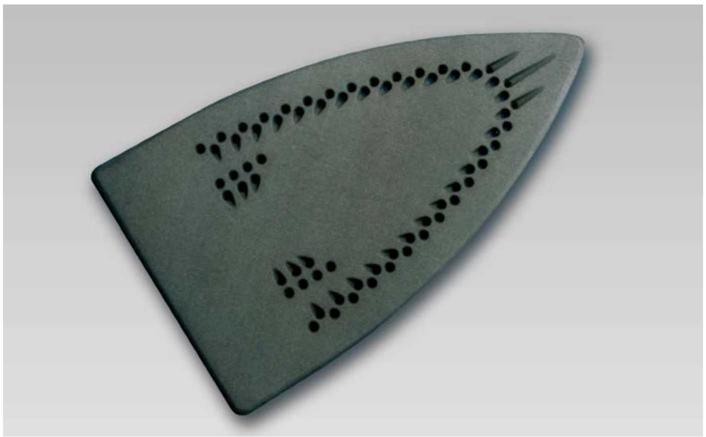

Figure 20 – Coated household steam iron soleplate

3.1.8 Automotive industry

Next to the coating of numerous small parts, the newest breakthrough development for Oerlikon Metco is coatings for aluminum engine blocks. The cylinder bores of the engines are coated by means of a special rotating plasma gun manipulator (Figure 21), which can apply the coating to the interior of the small bores with a wear resistant surface.

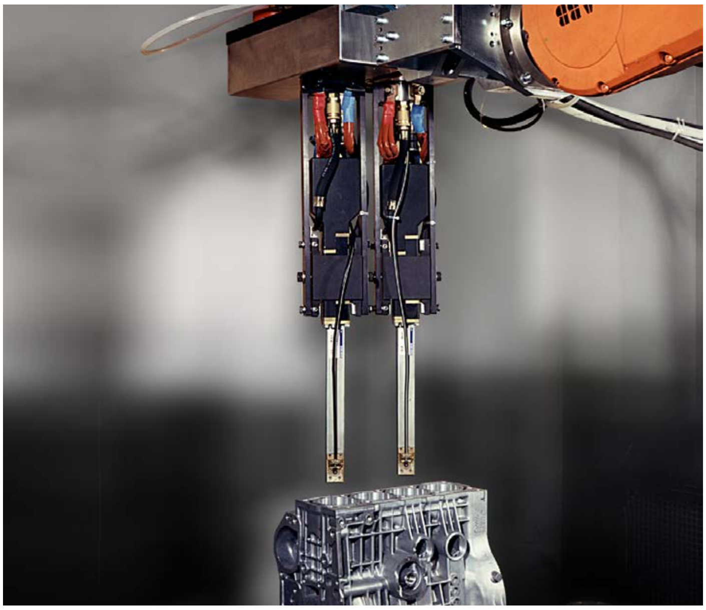

Figure 21 – Dual-RotaPlasma™

3.1.9 Steel industry

The rolls used in the steel working industry must handle very heavy thermal loads of hot steel. In addition, slag from steel production must be reckoned with, and in zinc production, corrosive attack from the molten zinc. Several different Metco™STEEL coating systems have been qualified for use on both new parts and repair applications (Figure 22).

Figure 22 – HVOF coating of a sink roll

3.1.10 Paper industry

Rollers in the paper industry are subject to the most diverse of operating environments including wear, chemical attack from dyes, thermal stress on heated rollers and mechanical stress from doctor blades. At the same time, they must exhibit a high surface finish over as long a length of time as possible. The Metco™CAL coatings were developed to meet these requirements, particularly for calendar rolls (Figure 23).

Figure 23 – Metco™CAL coating after superfinishing

3.1.11 Aerospace

Besides those components already mentioned for gas turbines, there are additional coatings used on airplanes. Figure 24 shows a coating on the interior of a combustion chamber.

