MATERIAL COATING BY THE DETONATION GUN PROCESS

by

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ABSTRACT

There are numerous methods available to repair compressor and turbine shafts when bearing journals, seal surfaces and other critical areas require resurfacing. One of these methods is by the use of detonation gun coatings. The detonation gun is a device that can deposit a variety of metallic and ceramic coating materials at supersonic velocities onto a work piece by controlled detonation of oxygen-acetylene gas mixtures. Coatings applied by this method are characterized by high bond strength, low porosity and high modulus of rupture. This paper describes the equipment used to apply D-Gun coatings and provides data on coating thicknesses used, surface finishes available and physical properties of some popular D-Gun coatings used in machinery repair. Examples are cited showing increases in operating life that can be achieved on various pieces of equipment by properly selected and applied coatings.

INTRODUCTION

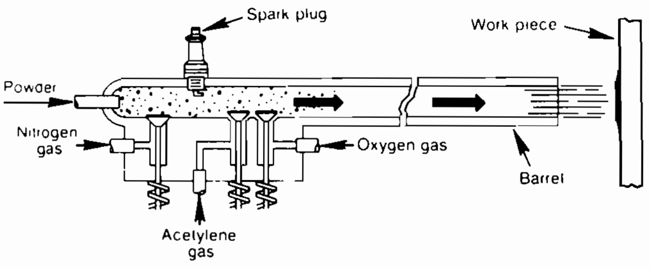
Shaft repairs on turbomachinery and other equipment can be accomplished in many ways. Repair methods have included weld deposit, sleeving, electroplated hard chromium, flame spraying, plasma arc spraying and detonation gun coatings. Each of these various methods has its own advantages and disadvantages. Factors such as time needed to make the repair, cost, machinability, surface hardness, wear resistance, corrosion resistance, material compatibility, friction factor, minimum or maximum allowable coating thickness, surface finish attainable, bond strength, coefficient of thermal expansion, coating porosity and the amount of thermal distortion from the repair; all have varying degrees of importance depending on the particular application. In some cases, the repair method to be used is simply based on the availability of a shop in the area that can make the repair within the desired schedule. Sometimes compromise coatings or repair methods are selected. In other cases, a planned, scheduled and engineered solution is used to affect a repair that provides service life that is far superior to the original equipment.

A properly chosen method of repair can provide improved durability of the repaired part over that of the original part with properties such as higher hardness, better surface finish, improved wear resistance and improved corrosion resistance. Properly chosen coatings can combine the favorable attributes of several materials, thus lessening the compromises that would have to be made if a single material was used. Equipment users have frequently found that repaired components have withstood service better than the original equipment manufacturer's components. This has led many users to specify specialized coatings on key components of new equipment being purchased. In some cases the use of coatings has led to reduced first cost of components since the special properties of coatings allow the use of lower-cost, less exotic base materials.

Comparing repair prices to the purchase price of new parts, assuming that the new parts are available when needed, shows that the price of repaired parts may be only ⅓ to ½ that of new O.E.M. parts. If the repair method eliminates the need for expensive disassembly such as rotor unstacking, the savings become even more dramatic. Coupling these savings with the frequently extended service life of the repaired parts over the original ones, which in turn extends periods between inspections and repairs, the coating repair of parts is extremely attractive from an economic standpoint.

PROCESS DETAILS

This paper will concentrate on the detonation gun process of coating which is often referred to as the D-Gun process. The system is shown schematically in Figure 1 and pictorially in Figure 2. It consists of a water-cooled gun barrel, approximately 3 feet long, that is fed with oxygen, acetylene and coating powder. Ignition of the oxygen-acetylene mixture is accomplished by means of a spark plug. The detonation wave in the gun barrel, resulting from the ignition of the gas mixture, travels at ten times the speed of sound through the barrel and temperatures reach or exceed 6000°F inside the gun. Noise levels generated by the D-Gun require isolating the process in a noise attentuating enclosure. The equipment operator monitors the coating operation from a control console while observing the operation through a view port. Detonation is cyclic and subsequent to each detonation, the barrel is purged with nitrogen before a fresh charge of oxygen, acetylene and coating powder is admitted. The particles of coating powder are heated to plasticity and are ejected at supersonic speeds averaging approximately 2500 feet per second. Kinetic energy of the D-Gun particles is approximately ten times the kinetic energy per unit mass of particles in a conventional plasma arc



Detonation Gun Schematic

Figure 1.

