Use of Flame Sprayed Coatings for Reduction of Initial and Subsequent Repair Costs of Gas Turbines and Components

R. B. HILL
Process Engineer,
Brooks Flame-Spray, Inc.,
Tulsa, Oklahoma

As a result of considering coatings as a tool to parts reclamation, enhancing a part, new parts processing and value analysis, this paper covers the subject title in a manner which the author hopes will give a basis for problem solving by flame sprayed coatings. To assist in this basis, a chart of material analysis, a nomograph of masking time, typical charts of spray, blast, and machine times, and a discussion of a micro surface are included for future reference.
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In the presentation of this paper we will not cover the actual technique or basic process of flame-spraying, but will cover the subject title with the assumption that you know or will know the basic fundamentals of flame-spraying. This paper does not cover the aspect of "Flame Plating," which is a patented process by Union Carbide Corporation, Linde Division.

To start with, familiarity of Table 1 will be beneficial because we will be referring often to materials covered therein. The materials in Table 1 are the more common ones available, but mixtures and blends of these have been applied with success to solve a specific problem.

The characteristics of flame-sprayed coatings range from soft to hard, dense to very porous, and contaminated with oxides to oxide-free. The prime question is, "What is a good coating?" This can only be answered when the coating is considered in its environmental application.

**TYPICAL APPLICATION**

Considering a typical application within a turbine compressor, the problem is one of parts reclamation. The compressor alignment snap diameter wears in service by fretting, which will not allow proper alignment in overhaul reassembly. It is felt, also, that in an effort to extend hours between overhaul, this wear would be sufficient.

**Table 1 Typical Sprayed Material Analysis**

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**Coating Characteristics and Uses**

- 655: Anti-corrosion protection
- 1175: Heat resistant
- 1585: Oxy-free corrosion resistant
- 1758: High wear resistant
- 2638: Abrasion resistant
- 2829: Abrasion resistant
- 6010: Abrasion resistant
- 6020: Abrasion resistant
- 7010: Abrasion resistant
- 7020: Abrasion resistant
- 7030: Abrasion resistant
- 7040: Abrasion resistant
- 7050: Abrasion resistant
- 7060: Abrasion resistant

* Used only in G-1000 F. Nickel precursors to chromium are not longer available
** Used only in G-1500 F. Nickel precursors to chromium are not longer available
TYPICAL RMS OF POROSITY

TYPICAL RMS OF FLATS

Fig.1 Typical Tungsten Composite

500X 10 RMS Finish

Fig.2 Masking Time

Connect point of applicable method and type of part to be processed with Delta Area to estimate time required.

enough to cause a compressor failure during operation. Base material is 7075-T6 anodized aluminum. We know that if we wire-spray aluminum and hard anodize that this will be as good as new, but will not fulfill the requirements for a better wear surface. With a 400 series stainless-steel coating, the question arises: "What would be the galvanic corrosion aspect of bi-metallics in this application?"

First, we must consider the bond material. Molybdenum is an excellent bond material, but highly corrosive in conjunction with aluminum and oxidizes above 600°F. This area, operating in a slightly salty atmosphere, could conceivably approach 800°F. Molybdenum bond is eliminated as a result of these considerations. An exothermic nickel aluminum (Metco 404) is impractical because of its corrosiveness. Two other choices of bond material are nickel aluminum (Metco 450) or nickel titanium (Avco PP-67). Since neither of these materials is highly corrosive, they are workable choices (0.004 to 0.006 in. thick of bond material). Stainless steel 420 series will pass a standard 24-hr salt spray test with results equal to or superior to that of anodized aluminum. This area is then sprayed with 420 stainless-steel wire and finished ground to 63 rms, resulting in a 48 Rockwell-C particle hardness.

Limits must be set on the amount that we are allowed to build up, so consideration must be given to the bond material area and whether it is on an id or od. For example, if we are coating an id

with a diameter of 30 in. and an area width of 1/4 (0.250) in., we must consider shrink and bonding area. With flame-sprayed coatings, the bond is primarily mechanical; therefore, we consider 0.020 in. maximum buildup in this application because of shrink rate and limited bond area. The cost of this rework will range from 10 to 80 percent of new price, depending on the complexity of the part. It must be remembered that the part is now superior to that of the hard anodized original part because of the stainless steel. How did we establish the fact that this repair would cost 10 to 80 percent of new price? In our shop we do not estimate the cost of the new part and pick a number between 10 and 80 and invoice the customer for the results. We estimate rework cost in relation to the machine element for pre-machining and finish machining of the area.

You, in estimating an application or rework, can use the original machine element cost and apply it to either to establish the cost. As can now be seen, coating is directly related to new parts processing.

Cost Analysis

The additional cost above a new production item is masking, grit blasting, and spraying. The more complicated the part, the higher the production costs and the more time consumed in masking (refer to Figs.2-4). The closer the tolerance, the higher the machining time for both production and rework. Now that a decision has been made for a better wear surface, consideration must be focused upon the mating part, since after the application of the 420 stainless steel the problem of the mating part wearing out may arise. Also, it may
be cheaper to allow this snap diameter to wear out rather than the mating part. The application in this aspect would be one of spraying on the silicon aluminum, finish machining, and possibly hard anodizing after flame-spray and machining. It must be kept in mind also that the cost of this application of 420 stainless steel is more than that of the aluminum application because of the grind finish rather than point tool-machine finish. This cost is weighed in extended T.B.O. The question might be asked "why not put on a carbide coating to really extend the wear characteristic of this part?" It is agreed that one could put on a coating that would be a carbide or oxide coating that would outwear the 420 stainless steel and be superior to that of the stainless steel. The decision was made for the 420 stainless-steel wire because the wire process is less expensive. Also, the machine finish can be done by standard grinding wheels. Many of the carbide coatings, which will outwear that of the 420 stainless steel, must be ground finish with a diamond wheel. Consequently, this adds to the cost of the part. An appropriate analogy makes my point: 'Why drive a Rolls Royce back and forth to work when a Ford would do just as well.'

