A COMPARISON OF HVOF AND LPPS APPLIED MCrAlY COATING

Hans van Esch
Component Repair Division
Hickham Industries Inc.
La Porte, Texas

Wayne Greaves
Component Repair Division
Hickham Industries Inc.
La Porte, Texas

ABSTRACT

This study examined the ability of two High Velocity Oxyfuel (HVOF) systems, the Hobart Tafa JP 5000 and the Sulzer Metco DJ 2600 Hybrid, to apply MCrAlY coatings. The results were compared to a Low Pressure Plasma Spray (LPPS) applied material of the same chemistry. Each system is described and the optimum parameters are given. Also, an analysis of the powders is included.

The results were metallurgically evaluated for porosity level, oxygen content and yttrium distribution. Static oxidation tests were also performed on the NiCoCrAlY coating applied by each system. Conclusions were based on the relative performance of the JP 5000 and DJ 2600 Hybrid coatings as compared to the LPPS baseline material.

INTRODUCTION

MCrAlY coatings are widely used for the protection of combustion turbine blades and vanes. Traditionally, the application of these coatings was done by Vacuum Plasma Spraying (VPS) or Low Pressure Plasma Spraying (LPPS). Other technologies like, Electron Beam Physical Vapor Deposition (EBPVD), Plating, and HVOF spraying processes are now available to apply MCrAlY coatings.

Hickham Industries started a program to determine whether current HVOF systems could produce MCrAlY coatings of a comparable quality to those applied by VPS or LPPS. Testing was performed with the Hobart JP 5000 system and the Sulzer Metco DJ 2600 Hybrid. For each system the parameters were optimized for three different chemistries, NiCoCrAIY, CoNiCrAlY and NiCrAlY. Due to time and monetary constraints, a single powder chemistry was chosen for the study and the results were compared to a LPPS applied coating with the same composition.

THE EQUIPMENT

Low Pressure Plasma Spraying

This unit was developed and produced by Sulzer Metco (formerly Electro-Plasma Inc.). The workpiece is placed in a chamber with an inert gas backfilled soft vacuum of about 50 torr and is heated to approximately 980°C. Oxidation products which may have formed during the preheating of the workpiece, are easily removed with transferred arc.

A plasma gun inside the chamber applies the MCrAlY coating. Because there is little oxygen present in the atmosphere, oxide levels in the coating are minimal. Although the particle velocity is limited to 250 m/s, the porosity is minor since the part is heated to high temperatures during spraying.

An electric arc changes the condition of the gas to a plasma which forms the heat source of this coating process. The temperature can be in the range of 14,700°C (Meyer and Hawley, 1991).
TABLE 1. EQUIPMENT COMPARISON TABLE

<table>
<thead>
<tr>
<th></th>
<th>LPPS</th>
<th>JP 5000</th>
<th>DJ 2600 Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Gases</td>
<td>Argon</td>
<td>Kerosene</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Max. Flame Temperature [°C]</td>
<td>12,700</td>
<td>2,860</td>
<td>2,800</td>
</tr>
<tr>
<td>Max. Comb. Chamber Pressure [kPa]</td>
<td>N/A</td>
<td>830</td>
<td>690</td>
</tr>
<tr>
<td>Flame Velocity [m/s]</td>
<td>500-1000</td>
<td>1850</td>
<td>2150</td>
</tr>
<tr>
<td>Max. Particle Velocity [m/s]</td>
<td>250</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Barrel Length [cm]</td>
<td>N/A</td>
<td>20-30</td>
<td>7.5</td>
</tr>
<tr>
<td>Powder Feed Point</td>
<td>In Plasma (Radial)</td>
<td>In Barrel (Radial)</td>
<td>In Chamber (Axial)</td>
</tr>
</tbody>
</table>

Hobart JP 5000

The Hobart JP 5000 thermal spray system is a High Pressure/HVOF (HP/HVOF) process. Combustion chamber pressures are two or more times higher than the early HVOF systems. The higher pressure produces particle velocities approximately 300 m/s greater than conventional HVOF. This higher velocity gives the particles higher kinetic energy upon impact producing a dense (low porosity) coating. Also, oxidation is held to a minimum since the amount of time the particle travels in the atmosphere is shortened.

