COATINGS

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TSSEA
THERMAL SPRAYING & SURFACE ENGINEERING ASSOCOATION

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"quality coatings for engineers"

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Sulzer Metco high-pressure low-temperature experimental HVOF system.

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TSSEA

THERMAL SPRAYING & SURFACE ENGINEERING ASSOCOATION

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TSSEA News in Brief .....

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- Back copies of Coatings and the Code of Practice are available to members free of charge by using their log on details.
- Non members may obtain copies of "Coatings" at a price of £25.00 each. The Code of Practice is available at £50.00 with a discount of 50% for non members attending the conference on Health and Safety (29 April 2004). See page 11 of this issue
- In future back issues of "Coatings" will be available to members of the TSSEA via the web-site whilst non-members will be able to order issues through the secretary of the TSSEA.

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TSSEA Committee

New HVOF Developments

Richard K. Schmid, Harald Zimmermann
Richard McCullough. Christian Warnecke
Sulzer Metco

Third-generation high-velocity oxy fuel spray devices (HVOF) are still the standard in the industry, since the new developments of the recent years are suitable for niche applications only. With cold spray, for instance, it has been shown that only for a few coating materials (Cu, Al) higher particle velocity does result in higher coating quality. Sulzer Metco has thus developed a high-pressure HVOF system which can combine the advantages of higher particle velocity and particle heating by flame. Early investigations are promising, though showing economic limits.

The HVOF process is a well established thermal-spray process with well defined and established fields of application. The quality improvement of HVOF-sprayed carbide coatings compared with those produced by plasma or flame spraying was revolutionary. HVOF contributed also to replacing coatings previously only available from specific vendors and rendering it accessible for wide application. The achievable particle velocity increased from one HVOF generation to the next, three being distinguishable to date. The question arises as to whether a further increase – representing the 4th generation – would bring essential advantages.

Trials with Higher Particle Velocity

With the "Diamond Jet Hybrid" (DJ Hybrid), a third-generation HVOF device, work was carried out to examine what occurs with an increase in gas flow. With this spray gun, the powder is injected axially, resulting in a lesser tendency to form deposits on the barrel walls than is the case with radial injection. To obtain higher particle velocities higher gas flows are required, i.e. increased pressure and therefore also a high-pressure powder feeder will be required. However, these are not only difficult to handle but also pose a safety risk and are presently not obtainable for fine powders.

In the absence of adequate cooling, HVOF presents a risk of substrate overheating with increasing combustion gas and oxygen flows. The particles undergo a velocity increase and impact on the substrate surface with considerably greater energy than with plasma or conventional flame spraying. Certainly, the DJ Hybrid, with its comparatively low gas flows, is superior in this respect to kerosene-operated devices of the third generation. Nevertheless, numerous applications are known in which the operator points the gun away from the target to allow for cooling. During this time, powder is wasted.

High-pressure Trials with Prototype

To investigate the possibilities of fourth-generation HVOF devices, Sulzer Metco developed a prototype gun operating at pressures up to 30 bar (Figure 1). The technology is based on a US Patent by Browning (No. 5,271,965) dealing with "impact fusion", i.e. coating through particle deposition below its melting point, where the fusion energy necessary for particle bonding is supplied by the conversion of kinetic energy upon impact.

The high-pressure HVOF device operates at a pressure between 10 and 30 bar, running on natural gas and oxygen. Nitrogen is used for cooling and increases the backpressure. The high operating pressure necessitated radial injection after the throat into the low-pressure region. Particle velocities for the device were far higher than those of third-generation devices and are estimated to be around 1000 m/s.

Tests with Different Materials

All materials presently being sprayed on a large scale by third-generation HVOF devices were tested with the new prototype: Carbide coatings could only be deposited at the lower pressure range (10–15 bar). When higher pressures were used, the deposition efficiency (DE) fell dramatically. The abrasion resistance of the produced coatings was only slightly improved. High-pressure HVOF guns therefore cannot be regarded as a replacement for previous devices and are at the most suitable for niche applications.