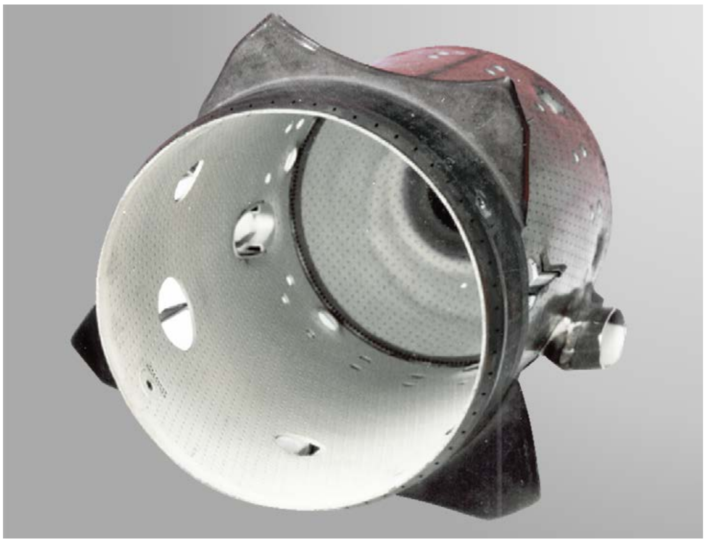

Figure 24 – Combustion Chamber

3.2 Salvage and restoration

Thermal spray can be used also in repair procedures to restore components to their original dimensions. The coatings can be turned or ground to finished size. Ni-Cr, Ni-Al or Ni-Cr-Al are used as repair materials for alloyed steels.