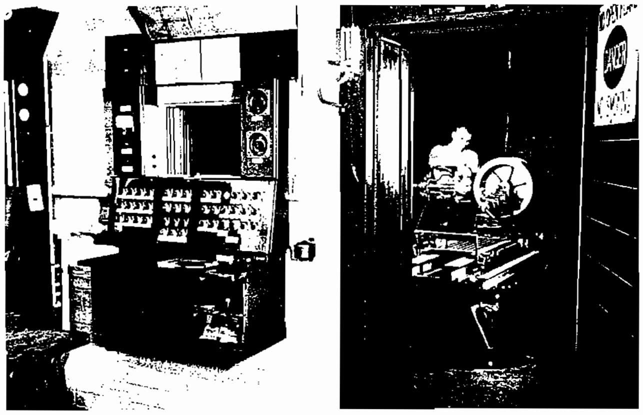


Figure 2. D-Gun Installation.

Figure 3. D-Gun Coated Piston Rod.

gun and twenty-five times the energy of particles in an oxy-acetylene spray gun. The high temperature, high velocity coating particles imbed into the surface of the part being coated and a combination of mechanical interlocking and microscopic welding action may take place, giving a very strong coating bond at the interface and low porosity in the coating. This coating does not depend on a severely roughened surface to provide mechanical interlocking to obtain a bond. Surface preparation for hardened steel consists of grinding to the desired undersize plus grit blasting. Titanium parts do not need grit blasting before coating.

In spite of the high temperatures generated in the barrel of the D-Gun, the part being plated remains below 300°F, so there is little chance of part warpage and the base material metallurgy is not affected.

COATING DETAILS

The D-Gun deposits a very thin coating of material per detonation so multiple passes are used to build up to the final coating thickness. Figure 3 shows the pattern formed by the overlapping circular deposits being built up on the surface of a piston rod. Finished coating thickness may be as low as 1.5 to 2 mils for some high pressure applications such as injection pump plungers or polyethylene compressor piston rods but many typical applications use thicknesses of 3 to 5 mils. Greater thicknesses may be used for repair jobs. Finished thicknesses greater than is practical for a given cermet or ceramic coating may require prior build-up with metallic coatings such as nickel. Generally 3 to 5 mils of additional coating thickness is deposited to allow for final finishing of a part to its required size.

The as-deposited surface finishes of carbide coatings are in the range of 120 to 150 microinches rms when deposited on a smooth base material. Finishing of low tolerance parts, such as bearing journals, is usually accomplished by diamond grinding. Parts that don't require extremely close dimensional control such as hot gas expander blades can be left as coated or, if a smoother finish is desired, they can be given a non-dimensional finishing by means of abrasive belts or wet brushing with an abrasive slurry.

A number of ceramic and metallic coatings are available for application with the D-Gun. These include mixtures or alloys of aluminum oxide, chromium oxide, titanium dioxide, tungsten carbide, chromium carbide, titanium carbide, cobalt, nickel and chromium. Figure 4 lists some of the more popular coatings with their compositions and some key physical properties. Tungsten carbide and cobalt mixtures are frequently used for coating journal areas and seal areas of shafts. In cases where additional corrosion resistance is required, the tungsten carbide and cobalt mixtures have chromium added. Such a powder is often used on the seal areas of rotors. Greater oxidation and corrosion resistance at elevated temperatures are accomplished by using powder with chromium and nickel in conjunction with either tungsten carbide or chromium carbide.

