International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:5, No:6, 2011

Residual Stresses in Thermally Sprayed Gas Turbine Components

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***Abstract*—**In this paper, the residual stress of thermal spray coatings in gas turbine component by curvature method has been studied. The samples and shaft were coated by hard WC-12Co cermets using high velocity oxy fuel (HVOF) after preparation in same conditions. The curvature of coated samples was measured by using of coordinate measurement machine (CMM). The metallurgical and Tribological studies has been made on the coated shaft using optical microscopy and scanning electron microscopy (SEM)

***Keywords*—**Thermal spray, Residual stress, Wear mechanism, HVOF, Gas compressor shafts

I. Introduction

SUBSTITUTION of hard chromium plating has been promoted due to the new legislation concerned to hazardous wastes of Galvanic Industries over the last years. Thermal spray technology has been proposed as an alternative to hard chromium plating showing in some applications promising results. For instance, one requirement for tungsten carbide coatings is to have better wear and fatigue properties than hard chromium when applied in aircraft manufacturing [1], [2]. Thermal spraying with high velocity oxygen fuel (HVOF) has been very successful in spraying wear resistant WC–Co coatings with higher density, superior bond strengths and less decarburization than many other thermal spray processes. This is attributed mainly to its high particle impact velocities and relatively low peak particle temperatures [3]. As a class of hard composite materials of great technological importance, WC–Co powder cemented carbides are widely used by various thermal spray processes to deposit protective coatings in a large variety of applications such as power plants, oil drilling, turning, cutting and milling, where abrasion, erosion and other forms of wear exist [4]. Less attention has been given to develop thick coatings for repair applications, which is significant interest for the aerospace industry. One challenge is to control the residual stresses through the deposit thickness when a coating to be sprayed is several millimeters thick, and to understand the relationship between these stresses and coating adhesion. The adhesion strength of a coating is depends on the bonding between the coating and substrate as well as on the coating microstructure. Both the bonding and the microstructure are strongly influenced by residual stress distribution. It is commonly known that the level of residual stresses can significantly change at the coating substrate interface creating delaminations, which in worst cases can cause spallation. Compressive residual stresses at the interface are known to inhibit the formation of through thickness cracks and to improve adhesion bonding and fatigue strength [5], [6].In this paper, the residual stress of thermal spray coatings in gas turbine elements by curvature method has been studied. The samples and shaft were coated by hard WC-12Co cermets using high velocity oxy fuel (HVOF) after preparation in same conditions. The curvature of coated samples was measured by using of coordinate measurement machine (CMM). The metallurgical and tribological studies have been made on the coated shaft using optical microscopy and scanning electron microscopy (SEM).

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II. Experimental Procedure

The coating was deposited industrially by employing a HVOF gun type Metjet III onto AISI 1045 steel substrate samples of 120×20×1 mm^3. The WC-12Co powder used had a particle size between ~15 and 40µm. A spraying distance of 340±10 mm, a spraying angle of 90^o, kerosene flux of 25 l/min, oxygen flux of 83 l/min, were the main parameters indicated by the spraying company. Before deposition the substrate was grit blasted with alumina particles with 16µm mesh. The average roughness value (R_a), determined by optical profilometery. Coatings with thickness of 400±50 µm were thermally sprayed. In the as deposited condition, the coating had an average roughness of ~4 µm. Subsequently, the coating was ground in order to achieve uniform thickness of 160 µm. The roughness of as ground coating was ~0.2 µm. The coating hardness was 1000-1200 HV_{30N}. The microstructure of the coatings was investigated by canning electron microscopy (SEM). The observations were done both on the cross section and the deposition top surface. The average coating porosity was determined by optical microscopy and image analysis of the cross section of the samples. The present phases in the powder and coating were investigated using X-ray diffraction.

III. Residual Stress Measurment Techniques

A number of techniques have been used in the past decades to measure residual stresses in thermal spray coatings. Curvature measurement method relay on the monitoring of changes in component distortion, either during deposition or after. The modified Layer Removal Methods use material removing to allow relaxation of the stresses. Layers are removed by polishing one side of specimen, then the stresses become unbalanced and the specimen bends. Diffraction methods (X-Ray and Neutron) are based on the elastic deformation within polycrystalline material to measure internal stresses in a material. The stresses cause deformation i.e., change in the distance between the lattices, which are used as internal strain gages. Shift in diffraction peaks are recorded from which the strain distribution is calculated. Compared to low energy X-rays the main advantage of working with neutrons is the Possibility to analyze greater depths, i.e., higher coating thickness.The through-thickness stress field is also determinable. By means of the incremental hole drilling method the tests conduct by carrying out successive drilling steps in depth until the substrate be reached[7-10]

IV. Results And Discussion

Fig.1 shows the SEM micrograph of WC- 12%Co powder to be used. The shape of powder particle is spherical in range of 12-40 µm. As mentioned in literatures [11] the spherical particles require less kinetic energy to have a effective peening action and good bonding to the substrate.