In comparison to plasma spraying, the particles are heated by a lower temperature heat source but remain in the source longer due to the barrel design. The barrel can vary from 10 to 30 cm in length and is water cooled to avoid melt down (Table 1). This system uses liquid fuel such as kerosene (Irons, 1993).

Sulzer Metco Diamond Jet 2600 Hybrid

The Sulzer Metco DJ 2600 Hybrid system is a result of continuing development of the conventional Diamond Jet system. The Hybrid system has a newly designed gun, which allows a higher pressure in the chamber, making this a HP/HVOF system. These design changes increase the flame velocity from 1000 to 2150 m/s. Hydrogen is used as the heat source. The fuel mixture can be varied to change the flame temperature and reduce the amount of oxygen available for particle oxidation (Nestler et al., 1993).

OPTIMIZING HVOF PARAMETERS

Chemistry of the Powder

The three chemistries (CoNiCrAlY, NiCrAlY, and NiCoCrAlY) initially tested yielded satisfactory results when sprayed with each system. The NiCoCrAlY was chosen for subsequent testing based on its proven performance as applied by LPPS.

In addition to the differences in melting points, the aluminum and yttrium contents varied between powders. Aluminum and yttrium are important since these elements will oxidize faster than others in the alloy. This could result in higher concentrations of oxide inclusions in the sprayed coatings. The yttrium content of the powders used varied from 0.4% to 0.9%, and aluminum from 8% to 13%.
Particle Size of the Powder

Particle size influences the bond strength (the particle speed), number of unmelted particles, porosity and oxide level of a sprayed coating. The most optimum powder would be that having single sized particles. However, this is not commercially feasible. The smaller the distribution of particle sizes, the better the resulting coating. To examine the effect of varying particle size distributions, two different lots were tested. One lot had a relatively fine (FP) size and the other was more coarse (CP).

Particle size distributions were determined using a MicroTrac system. This method measures the surface area of the particles using a laser. Light flux patterns produced by diffraction are analyzed to yield a particle size distribution for the given powder. Figure 2 shows the distribution for the two lots tested.

The DJ 2600 Hybrid was able to spray both powders with good results, while the JP 5000 had unacceptable oxidation levels in the coating using the fine powder (Fig. 3).

Composition of the Fuel and Carrier Gas

The carrier gas transports the powder from the powder feeder to the nozzle or the chamber. The fuel, kerosene for the JP 5000 and hydrogen for DJ 2600 Hybrid is burned with near stoichiometric levels of oxygen to insure complete consumption.

When heated in the flame, the powder is changed from a solid to a semi-molten state making it very sensitive to oxygen, nitrogen and carbon impurities. Therefore, the mixture of fuel, oxygen, and carrier gases is critical to achieving low impurity levels in the applied coating. Stoichiometric, or even oxygen poor mixtures, limit the amount of oxygen available to form oxides during the spray process. On the other hand, safety and the possibility of picking up carbon, (when fuels other than hydrogen are used) are reasons not to limit the oxygen supply. Since MCrAlY coatings are sensitive to nitride formation at high temperatures, argon, rather than nitrogen was used as the carrier gas.

Shroud and Shielding Gas

A shroud is a device that creates a protective gas flow around the sprayed particles before they reach the workpiece. Attempts were made to shroud the JP 5000, but efforts failed due to overheating. The DJ 2600 Hybrid is internally shrouded by design. All tests used argon as the shrouding gas.

Shielding gas is used to protect the base material and coating from oxidation. Testing with the JP 5000 utilized an argon flow over the workpiece surface. A slightly better result was achieved when the shield was applied. No shielding gas was used when testing the DJ 2600 Hybrid.

Distance of Gun to the Workpiece

During all testing, the distance between the spray gun and the workpiece was kept constant. For the JP 5000, this was 38 cm and for the DJ 2600 Hybrid, 28 cm. When spraying flat surfaces, the spray distance can easily be kept constant. However, when complex shapes are coated (turbine vanes and blades), variation in the spray distance will occur. Every method has its own characteristics. It is generally accepted that the quality of LPPS and plasma sprayed coatings is more sensitive to variations in workpiece distance than in HVOF applied coatings.