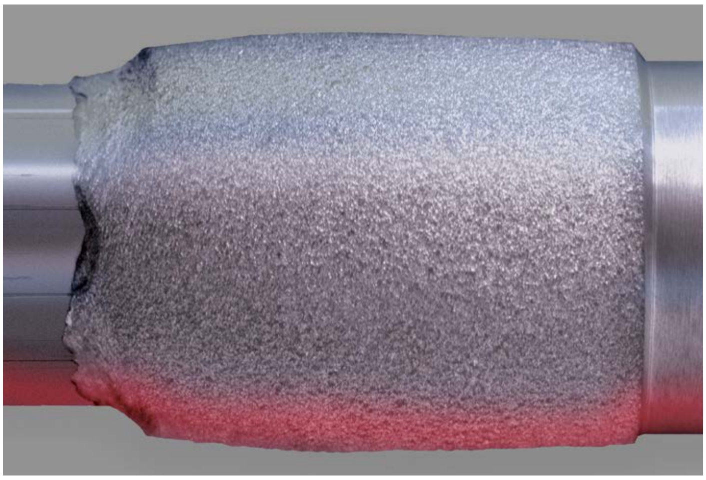

Figure 25 – Repair procedure

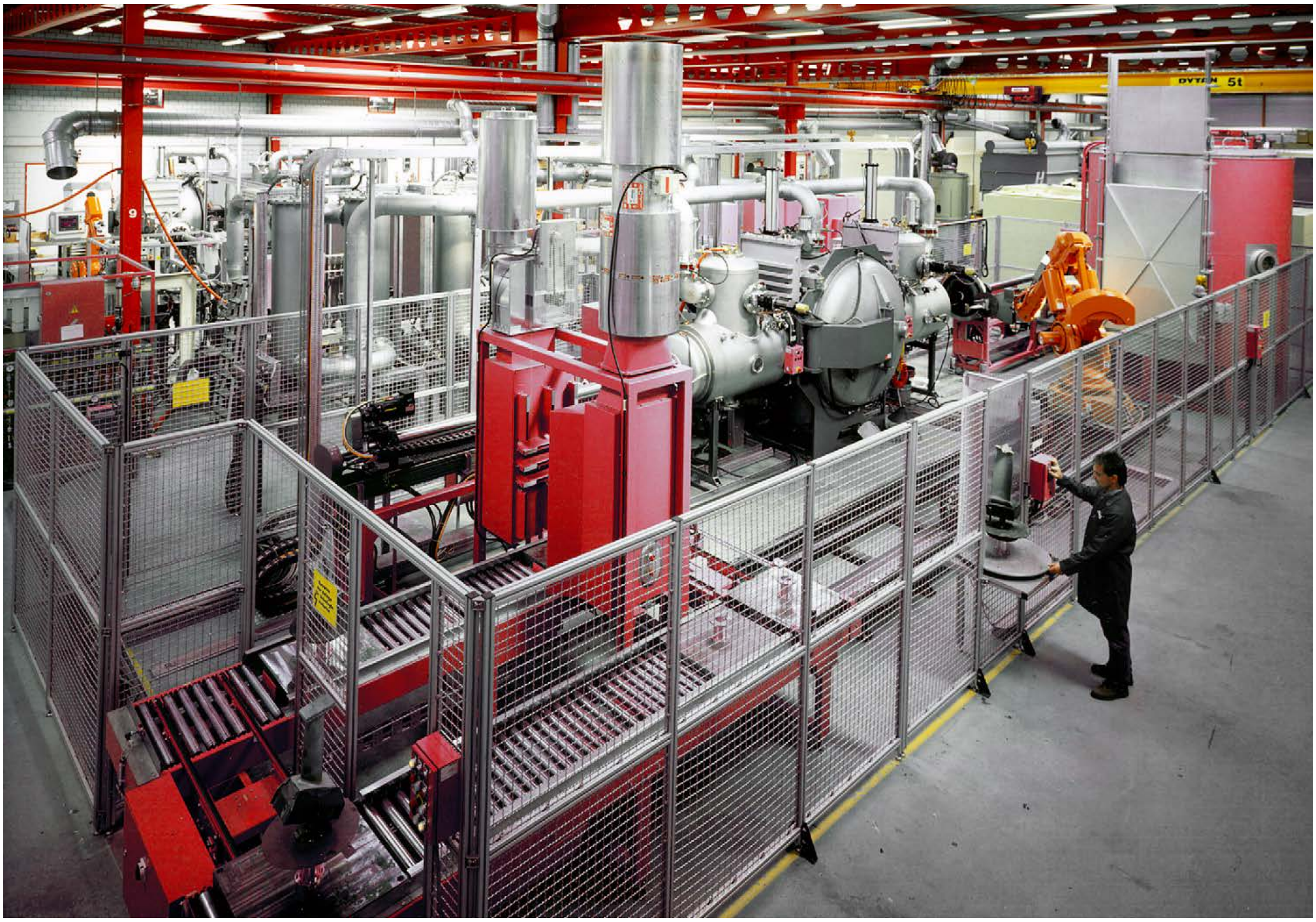

Figure 26 – A modern LPPS high-volume production system for coating gas turbine blades

4 Summary

With thermal spray, probably more so than any other coating process, there is almost no limitation in the number of options available for substrate and coating material combinations. As a result, thermal spray coatings lend themselves to a broad scope of applications, both for new component manufacture and for repair. The characteristics of the coatings can be varied within a wide range to suit specific application requirements. This presupposes, however, the many years of experience and the know-how of specialists.

With our unsurpassed in-house knowledge in the design and construction of thermal spray systems, equipment and materials, as well as many years of coating experience for both prototype and production components, Oerlikon Metco is the ideal partner for all thermal spray needs.

Please contact your Oerlikon Metco account representative for further information or visit us on the web at www.oerlikon.com/metco.

5 Appendix

5.1 Reference tables

Rockwell HRC	Vickers HV	Brinell HB	Tensile strength Rm [N/mm²]
80	1865		
79	1787		
78	1710		
77	1633		
76	1556		
75	1478		
74	1400		
73	1323		
72	1245		
71	1160		
70	1076		
69	1004		
68	942		
67	894		
66	854		
65	820		
64	789		
63	763		
62	746		
61	720		
60	697		
59	674		
58	653	620	2180
57	633	599	2105
56	613	580	2030
55	595	570	1995
54	577	551	1920
53	560	532	1845
52	544	515	1780
51	528	495	1700
50	513	485	1665
49	498	475	1630
48	484	456	1555
47	471	447	1520
46	458	437	1485
45	446	423	1450
44	434	409	1385