Results with metallic coatings were far more promising, and pressures approaching 30 bar could be used.

Figure 1 *Experimental high-pressure HVOF device. Due to its low temperature the spray stream is barely visible.*

Under these conditions, the spray stream is barely visible. A glow can be seen where the particles impact. Fine powder cuts (10–25 µm) yielded the best results. The problem relating to radial powder injection was confirmed where powders with an excessive fine component were particularly prone to adhesion to the barrel wall. Because the device permitted temperature increases above that of cold spray, it was also possible to use powders of over 45 µm, although without the efficiency levels and densities of the finer cuts.

Numerous MCrAlY powders were deposited with mixed results. Using Amdry 9954 (10–62 µm), a CoNiCrAlY powder, the DE was investigated as a function of the angle of impact (Figure 2). The maximum DE was 55% at 90° falling off to 25% at 70°. Considering the large particle size range, this was regarded as acceptable for HVOF, where the DE can drop off dramatically as the gun angle deviates from the normal axis. If the effect is too extreme, objects with complex geometries such as turbine blades can no longer be coated, because the coating thickness fluctuations would be too great.

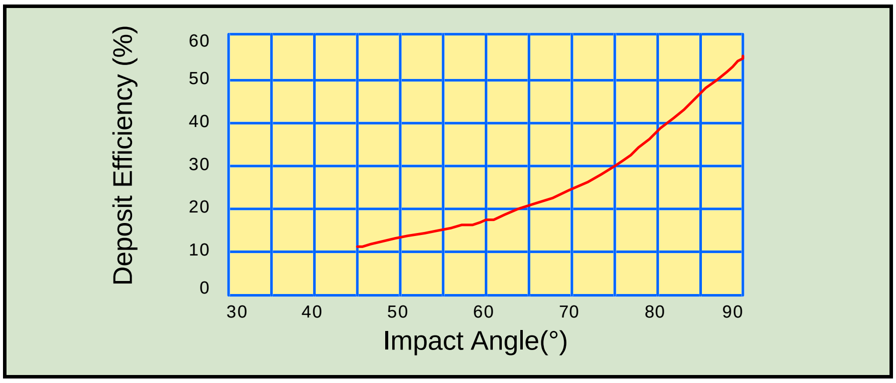


Figure 2 *Deposition efficiency as a function of impact angle for the high-pressure HVOF gun..*

A blade was sprayed to test the viability for coating complex shapes. The turbine blade rotated whilst the gun moved linearly. A finer cut (37 µm in max.) was used, and a very uniform coating was achieved (Figures 3 and 4).

The Amdry-9954 coatings were deposited using various processes: low-pressure plasma spraying (LPPS), atmospheric plasma spraying (APS), HVOF and high-pressure (HP-)HVOF. The coatings were then oxidized in air at 950 °C. Weight change was measured after 30, 100, 300, and 1000 hours. The ranking sequence was as follows: LPPS > HP-HVOF > HVOF >> APS. These results confirm what was already known from practice. But here too, any benefit with respect to oxidation resistance achieved by the HP-HVOF compared to HVOF would appear not to justify the outlay. From a purely cost aspect, despite its high capital investment, LPPS is still the best deposition technique for large series production.

Only the oxidation resistance of the coatings was experimentally compared, although other properties such as structural integrity are very important. If the fatigue strength of cold spray deposits is examined, it can be seen that, apart from a

Rotating HVOF

Over the past few years, Sulzer Metco has gained considerable experience with rotating plasma gun applications, particularly in the automotive industry. Here, systems are running reliably round the clock in series production. Against this background, Sulzer Metco has also extended the technology of the rotating systems to the DJ Hybrid. In contrast to plasma systems, which are also suitable for coating internal surfaces, HVOF is used mainly for outer surfaces, amongst other reasons due to the large spray distances required. The DJ Hybrid, on the other hand, is compact and light and ideally suited to this application.
The Rota DJ, as the rotating device is called, is in use with a major US airline to coat landing gears. This application concerns the substitution of hard chrome coatings for thermal-spray coatings. It was found that most WC-Co-Cr materials deposited with the DJ Hybrid satisfy the fatigue strength requirements of the landing gear manufacturers.