THE RESULTS

Optical Microscopy

All tests were conducted using Hastelloy X substrates and each were vacuum annealed prior to examination. Since metallographic technique is critical when analyzing thermal sprayed coatings, cross sections were prepared automatically using identical techniques. Spray parameters for each system were optimized by examining the test coupons by optical microscopy. Once the best attainable results were achieved with the JP 5000 and DJ 2600 Hybrid, these coupons were compared to the baseline LPPS material. Since the JP 5000 was unable to apply an adequate coating with the fine powder, no additional testing was performed with that coupon.

Both the JP 5000 and the DJ 2600 Hybrid sprayed NiCoCrAlYs had less than 0.02% apparent porosity as determined by ASTM B 276 comparison. The LPPS coating of the same chemistry also had negligible porosity levels.

Visible oxide content for coatings applied with all three systems was light. The coarse powder sprayed with the DJ 2600 had some unmelted particles. The other three coatings had no indications of significant unmelted particle contents and appeared relatively homogenous. Since surface preparation methods differed between the LPPS and other coatings, interface contamination was not examined.
EDAX Analyses

It has been shown by Russo and Dorfman (1995) that yttrium concentrations and morphology can affect oxidation resistance. The optimum morphology appears to include yttrium rich islands near the coating surface. It was determined by EDS elemental dot mapping (Fig. 4) that these structures were present in the baseline LPPS sprayed coating. Yttrium levels in all the HVOF applied materials were mostly homogeneous with yttrium dispersed throughout the matrix.

Oxygen Analyses

To compare the oxygen content introduced by thermal spraying, quantitative analyses were performed. The Inert Gas Fusion method heats the coatings with the substrates removed to 2500° C in a carbon crucible. Oxygen, freed at that temperature, reacts with carbon. This gas is then measured with infrared detection systems.

The baseline LPPS coating contained about 0.11% oxygen by volume whereas the coarse powder applied by DJ 2600 had 0.30%. The DJ applied fine powder and the JP 5000 coating contained 0.24% and 0.15%, respectively.

FIG. 3. OPTICAL PHOTOMICROGRAPHS OF COATING TEST RESULTS, 200X, Unetched, a) LPPS, b) DJ 2600, FP, c) DJ 2600 CP, d) JP 5000, FP, e) JP 5000, CP.

EDAX YTTRIUM DOT MAPS A) LPPS, B) TYPICAL HVOF (DJ 2600, FP)

FIG. 4 EDAX YTTRIUM DOT MAPS A) LPPS, B) TYPICAL HVOF (DJ 2600, FP)
In order to have an indication of how the HVOF and LPPS coatings behaved under oxidation attack, static oxidation tests were performed. Common superalloy base materials were also tested for comparison.

The substrates were removed from the coated samples. These specimens along with the base material samples, were exposed to air at 1150°C. Weight change as a function of thermal exposure time is plotted in Fig 5.

The LPPS baseline material had no appreciable weight change during the 400 hour test. All HVOF coatings also showed little or no change. The base materials all performed poorly by suffering significant weight losses.

**DISCUSSION**

Powder particle size and distribution play significant roles in thermal spraying. The tighter the distribution, the better the coating results. Also, every equipment type has its own characteristics. It appears that the DJ 2600 Hybrid is more forgiving in powder size differences than the JP 5000.

Yttrium forms "islands" in the matrix of LPPS applied coatings, while in all HVOF sprayed NiCoCrAlY samples, yttrium was evenly distributed. Some studies have suggested that the later morphology may negatively influence oxidation resistance. Therefore, LPPS coatings should outperform HVOF sprayed coatings. Yet, others believe that an even distribution of yttrium will make the coating perform better. Additional testing needs to be performed before the role of yttrium distribution in coating performance can be clearly understood. The static oxidation tests of this study showed no significant differences in oxidation resistance between the HVOF and LPPS applied coatings.

**CONCLUSIONS**

1) The particle size and distribution of the powders has a significant influence on the final coating results.

2) When using the correct equipment settings, HP/HVOF equipment can spray MCrAlY coatings with a minimum of porosity and internal oxidation.

3) Tests with the JP 5000 and DJ 2600 Hybrid have shown that a NiCoCrAlY having comparable isothermal oxidation resistance to a LPPS sprayed coating can be attained.

**REFERENCES**


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