Rockwell HRC	Vickers HV	Brinell HB	Tensile strength Rm [N/mm²]
43	423	399	1350
42	412	390	1320
41	402	380	1290
40	392	371	1255
39	382	361	1220
38	372	352	1190
43	423	399	1350
42	412	390	1320
41	402	380	1290
40	392	371	1255
39	382	361	1220
38	372	352	1190
43	423	399	1350
42	412	390	1320
41	402	380	1290
40	392	371	1255
39	382	361	1220
38	372	352	1190
37	363	340	1150
36	354	335	1140
35	345	330	1115
34	336	323	1095
33	327	314	1060
32	318	304	1030
31	310	295	995
30	302	285	965
29	294	280	950
28	286	271	915
27	279	266	900
26	272	257	865
25	266	252	850
24	260	247	835
23	254	242	820
22	248	238	800
21	243	233	785
20	238	228	770

Table A1 – Hardness within the range HRC 80 to 20 (approximate cross-reference values)

Surface Finish	Ra [µm]	Ra [µin]	Rz [µm]
N0	0.0125	0.5	
N1	0.025	0.1	0.29
N2	0.05	2	0.55
N3	0.1	4	0.91
N4	0.2	8	1.74
N5	0.4	16	2.6
N6	0.8	32	4.65
N7	1.6	64	7.87
N8	3.2	128	15.6
N9	6.3	250	40
N10	12.5	500	63
N11	25	1000	100
N12	50	2000	160

Table A2 – Surface finish (approximate cross-reference values)

5.2 Literature references

[1] DIN EN 657; Thermal Spray – Begriffe, Einteilung; Beuth-Verlag, Berlin (1994)

[2] H.D. Steffens, J. Wilden: “Moderne Beschichtungsverfahren”, DGM-Verlag, ISBN 3-88355-223-2, (1996)

[3] P. Huber: “Vakuumplasmaspritzen”, oberfläche surface, 10 (1992), 8

[4] H. Simon, M. Thoma: “Angewandte Oberflächentechnik für metallische Werkstoffe”, Hanser-Verlag, München (1985)

[5] E. Lugscheider. H. Reymann: «Hochgeschwindigkeitsflammgespritzte Chromschichten zum Verschleiss-und Korrosionsschutz», Schweissen und Schneiden, 50 (1998), 44

[6] DIN 50600; Metallographische Gefügebilder, Beuth-Verlag, Berlin
DIN EN 582 Ermittlung der Haftzugfestigkeit, Beuth-Verlag, Berlin (1994)
DIN EN 10109 Teil 1; Härteprüfung, Beuth-Verlag, Berlin (1995)
DVS 2310 Teil 2; Anleitung zur Schliffherstellung, DVS, Düsseldorf, (1989)

Thermal Spray
Advanced Technology Solutions and Services

Thermal Spray

Perfect solutions through optimum materials and innovative technologies

Oerlikon Metco is a global leader in surface engineering solutions and services offering:

- A broad range of thermal spray, laser cladding and other advanced surface technology equipment and materials
- Integrated systems
- Specialized coating and surface enhancement services
- Manufactured components for the turbine, automotive and other industries
- Customer support services

Oerlikon Metco provides a comprehensive manufacturing, distribution and service network, catering to aviation, power generation, automotive and other strategic growth industries.

To take control of your surface engineering challenges, contact your Oerlikon Metco sales office, visit our website at www.oerlikon.com/metco or email us at info.metco@oerlikon.com

About Oerlikon Metco
Oerlikon Metco enhances surfaces that bring benefits to customers through a uniquely broad range of surface technologies, equipment, materials, services, specialized machining services and components. The surface technologies such as Thermal Spray and Laser Cladding improve the performance and increase efficiency and reliability. Oerlikon Metco serves industries such as aviation, power generation, automotive, oil & gas, industrial and other specialized markets and operates a dynamically growing network of more than 40 sites in EMEA, Americas and Asia Pacific. Oerlikon Metco, together with Oerlikon Balzers, belongs to the Surface Solutions Segment of the Switzerland-based Oerlikon Group (SIX: OERL).

oerlikon metco

www.oerlikon.com/metco
info.metco@oerlikon.com