Practical Application Of HVOF Thermal Spray Technology For Navy Jet Engine Overhaul & Repair

By Donald S. Parker

Innovations in the area of high-velocity oxygen fuel (HVOF) thermal spray coating deposition have provided aircraft repair facilities numerous new options in overhaul procedures. Parts that were previously approved for repairs utilizing only D-gun technology can now be successfully coated using an HVOF gun to achieve similar properties. This edited version of a presentation at the 31st Annual Aerospace/Airline Plating & Metal Finishing Forum, held April 25–27 in Denver, CO, examines the test program developed by the Naval Aviation Depot Jacksonville, FL, to apply coatings using an HVOF gun.

The presentation won the Robert C. Garland Award, named for a long-time supporter of AESF who helped create and organize the first Forum in 1963. As the Garland Award winner, the author of the presentation receives a certificate and an honorarium.

The Naval Aviation Depot Jacksonville's engineering group identified 12 parts in the engine oil system that were to be repaired with thermal spray coatings. Three were to be coated with a tungsten-carbide coating meeting the requirements of Pratt & Whitney Aircraft (PWA) specification 46, and nine others were to be repaired with PWA 50, utilizing a chromium-carbide/nickel-chromium coating. Until recently, the only method of achieving the specified properties was to have the coating applied using D-gun technology. The Naval Aviation Depot Jacksonville's Thermal Spray Shop, Materials Engineering Division, J52 Engine Branch, and Daiichi Metco Inc. developed a test program to apply these coatings using an HVOF gun and achieve the properties outlined in the PWA specifications.

Initial results have shown promising potential, with fuel gas mixtures and spray distance being the limiting factors addressed in the study. The laboratory testing includes repetitive evaluation of bond-strength coupons (IAW ASTM C633), metallographic examination to determine porosity, oxide content, and coating microstructure. Additionally, scrap parts are being coated to determine machining capabilities for surface finish requirements.

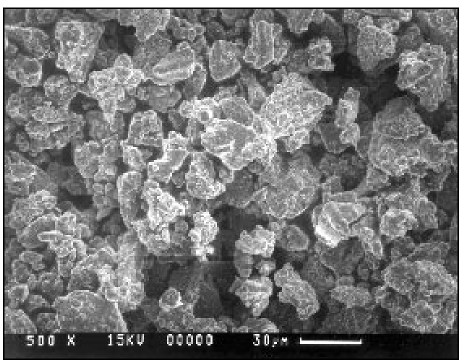

Fig. 1—SEM photograph of powder morphology.

Experimental Procedure

The powders used in this evaluation were sintered and crushed, with carbide particles completely clad with 20 wt percent nickel-chromium alloy. Previous experiments by Metco Inc. indicate that this manufacturing process produces a powder that, when sprayed, minimizes the carbide precipitation and produces coatings with higher bond-strength and hardness.

This chromium-carbide/nickel-chromium material[1] conforms to the requirements of PWA 50 specifications. The spray operation was performed using a thermal spray system[2] with a two-axis traverse unit. Oxygen and propane were used as the fuel gases, and argon as the powder carrier gas. The coatings were deposited onto properly cleaned and grit-blasted 0.0625-in. coupons[3] for metallographic examination. Tensile bond-strength samples were prepared in accordance with ASTM C633, with the substrate also manufactured from the same coupon material.

A matrix of six different gun parameter sets and spray distance settings was tested to determine the best configuration for producing the desired coating properties. Once an optimum parameter set was identified, scrap J52 oil system parts were coated to evaluate grinding capabilities to achieve specified surface finish requirements.

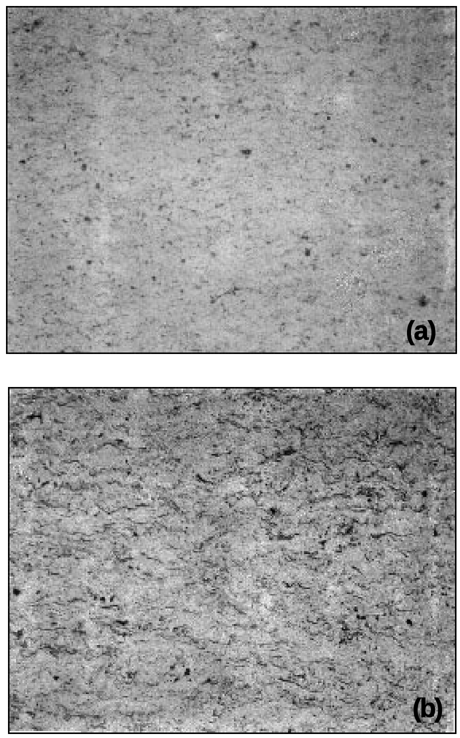

Fig. 2 (a) & (b)—Microstructure of samples that were cross-sectioned, mounted, ground and polished for metallographic examination, showing gray and white lamellar metal oxide phases, surrounded by a nickel-chromium matrix.

