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Arc Spray Process for the Aircraft and Stationary Gas Turbine Industry

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Technological advances in arc spray have produced a system that competes favorably with other thermal spray processes. In the past, arc spray was thought of as a process for very large parts that need thick buildups. However, an attachment device known as the arc jet system has been developed that focuses the pattern and accelerates the particles. This attachment device, coupled with the introduction of metal-cored wires that provide the same chemistries as plasma-sprayed powders, provides application engineers with a viable economic alternative to existing spray methods. A comparative evaluation of a standard production plasma spray system was conducted with the arc spray process using the attachment device. This evaluation was conducted by an airline company on four major parts coated with nickel-aluminum. Results show that, for these applications, the arc spray process offers several benefits.

Keywords aircraft overhaul, arc spray, process benefits

1. Process Description

THE ARC JET system (Ref 1), is an attachment on the front of a standard production arc gun that introduces secondary air axially. This accelerates the particles being stripped from the arc "ball" and produces a more concentrated pattern. In the process, two consumable wire electrodes are fed into the gun, where they approach each other and form an arc in an atomizing air stream. The process is energy efficient; only enough input energy to melt the wire is used. Spray rate per kilowatt is about 5 lb/h. Substrate temperatures can be low because the energy input per pound of metal is only about one-eighth that of other spray methods.

Plasma provides controllable temperatures well above the melting point of any known substance. To generate the plasma, an inert gas is passed through a direct-current arc and becomes partially ionized. Powder feedstock is introduced and is carried to the workpiece by the plasma jet. Provisions for cooling or regulation of the spray rate may be required to maintain substrate temperatures in the 95 to 205 °C (200 to 400 °F) range. Typical spray rate per kilowatt is 0.2 lb/h, and power ratings of systems range from 14 to 80 kW.

The arc jet process provides high-quality microstructures and bond strengths that exceed plasma for thick coatings up to 2.0 mm (0.080 in.) at any angle from 30° to 90° to the substrate (Fig. 1) (Ref 2). All bond tests were conducted to the ASTM 633 specification. The comparisons show that edge chipping of the machined coating was eliminated, the finish was as good or better for the arc coatings, and the machining time appeared to be improved by 30% for the arc-sprayed parts versus components sprayed by the plasma process. As a result, an airline requested a direct evaluation of the two processes on four actual parts.

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2. Airline Evaluation

At a European airline (using the plasma process in production), a survey was conducted to compare experiences with the arc jet and standard plasma spray systems. This survey evaluated coating quality, spray times, and observations by operators and machinists. The following main engine parts were used: compressor case, spool, compressor rear frame, and compressor rear case.

2.1 *Coating Quality*

All the sprayed materials (Table 1) had been approved by the original equipment manufacturer and were covered by procedures in the standard practices manual. Bond strength tests for the approvals were extensive and are documented in Ref 2.

Coating quality was evaluated by comparing the arc-sprayed microstructures with repair manual specifications. The plasma- and arc-sprayed NiAl microstructures indicated that the overall structure of the arc coating was similar to the plasma coating. The airline quality department reported that the arc coating was as good or better than the plasma coating and met all overhaul manual requirements.

A preliminary one-part spraying and machining evaluation for the amount of chipping and the machining time was then conducted. The results showed no chipping and a 30% reduction in machining time. These results led to the decision to further evaluate this process.

2.2 *Spray Time*

The spray time per part is of significant importance when selecting the production process (Table 2). For comparison,

Table 1 Materials sprayed for survey

Part	Bond coat	Top coat
Compressor case	Ni-5Al	Aluminum
Spool	Ni-5Al	Aluminum
Compressor rear frame	Ni-Cr-Al	Ni-Cr-Al
Compressor rear case	Ni-5Al	Ni-5Al

the plasma spray times were also measured. These spray times need some explanation. All arc spray tests were performed with a 200 A arc jet unit. For the NiAl and the NiCrAl feedstocks, the 200 A unit is sufficient for currents of 175 to 200 A. For aluminum, the current was 200 A. The plasma system used was a standard production external feed unit. Plasma coatings were sprayed at a maximum rate of 12 lb/h. (Note: For production, the 275 to 300 A spray parameter would be used, which delivers aluminum at 18 lb/h.) At higher spray rates, the deposit efficiency increases. Production spray time is reduced further at 300 A.

The four main reasons for the time reduction associated with arc spraying are:

- The arc jet system has higher spray rates with NiAl (18 to 20 lb/h), NiCrAl (15 to 17 lb/h), and Al (12 to 18 lb/h).
- Heat input to the part was low; therefore, thicker coatings could be applied without having to stop the spray processing for cooling.
- Deposit efficiency increased at high currents (Fig. 2).
- There was less need to rework parts subject to chipping during machining.

2.3 *Spray Costs*

The thermal spray costs include a number of factors. Direct costs include feedstock, gases, and other costs dependent on spray time. Nickel-aluminum wire in some cases costs more per pound than powder. However, this wire decreased in price over recent years due to the increased volume used. The costs associated with respraying and setup operations are more difficult to measure. Based on data gathered during the testing period, the airline expected to save $25,000 U.S. dollars per year (Ref 3).