CAD drawing of the Rota DJ, an HVOF gun, fixed to a rotating fixture for coating internal surfaces.

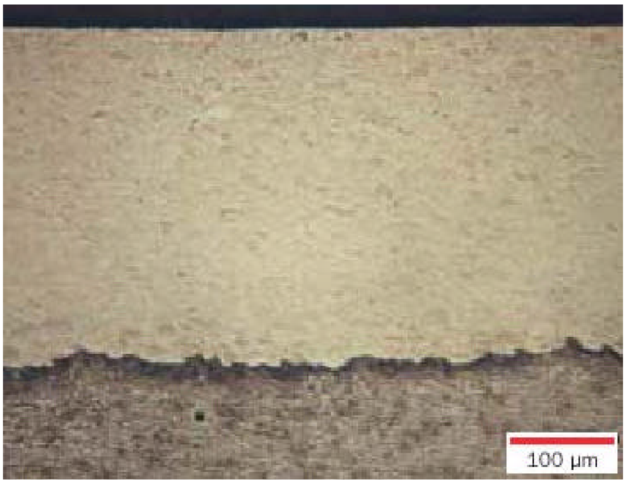
slight porosity and good electrical conductivity, the coatings have only poor fatigue strength. This is probably because the inter-particle bond is weaker than that created with LPPS or HVOF.

Ductile materials such as aluminum, copper, and stainless steel can be sprayed with very high deposition efficiency when available in the correct particle size distribution and if high back pressures are used. DE levels of up to 80% are not uncommon, and very thick coatings can be produced. For applications where these materials have to be deposited on large, simple shapes, HP-HVOF appears to be the suitable process. Doubtless here too, more investigations must be carried out with respect to coating properties, but these would appear to be in the cold spray realm; i.e. low density and low oxide content.

Corrosion Protection Trials

Numerous salt spray tests were performed to investigate corrosion protection, in which HP-HVOF coatings were compared with high-quality HVOF coatings. The results of the HP-HVOF coatings were identical or better, but once again, more detailed investigations are necessary.

Figure 4 Cross-section through a high-pressure HVOF-MCrAlY coating. The coating has been etched. It is very dense and uniform



Initial results with HP-HVOF indicate some very promising coating properties, but also problems concerning coating adhesion or internal stress ratios. It is also evident that the new technique reacts very sensitively to particle size distribution. Based on initial evaluations, no significant advances are to be expected in achieving increased particle velocity as compared to existing third-generation devices. But further investigations are necessary.

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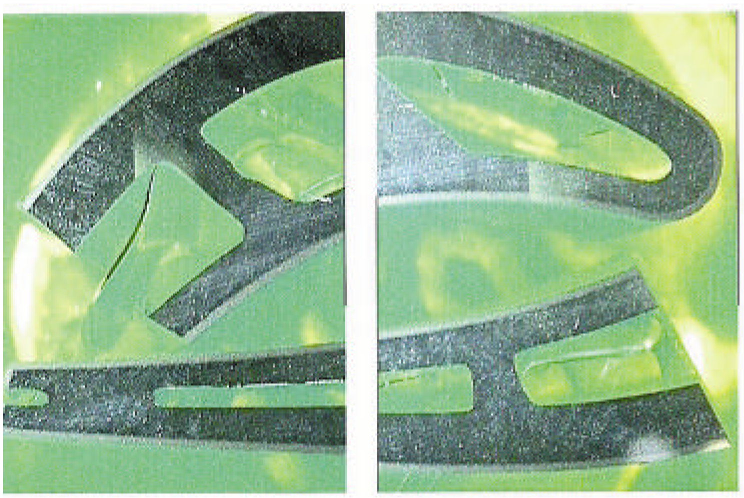
Figure 3 Cross-section through a turbine blade, coated by using the high-pressure HVOF. A very uniform coating thickness was obtained