Metallic coatings applied by the D-Gun have high bond strengths. Bond strengths, as measured per ASTM C633-69 modified to use a reduced coating thickness of 10 mils, are in excess of 10,000 psi which is the limit of the epoxy used in the test. Special laboratory methods of testing bond strengths of D-Gun coatings by a brazing technique have given values in excess of 25,000 psi. This type of test, however, does change the coating structure. Porosity is less than two percent by volume for these coatings. Figure 5 shows a photomicrograph of a tungsten carbide coating applied to steel. The original photo was taken through a 200 power microscope. The markers in the margin denote from top to bottom: the coating surface, tungsten carbide and cobalt coating, bond interface and base metal. The tight bond and low porosity are clearly evident. Low porosity is an important factor in corrosion resistance and it enhances the ability of a coating to take a fine surface finish. A combination of grinding, honing and polishing is routinely used to finish tungsten carbide coatings to 8 microinches and finishes as fine as 2 microinches or better are attainable with these coatings.

Carbide coatings exhibit excellent wear resistance by vir-

COMMERCIAL DESIGNATION	LW-IN30	LW-15	LW-5	LC-1C
Nominal Composition (Weight %)(a)	87WC, 13Co	86WC, 10Co, 4Cr	73WC, 20Cr, 7Ni	$80Cr_3C_2$, 16Ni, 4Cr
Tensile Bond Strength (psi) (b)	>10,000	>10,000	>10,000	>10,000
Modulus of Rupture (psi)	90,000		40,000	70,000
Modulus of Elasticity (psi)	31 X 10^6		17 X 10^6	18 X 10^6
Metallographic Apparent Porosity (Vol. %)	≤1	≤1.5	<1	≤1
Nominal Vicker's Hardness (kg/mm^2, 300 g load)	1150 HV	1100 HV	1100 HV	775 HV
Rockwell "C" Hardness - Approx.	71	70	70	63
Max. Rec. Operating Temp. (°F)	1000	1000	1400	1400
Avg. Coef. of Thermal Expansion (in/in/°F)	4.5 X 10^{-6} (70 to 1000°F)	4.2 X 10^{-6} (70 to 1832°F)	4.6 X 10^{-6} (70 to 1400°F)	6.1 X 10^{-6} (70 to 1475°F)
Characteristics	Extreme Wear Resistance	Good Wear Resistance to Approx. 1000°F. Greater corrosion Resistance than WC-Co.	Good Wear Resistance to Approx. 1400°F. Greater oxidation and corrosion Resistance than WC-Co.	Excellent Wear Resistance at Elevated Temp.

(a) The composition shown represents the total chemical composition, but not the complex microstructural phases present.

(b) Measured per ASTM C633-69 modified to use a reduced coating thickness of 10 mils.

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Figure 4. Physical Properties of Some UCAR® D-Gun Coatings.

Figure 5. Photomicrograph Tungsten Carbide-Cobalt Coating.

tue of their high hardnesses. Chromium carbide coatings have a cross sectional Vickers hardness number (HV) in the range of 650 to 900 kg/mm^2 based on a 300 g. load which is approximately equal to 58 to 67 Rockwell "C". The tungsten carbide coatings are in the range of 1000 to 1400 HV or approximately 69 to 74 Rockwell "C".

LIMITATIONS

All thermal spray-applied coatings have restrictions in their application since a line of sight is needed between the gun and the surface to be coated. The barrel of a D-Gun is positioned several inches away from the surface to be coated and the angle of impingement can be as little as 45° to direct impingement at 90°. Coating of outside surfaces generally presents no problem, but small diameter, deep or blind holes may be a problem. It is possible to coat into holes when the length is no more than the diameter. The structure and properties of the coating may vary somewhat as a function of the geometry of the part, because of variations in angle of impingement, stand-off, etc. Portions of a part in close proximity to the area being plated may require masking with metal.