**Seal Areas**

Another consideration would be that of knife-edge seal areas. Most knife-edge seal-mating areas are fabricated from honeycomb, metal felt, and similar materials. Consideration for a flame-sprayed coating in these areas could be nickel graphite or combination of nickel graphite and diatomaceous earth. As seen in Table 1, nickel graphite is good for a maximum of 800 to 1000 F, at which time the graphite will precipitate into nickel carbide. The diatomaceous earth will exceed 1000 F for hot section knife-edge seal areas. The application of nickel graphite can be made for 5 to 10 percent that of the honeycomb or similar materials. Utilization of the sprayed coatings in these areas will eliminate problems resulting from heat treat and heat distortion as a result of the part requiring a furnace treatment for fusion bond to the base material. The part when sprayed will be kept less than 300 F during the entire spray process and does not require a furnace treatment or fuse cycle in order to obtain a bond. The bond obtained by this material will range from 3000 to 6000 psi, depending on the material to which it is applied. Granted, this material will not always replace honeycomb or similar materials for seals, but it is doing a very good job in many areas at a definite reduction in cost.

We could go on and on and give illustrations of coatings, reclamation of parts, extending the T.B.O., solving research and development design problems and a tool for the value analysis group; but rather than dwell on these areas and illustrations of applications, let us consider some of the problems involved in parts reclamation or the coatings of new parts for turbine engines.

**PARTS RECLAMATION**

When considering coatings in view of the finishing, as seen in Table 1 in the hardness column, standard machining can be used except in the carbides and some of the oxide coatings. These coatings must be ground with diamond wheels or some of the other special composite wheels. A grinding technique must be learned and applied in respect to the speeds and feeds used on the sprayed coatings because of the "globular" makeup of the coatings. The wrong technique in this area will result in particle pullout and also cracking. When we speak of techniques here, we are not speaking of any deep dark secrets, but of techniques similar to those of grinding hard chrome so that
cracks are not found in the chrome. Many problems are encountered when using E.C.M., E.D.M., electrostatic grinding, and so forth, but there can also be overcome by technique. A couple of these problems are: electrolyte entrapment causing corrosion of the innerface resulting in failure of the coating or possible failure of the part because of stress corrosion points. Too high a current density will cause an undercut when machining from hard coatings to a soft-base material.

Finishing

In the realm of finishing, there is a controversial area as to what microfinish is really required. To discuss this we must consider the part in its assembly function. For instance, let us consider a sliding piston in a low psi hydraulic application (100 to 200 psi hydraulic fluid). The original part requires an 8 rms finish. This is required to reduce any cylindrical machining marks which would cause excessive wear. With normal wire or plasma spray, it is very difficult to obtain an 8 rms finish economically because of the porosity. As can be seen in Fig.1, the "flats of the particles" would have to be in the 1 to 2 rms range or better. The reason for this is that the profilometer stylist picks up the pores and scatters the average into a wider range. Because the pores are not cylindrically connected, they will not have the same detrimental effects of machining marks that are cylindrical. So it is possible to use this sprayed part at a 16 to 20 rms which would put the "particle flats" in the area of 6 to 10 rms. This consideration must be kept in mind when setting up specifications for use of sprayed coatings. The pores are not longitudinally connected, so leakage is not a problem unless thick coatings are used which would possibly result in edge seepage. In some areas this can be overcome with a sealer-impregnated coating. On the other hand, the porosity in this application could possibly enhance the operation because of the pores which are sometimes referred to as "lubrication reservoirs."

CONCLUSION

This brings up the questions: "What is a good coating?" and "How is quality controlled?" Because flame-spraying primarily is a "state of the art" process, test specimens will be required in setting up initial specifications. In-process tests can be made from eddy-current checks, parts sectioning, panels, and so forth. If a coating is applied poorly, or a wrong selection of material is made, nothing but a failure is obtained; and no one likes failures.

We have already considered flame-spraying from the value analysis approach for parts reclamation, but now take a look at flame-spraying as a means of true value for the design engineer. Flame-spraying requires the following steps:

1. Masking for grit blasting of the base material (Fig.2)
2. Grit blasting for base material preparation (Fig.3)
3. Spraying material buildup (Fig.4)
4. Finish machining (Fig.5)

Flame-sprayed coatings will not:

1. Add strength
2. Reduce strength
3. Stand high-point loading
4. Cause base material property change (except for the hardfacing process)

With these basic requirements, limitations, and aspects in mind, we can now consider flame-spraying to replace heat-treated steels for hard surface requirements, sleeves for bearing retainers, bushing type bearings, knife-edge seal surfaces, compressor and turbine efficiency by adding abrasible coating, organic corrosion coatings, exotic steels for thermo properties. In fact, we have coined the word "Imagenuity" for applications of flame-spraying. With some imagination and ingenuity applied to the three processes, many problems in design can be solved.

In considering any one of the processes for design, your company overhead and labor factor can be applied to the various applicable figures of in-house spraying, when in-house spraying is avail-
able. By applying these figures, an end cost for spraying can be obtained. If no in-house processing is available, many companies specializing in flame-spraying will be more than willing to make quotations and assist in the recommendation of coatings.

Flame-spraying is a process for the reduction of an initial and subsequent repair cost to gas turbines and components, but it is not the answer for solving all problems.