Polishing of hard coatings using abrasive belts

James Barber,
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Introduction

For more than 70 years Cross Manufacturing Company has been developing and manufacturing high quality sealing rings that are used in a variety of engineering applications throughout a wide range of industries. As a result of the hostile environment into which these rings are often placed, coupled to the cost of the components being sealed, it is imperative that the wear produced by the seal arrangement is kept to a minimum. This is necessary not only to maintain the performance of the seal but also to increase the longevity of the components in the seal assembly.

For this reason Cross Manufacturing Company has devoted much of its R&D efforts into investigating methods of reducing the wear experienced between the sealing ring and contacting bore. Particular focus has been placed on the wear performance of various material and coating combinations, along with the effect that surface finish has on the wear performance.

The Problem

One particular problem that has caused many headaches over the years has been the sealing of large diameter thin walled bores, such as those found in an aircraft engine. The high temperatures present demand the use of heat resistant Nickel alloys, which if left uncoated produce high levels of wear when placed in moving contact with similar alloys. This has meant the coating of these parts is often a necessary requirement, shifting the problem to one of coating selection and subsequently that of achieving an acceptable surface finish.

Traditionally the coating would be ground to a smooth surface finish, but in the case of large diameter thin walled bores this is impossible. The cost of grinding a 40” diameter bore which is only 0.050” thick would be immense, if at all possible. Hence the majority of these arrangements are left ‘as coated’ with quite a rough surface CLA.

Feedback from our customers suggested that this solution was still producing fairly high levels of wear and as such a project with a clear objective of identifying an alternative method of smoothing the coating was initiated. What follows is an overview of the initial stages of this project including the major results and conclusions.

The Solution

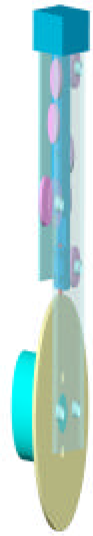
Rather than grinding the coating the question was asked could the coatings be polished instead, as this represented a far simpler and cost effective method of obtaining a good surface finish. After consulting with Klingspor Abrasives Ltd it became evident that this would be possible with their current range of abrasive belts and as such it was decided to conduct a range of tests designed to determine the effectiveness of polishing as a smoothing technique on a variety of coatings. A secondary investigation to be run concurrently would focus on the effect surface finish has on the wear performance of the various coatings when placed in moving contact with a Nickel alloy. The ultimate aim being to identify the optimum coating and surface finish combination when considering both wear performance and the effort required to achieve that surface finish.

The Test

The decision was made to use a pin on ring test to simulate the moving contact between the two surfaces.

Figure 1 illustrates the test rig assembly. It shows how the Nickel alloy specimen, which for this test program was to be Haynes 25, (coloured red), is held in contact with the coated outside diameter of a rotating disc. The specimen holder has been designed so as to

Figure 1 *Test Rig arrangement*



produce a known pressure, (7 bar), at the point of contact and as standard discs have been used throughout, with each test being run for a set time at uniform speed, the only variables left to investigate with regards to the wear rate are the coating types themselves and the surface roughness of those coatings.

From the outset it had been the intention to link the wear to an effective distance travelled by the Haynes specimen relative to the rotating disc. Therefore an effective distance of 2km was chosen as the standard test duration, with further extended tests also being conducted to test the durability of the coating.

Measurement of the coatings surface finish was achieved using a Rank Taylor Hobson Surtronic surface-measuring device, taking CLA readings axially across the discs outside diameter. To measure the wear during the test the change in length of the specimen/disc combination was used since this directly represents the quantity of material removed during the test.