APPLICATIONS

Detonation gun coatings have been used in a large number of applications for rotating and reciprocating machinery as well as for special tools, cutters and measuring instruments; [1] and [2] attest to the success of such coatings. The tungsten carbide family of coatings has been used principally for its wear resistance. Tungsten carbide is combined with up to 15%

cobalt by weight. Decreasing the amount of cobalt increases wear resistance, while adding cobalt increases thermal and mechanical shock resistance. Coatings of this type are frequently used to coat bearing journals and seal areas on compressors, steam turbines and gas turbines. These coatings have a high resistance to fretting and they have been used on midspan stiffeners of blades for axial flow compressors. Their fretting resistance and ability to carry high compressive loads make them suitable to correct loose interference fits on impellers and coupling hubs. Addition of chromium to the tungsten carbide and cobalt mixtures adds corrosion resistance and improve wear resistance at higher temperature levels. In general, this family of coatings is most frequently used in neutral chemical environments but can be used with many oxidizing acids. Cobalt mixture coatings are usually not used in strongly alkaline environments.

Coatings that combine tungsten carbide with chromium and nickel exhibit greater oxidation and corrosive resistance than the tungsten carbide-cobalt mixtures. Their wear resistance capabilities are good up to 1400°F which is about 400°F higher than that of the tungsten carbide-cobalt coatings. This higher temperature capability makes these coatings useful for applications such as coating rotor blades on hot gas expanders used for power recovery from catalytic crackers. Coated blades resist the wear from catalyst fines and have extended life from just a few months, as experienced with uncoated blades, to a life of three to five years. This type of coating is suitable for use in many alkaline environments.

Chromium carbide combined with nickel and chromium provides excellent wear resistance at elevated temperatures and is recommended for temperatures up to 1400°F. These coatings do not have a hardness as high as tungsten carbide mixtures at lower temperatures, but they do perform well at high temperatures. Such coatings have found numerous applications in hot sections of gas turbines. Cobalt base alloys with excellent wear resistance to temperatures over 1800°F are also available.

In applications where hydrogen sulfide is present, ferrous base materials should not exceed a hardness of 22 Rockwell "C", per recommendation of the National Association of Corrosion Engineers, in order to avoid sulfide stress cracking. The tungsten carbide-cobalt-chromium coatings and tungsten carbide-chromium-nickel coatings have imparted wear resistant overlays on parts in such service while the base material retains a low hardness to avoid sulfide stress cracking.

Application of D-Gun coatings on reciprocating machinery has resulted in extended parts life. Uncoated hardened Monel piston rods in oxygen booster compressors that previously required rod resurfacing in one to two years of service have shown virtually no measurable wear in five to six years of service when coated with tungsten carbide-cobalt coatings. In addition, average life of the gas pressure packings went up by a factor of more than two. The high bond strength of the D-Gun coatings proves useful on polyethylene hypercompressors. There have been examples of tungsten carbide-cobalt coated plunger pistons that have operated 16,000 hours at 20,000 psi with a wear of only 1 mil and without any coating peeling problems.

SUMMARY

Detonation gun coatings have proven to be successful to both designers and maintenance engineers as a means of providing dependable wear and corrosive resistant surfaces on machine components operating under difficult service conditions. Properly selected coatings used within their intended limits, are significantly capable of extending wear life of parts. The extended wear life reduces the ratio of parts cost per operating hour, justifying the expenditure for coatings on both new and refurbished equipment.

REFERENCES

1. Locke, J. J., "Cobalt Alloy Overlays in a Petro-Chemical Refinery," COBALT 1974-2, pp. 25-31.
2. Mendenhall, M. D., "Shaft Overlays Proven Effective," Hydrocarbon Processing, pp. 191-192, May 1980.