Results & Discussion

Powder Morphology

The as-received powder material was examined with a scanning electron microscope (SEM) to evaluate the clad powder structure. The morphology is shown in Fig 1. The material was specified as -325 mesh, +5.6 µm clad composite. SEM analysis confirmed powder structure to be as specified, and qualitative EDS indicated the clad chemistry to be nickel-chromium, also as specified.

Metallography

Six flat samples were cross-sectioned, mounted, ground and polished for metallographic examination and microhardness measurements. The microstructure (Fig. 2) clearly shows the gray and white lamellar metal oxide phases, surrounded by the nickel-chromium matrix. Elliptical, partially unmelted particles, visibly deformed on impact, are also shown within the structure. Porosity appears to be approximately 1–1.5 percent as expected, and uniformly distributed throughout the coating. Microhardness measurements averaged HKN_{500}930 and are within the range of HKN_{500}840–960, specified by Metco Inc. and PWA 50.

Mechanical Properties

Superficial hardness tests were performed using a 3-kg minor load, 15-kg major load with a 1/16-in. diameter ball indenter. Results averaged R_{15N}90, which converts to approximately R_c58–65. Tensile bond-strength coupons were prepared using a one-part structural epoxy. Most of the samples failed in excess of 12,500 psi, with the limiting factor being the tensile strength of the adhesive.

Optimum HVOF Parameters

Fuel gas	Propane
Fuel flow (SCFH)/pressure (psi)	168 @ 83
Oxygen flow (SCFH)/pressure (psi)	606 @ 150
Carrier gas	Argon
Powder feed rate	3 lb/hr
Spray distance	6 in.
Spray angle	90° ± 5°
Deposit rate	1/4 of 0.001 in./pass
Coating thickness evaluated	0.015 in.

Increasing the spray distance resulted in a decrease in hardness and tensile strength. Decreasing the spray distance, however, resulted in higher hardness values, tensile strengths greater than that of the epoxy, and a significant decrease in the thickness limitation, causing some sample coatings to crack.

Variations in the fuel gas mixtures had only a slight effect on the hardness, but dramatic effects on the tensile strength were realized when the mixtures were altered. Increases in the gas ratio still resulted in tensile strengths >12,500 psi. Decreasing the gas ratio, however, reduced the bond strength to <9,000 psi, once the ratio was <2.5:1. The significant difference in mechanical properties can be explained by the microstructure. By increasing the fuel mix ratio (hotter flame), the oxide content increased tremendously. Decreasing the ratio caused a significant increase in unmelted particles, creating a less-stable distribution of oxide phases and unmelted particles within the nickel-chromium matrix, as well as increased porosity.

An optimum mixture was achieved, therefore, when oxide content was approximately eight percent, unmelted particles were minimized, and mechanical properties were maximized within acceptable ranges. The final parameter set, with propane as the fuel gas, is shown in the table.

Production Testing

Following optimization of parameters, the following three parts from the J52 engine oil system were coated and evaluated:

- #6 bearing housing (inner bearing bore)
- #3 bearing seal seat (flat surface)
- #1 bearing seal housing (inner diameter)

All parts had a 0.015-in. coating applied and were finish-ground for concentricity, using a 100-grit diamond wheel, followed by a 320-grit diamond wheel. Drawing requirements stipulated a 5–7 AA surface finish requirement for chromium plating or D-gun repair. All three parts were tested and achieved a 6.3 AA average finish, with no readings above 7 AA.

Conclusions & Recommendations

Nickel-chromium/chromium-carbide (80/20) clad composite powder can be deposited with an HVOF gun, using propane as the fuel gas, to achieve a hard, dense coating with mechanical properties sufficient to replace the original chromium plating and the D-gun repair. This development allowed increased repair capabilities, because the coatings can be applied locally and will fulfull the requirements of PWA specifications 46, 49 and 50.

This experiment resulted in significant reduction in J52 engine overhaul turnaround times and indirect production contract costs. The results of these tests were extrapolated to include application on all 12 oil system parts identified for thermal spray coating repair, after fixtures, permanent masks and grinding setups are finalized.

Similar studies are underway to repair other engine components on the GE F404, F404-F1D2, and TF34, with various materials.

About the Author

Donald S. Parker provides engineering support for the Naval Aviation Depot's Thermal Spray Facility, Naval Air Station, Jacksonville, FL 32212, for the overhaul and repair of military jet engines. He also develops new repairs for components that can no longer be successfully chromium- or nickel-plated, or that have worn beyond normal tolerance limits. He has a BS in materials science engineering, specialization in ceramic materials, from the University of Florida, and has taken post-graduate courses in corrosion and surface science. He previously provided engineering support for thermal spray coating repair of helicopter dynamic components and flight control systems for the Naval Aviation Depot, Naval Air Station, Pensacola, FL.

[1] Metco 3007, Daiichi Metco Inc.
[2] Metco Diamond Jet High-velocity Oxy Fuel thermal spray system.
[3] Inconel 718