With the test procedure fully defined the final stage was to select the coatings to be analysed. A total of seven coatings were chosen, four of which were applied using a plasma coating process, those being Chromium Carbide, Tungsten Carbide, Alumina and Tribaloy. Two coatings, Tungsten Carbide LW1N40 and Chromium Carbide LC1B were applied using the D-gun process and finally there was a Tribomet T104C coated disc, which was applied using an electrodepositing process.

Two separate investigations were completed on each coating, the first investigation being to run several standard tests on a variety of surface finishes, i.e. after each test

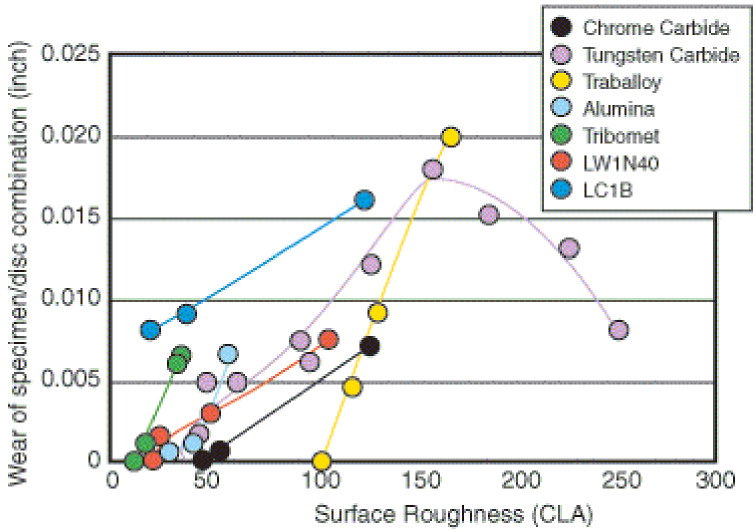


Figure 2 *Shows a typical propane and oxygen supply system for flame spray process*

polish the surface to a better surface finish than that tested previously. This investigation aimed to identify the optimum CLA for each coating, considering both the level of wear experienced and the time required to polish the surface to the respective CLA. Using this information the second investigation aimed to identify whether polishing directly to that optimum CLA would affect either the rate of wear or the length of time needed to achieve that CLA. An extended test of 10Km would also be completed to determine what level of wear could be expected over a prolonged period of time.

The Results

With all the data collected two graphs were constructed in order to display the key results, allowing a quick and easy comparison between the seven coatings and various surface finishes. The first graph, figure 2, plots the wear experienced during each test against the pre-test CLA of the coating surface. The second graph, figure 3, shows the cumulative time required to polish each coating to a certain CLA. The purpose of this graph is simply to compare the ease of polishing between coatings, identifying if polishing is a viable option for a particular coating.

As can be seen from figure 2, The LC1B and Tribomet coatings produced considerably more wear for the same surface finish than the other coatings, a trend that was confirmed on visual inspection of the coating surface, which provided clear evidence that both surfaces had experienced severe metallic welding, as would be expected with severe wear.

In contrast the plasma coated Chromium Carbide, Alumina and Tribaloy coatings all had low levels of wear for a given surface finish. However, while Tribaloy produced low wear, on visual inspection the surface had worn excessively, to the point it appeared the coating could be breached at any moment. For this reason Tribaloy would not be recommended for extended periods of use or for contacts where there is considerable relative motion.

Chrome Carbide on the other hand held up very well to the rigours of testing and on visual examination displayed only signs of mild wear. This combination of good wear performance with no appreciable loss in coating quality makes Chromium Carbide a very attractive option. The time required to polish Chromium Carbide to a good surface finish was also impressive, achieving optimum CLA with only a couple of minutes polishing.