2.4 *Operator and Machinist Survey*

Six operators on two shifts were surveyed at one European overhaul shop. Their comments are summarized in Table 3. Four machinists on two shifts were surveyed at the same overhaul facility. Their comments about machining the parts sprayed for this evaluation are listed in Table 4.

Table 2 Spray times for arc versus plasma at European overhaul facility

Part	Spray time, min Arc	Plasma
Compressor case	60	180
Spool	40	100
Compressor rear frame	30	60
Compressor rear case	12	120

Table 3 Operator survey results

Advantages	Disadvantages
Unit is mobile, small, and compact	Gun is heavier
Simple to set up and use	More dust than plasma
No powder feeder to clean	Only suitable for aluminum
Not necessary to keep spray material in an oven	
Only two parameters to control	
Relatively low noise level	
Low heat input	

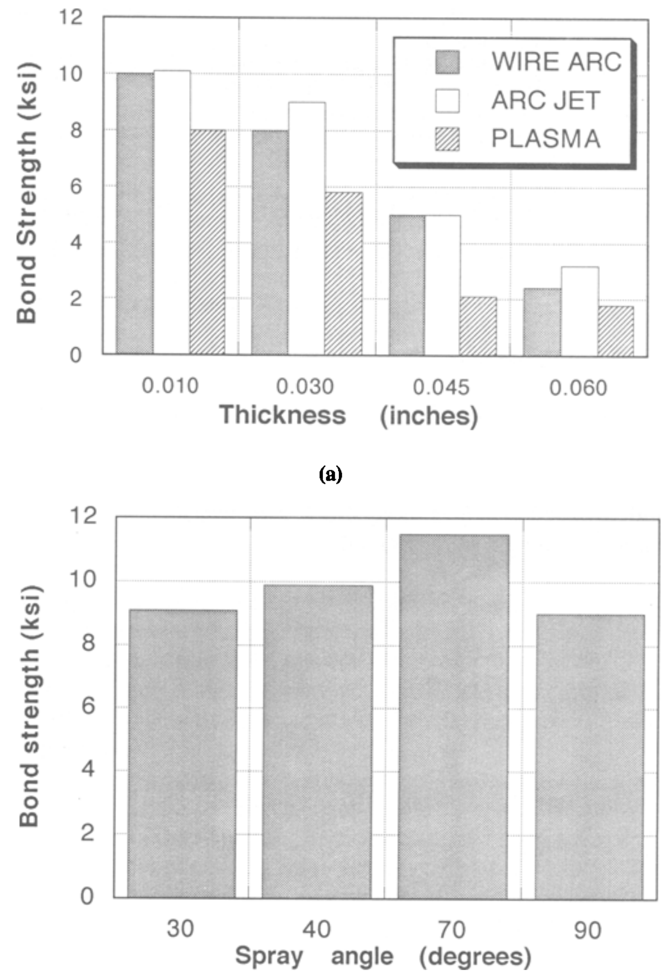

Fig. 1 (a) Bond strength versus thickness of Ni-5Al coatings on stainless steel for the wire arc, arc jet, and plasma processes. (b) Bond strength versus spray angle of Ni-5Al coatings for the arc jet process

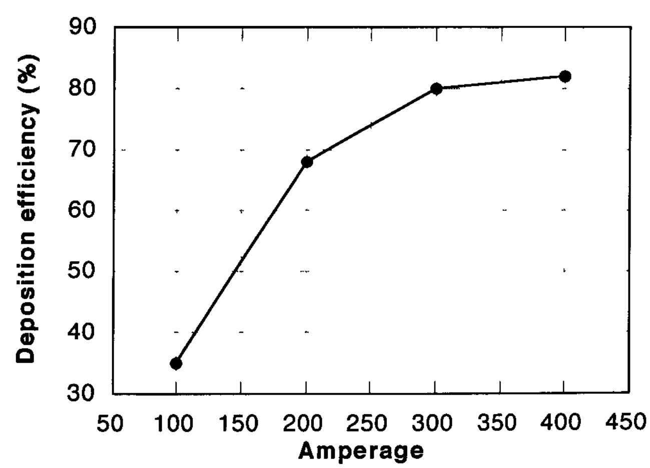

Fig. 2 Deposit efficiency versus amperage of aluminum coatings for the arc jet process

Table 4 Machinist survey results

Coating	Advantages	Disadvantages
NiCrAl	Structure looks finer Less chipping at the edges Tool cuts better Overall quality improved After machining, surface looks very smooth (easy to produce required surface finish)	None
NiAl	All diameters (OD, ID) machine better Material machines very easily Overhaul quality improved Minimum chipping at the edges	None
Al	After machining, coating looks good	As-sprayed coating looks coarse

3. Conclusions

The operator and machinist surveys demonstrated the benefits of the concentrated spray stream generated by the arc jet system. Reduction of spray times up to 50% for the arc jet combined with a reduction of machining times, with no need to rehabilitate chipped coatings, were reported.

This comparative evaluation demonstrated benefits of the arc jet process over the production spray process for the types of parts repaired. Other repair applications in the aircraft engine industry and the industrial gas turbine industry are also expected to benefit from the arc jet process.

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