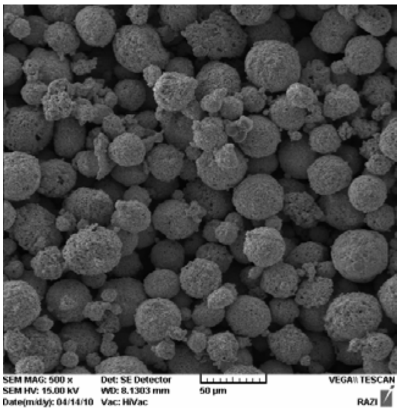


Fig. 1 powder Morphology by SEM micrograph

Fig.2 illustrates a general view of the coating after metallographic preparation. The WC-12Co HVOF thermally sprayed coating appear to be quiet dense. The presence of lamella boundaries, pores and equiaxial WC grain of different size embedded in the Co matrix is apparent.

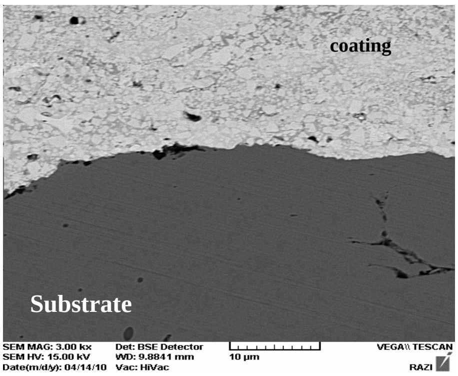


Fig. 2 General view of the coating-substrate cross section

Usually, the coated specimen bends gradually with the coating deposition, which is attributed to the actions of residual stress in the coating. If there is no stress existing in the coating, then the coated specimen will be relatively flat. Actually, it is impossible that no residual stress is introduced absolutely during the coating deposition process.Five AISI 1045 steel substrate samples of 120×20×1.5 mm^3 were used for residual stress evaluation by curvature method. Coatings with thickness of 650±50 µm were thermally sprayed. The curvature of coated strip was measured by use of Coordinate Measurement Machine (CMM). Residual stress was calculated according to Stony formulation:

$$\sigma_r = -\frac{kE_s t_s^{\,2}}{6(1-\nu_s)t_c}$$

Which

$$K = \frac{1}{R} = \frac{L_{arc}}{\cos^{-1}(1-\frac{\Delta X}{R})}$$

Superposition of residual stresses with tensile and compression natures are evaluated to be compressive. The mean value estimated for residual stress was -189 MPa in these coatings.

Tie Gang et al. developed a formulation to estimate the residual stress from the curvature of substrate-coating in thick coatings [12]. According to their calculations the residual stress of the coating is obtained by:

$$\sigma_r = -\frac{kE_s t_s^{\,2}}{6(1-\nu_s)t_c}\delta$$

$$(\delta = 1 + 4et + 6et^2 + 4et^3 + e^2t^4)/(1 + t)$$

Where:

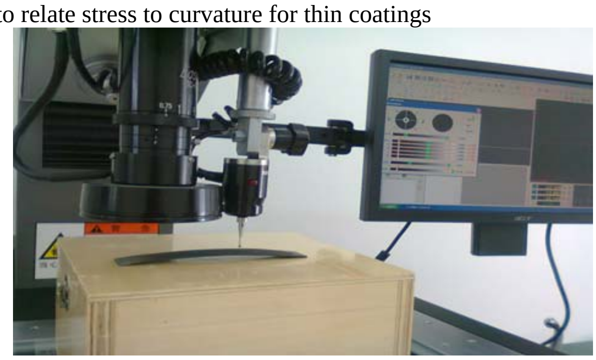
$$e = \frac{E_c^{\,*}}{E_s^{\,*}}; t = \frac{h_c}{h_s}$$

Where:

$$E_s^{\,*} = E_s/(1-\nu_s);$$

$$E_c^{\,*} = E_c/(1-\nu_c);$$

Where δ is the stress correction coefficient. When the coating thickness is much less than that of the substrate, $\delta \approx 1$, the form of mentioned equation is in accordance with the Stony formula which is commonly used to relate stress to curvature for thin coatings



V. CONCLUSION

The residual stress of gas turbine parts has been investigated. High velocity oxy fuel thermally spraying process and metallurgical analyses are employed for this purpose. A summery of conclusions is as follow:

- The resultant stress state in coated shafts is compressive stress. This is because of severe peening action in HVOF thermal spraying.

- High velocity oxy fuel thermal spray is an excellent choice for renewing the worn parts because of good adhesion, cohesion and fatigue strength.

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