The Alumina is another coating that performed very well, again producing low levels of wear and requiring a minimal amount of polishing to achieve a good CLA reading. One important point to note about this coating is that when tested above 50 CLA there was a sharp increase in the rate of wear, hence it is advisable to polish Alumina to at least a surface finish of 50 CLA, (but as said above this would not prove to be a difficult task).

The two other coatings tested were both Tungsten Carbide coatings, differing only in the method of application. The data set labelled 'Tungsten Carbide' was applied by plasma coating and the data set labelled 'LW1N40' was applied using the D-gun method. As would be expected the wear trend and time required to polish to a given surface finish were similar for the two coatings, the only difference being that the LW1N40 had a lower initial surface finish and slightly superior wear performance. A similar wear pattern was also observed with both surfaces appearing to have tear marks running circumferentially around the disk. The main disadvantage with the Tungsten Carbide coatings is the length of time required to polish to a CLA that yields good wear performance, however once a smooth surface is achieved, this coating represents an extremely resilient coating with a reasonably good wear performance. Thus if a method were developed to speed up the polishing process, Tungsten Carbide would represent a far more competitive choice of coating.

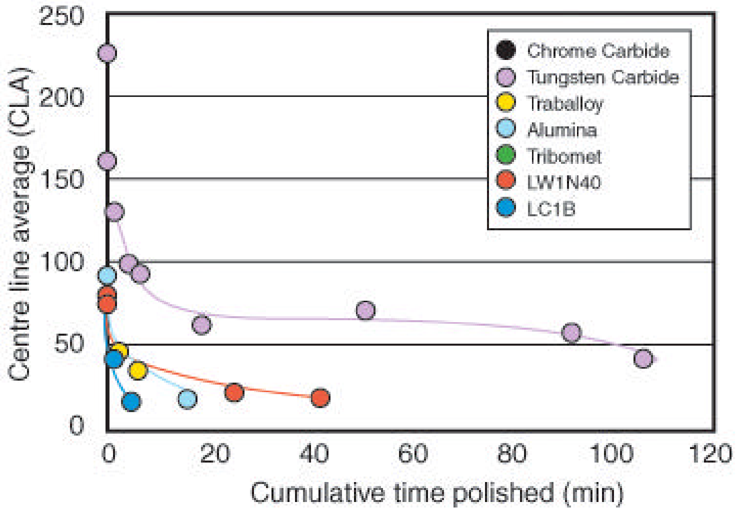


Figure 3 *Shows a wall mounted liquid withdrawal propylene delivery system with inert gas back pressure using nitrogen and 3kW-waterbath vaporiser*

Conclusion

Of the seven coatings tested three were completely eliminated, Tribomet and LC1B for their poor wear performance and Tribaloy because of the limited lifespan of the coating. The two Tungsten Carbide coatings both took too long to polish to their optimum CLA values to make them competitive. Ultimately it was the Chromium Carbide and Alumina coatings that stood out as the coatings of choice. Both producing very low wear below 50 CLA and both were easily polished to a surface finish well below this.

Overall these tests have identified that the polishing of the coatings as a method of improving surface finish is a viable alternative to grinding in the case of certain coatings. The fact that a good surface finish can be achieved in just a few minutes of polishing, which in turn can dramatically improve the wear performance of the coating, could be extremely useful both within the aerospace industry and indeed in many other industries where there are similar wear problems.

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HVOF Carbides in Hydro-Electric turbines

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In addition to being staggering in their scale and beauty and the source of the holy river Ganges the Himalayas have another less well-recognised attribute. Being a new range of mountains still rising from the crust they are composed mostly of very hard volcanic rocks containing minerals such as quartz. Whilst this adds to the overall ruggedness and produces a milky green tone to the waters of the rivers it causes a very significant problem for hydroelectric power generators.

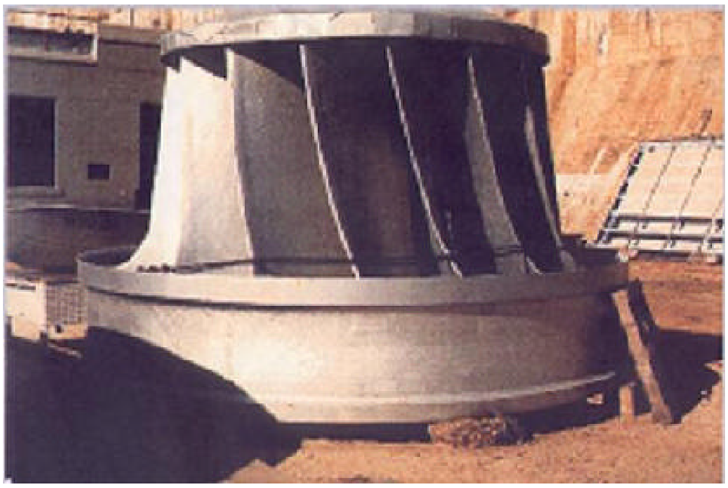

Figure 1 New turbine runner for Salal Station

With every monsoon season vast quantities of quartz particles are swept up by the flooding rivers and carried through the turbines of hydro electric power stations (Figure 1) taking a significant part of the turbine material with them (Figure 2). When similar quartz loading occurred in New Zealand after a volcanic eruption more than ten years worth of wear happened in one season. In northern India it happens every year.

Figure 2 Severely worn Pelton needles.

Hence Bharat Heavy Electrical (BHEL) the Indian state power plant manufacturer needed a solution to mitigate the effects of such wear and have successfully implemented a thermal spray coating method in two types of hydro-electric turbine.

The Pelton wheel is an updated version of the ancient water wheel. A jet of water impinges on bucket like fixtures on the periphery of a wheel, which spins and drives the generator. This layout is most efficient for high pressure areas where there is a large head of water. The flow is controlled by a conical needle valve which is also used to close the flow off altogether. The flanks of this needle are severely abraded by particles of quartz passing at high velocity and when they are no longer capable of shutting off they must be taken out of service.

Further downstream in the river a different type of turbine called a Francis turbine is used. This looks rather like a centrifugal compressor but in reverse. Water flows inwards through an impeller with curved vanes and then out through the bottom in what is called a draft tube. Unlike the Pelton wheel the Francis turbine always runs full of water. Flow into the vanes of the turbine is controlled by pivoting guide vanes called wicket gates operating between a top and a bottom ring. The impeller, the wicket gates and the top and bottom rings all suffer severe erosion (Figures 3 and 4).

BHEL tried several possible solutions to overcome this wear. They actually trialled electroplated hard chrome, boronising, plasma nitriding and HVOF sprayed tungsten carbide in a cobalt chrome matrix. Because there were a variety of HVOF methods available they first tested different processes using a proprietary quartz/water impingement test rig which could simulate the conditions of the turbine. Trials

Figure 3 Severe erosion on Francis Turbine runner

Figure 4 Severe erosion on Francis Turbine ring and wicket gate

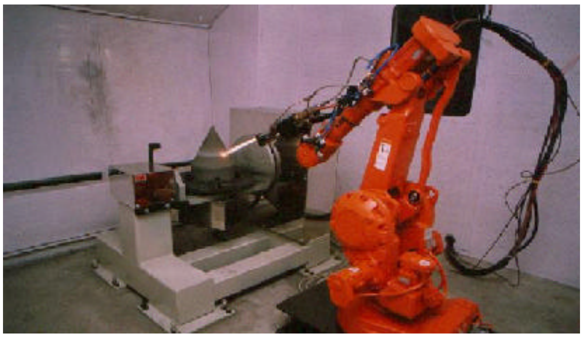

Figure 5 Robotic spraying of Pelton wheel needle

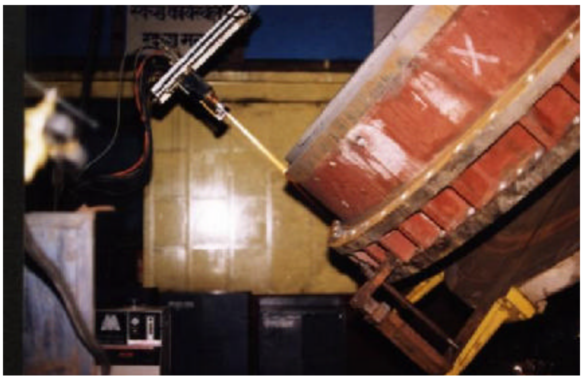

Figure 6 X – Y scanner spraying Francis turbine lower ringas the fuel gas.

Figure 5 BHEL's spray control room

dles were put in service for one season and then inspected. Upon removal no wear at all was measurable on the HVOF coated needles.

Translating this success from the Pelton wheel to the Francis turbine BHEL then sprayed the wicket gates, and the top and bottom rings. These are large pieces of metal some five metres in diameter and weighing several tonnes. Because the carbide coating is impossible to machine except by diamond grinding the coatings were left as sprayed. This meant that the control of the coating thickness had to be precise and in some cases a robot was used and in others a purpose built programmable x-y scanner.

For smaller parts they are placed inside an acoustic room and spraying is controlled from a console in a control room, keeping the personnel away from noise heat and dust associated with the process.

This material and method has been so successful that it has now been specified as the only one to be used for this application in their power stations throughout India. India has an unusually difficult problem due to the high loading of abrasive quartz in the water but the success of the coating demonstrates the toughness and survivability of these extremely hard and dense HVOF coatings.

For more Information about **Metallisation Limited** visit their web site at http://www.metallisation.com or contact Dr. T. Lester,

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TSSEA 2004 Programme

Spring Conference 2004

To be held on 29th April 2004
BOC Gases Technical Centre,
Lower Wallsall Street,
Walsall DY3 4DF

Health, Safety and Environmental Issues as applied to the Thermal Spraying Industry

On this occasion the theme will be Health and Safety and Environmental issues as applied to the Thermal Spraying Industry. This very important topic will be largely based on the Code of Practice which the TSSEA published in October 2001 which is entitled "The Safe Operation of Thermal Spraying Equipment". Covering all issues of safety requirements in this industry, this comprehensive document includes installation, operation and maintenance of all thermal spraying processes whether installed in soundproof enclosures or with local extraction systems typical of site operations. This document is recognised as an authoritative study on the different hazards and how best to combat them. Members of the association may freely download copies using their login details and non members may obtain copies for a nominal price of £50.00 Non members attending the conference will be supplied at a 50% discount.

Expert speakers from the Gas supply companies will deal with the issues of compressed gases used for combustion and inert gases typically used in the Plasma process or for cooling purposes. The major spraying equipment suppliers and Health and Safety experts will also be represented. Explanations will be given for Risk Assessments and Zoning of hazardous areas where special electrical equipment must be used. Noise, dust and fume will also be covered.

All who operate or are in any way concerned with thermal spraying equipment will find this conference to be very valuable in explaining the requirements for safe practices in this industry and how best to achieve them.

For further details please contact the secretary at :
thermal.sprayers@btinternet.com or Tel; 01789 842822 Fax 01789 842229. 18, Hammerton Way, Wellesbourne, Warwickshire. CV35 9NT.

TSSEA 2004 Programme

Diary Dates for 2004

The following dates have been arranged for 2004 Conferences:

Spring Conference

Health, Safety and Environmental Issues as applied to the Thermal Spraying Industry, 29 April 2004 BOC Gases Technical Centre, Lower Wallsall Street, Walsall DY3 4DF

Summer Conference

Coatings for Protection against Corrosion.
8 July 2004 - Venue to be advised

Autumn Conference

Surface Coatings in the Transport Industry.
November 2004 - Venue to be advised