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Residual Stress in Ground WC-Co Coatings

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Abstract**—**High velocity oxygen fuel (HVOF) spray technique is one of the leading technologies that have been proposed as an alternative to the replacement of electrolytic hard chromium plating in a number of engineering applications. In this study, WC-Co powder was coated on AISI1045 steel using high velocity oxy fuel (HVOF) method. The $\sin^2\psi$ method was used to evaluate the through thickness residual stress by means of XRD after mechanical layer removal process (only grinding). The average of through thickness residual stress using X-Ray diffraction was -400 MPa.

Keywords**—**Grinding, HVOF, Thermal spray, WC-Co.

I. Introduction

THERMAL spraying is a promising method replacing the hazardous chrome plating in the finishing industry. This method has demonstrated to have superior wear and fatigue properties when compared to hard chromium using cermets e.g. tungsten carbide-cobalt (WC-Co). High velocity oxy fuel (HVOF) coatings have exhibited wear resistant WC-Co coating with high density; superior bond strength and less decarburization than many other thermal spray methods. This is attributed to its high particle impact velocities and relative low peak particle temperature. Over the last years, the substitution of hard chromium plating has been promoted due to the new legislation concerned to hazardous wastes of galvanic Industries. In high velocity oxy fuel (HVOF) thermally spraying powder particles are accelerated in supersonic velocities toward the substrate (Fig. 1).

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], [4].

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.

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In this study, WC-Co powder was coated on AISI1045 steel using high velocity oxy fuel (HVOF) method and the effect of grinding processes on the surface residual stress was investigated. The result shows the presence enormous stress in the coating surface when compared with as sprayed or polished WC-12Co coatings.

II. Experimental Procedure

Studies were conducted using optical microscopy, scanning electron microscopy (SEM) and X-ray diffraction. The WC-Co coating was deposited industrially by employing a HVOF gun METJETIII onto AISI 1045 steel substrate. The WC-12Co powder used had a particle size between ~15 and 40µm. The main parameters indicated by the spraying company. Before deposition the substrates were grit blasted using alumina particles with 16µm mesh. Coatings with thickness of 300±50µm were thermally sprayed. In the as deposited condition, the coating had an average roughness of ~4µm. The spray parameters were according to Table I. The X-ray diffraction was applied using Cu-Kα radiation. The stress at the surface measured using $\sin^2\psi$ technique.

TABLE I
THERMAL SPRAYING PARAMETERS

F/O ratio (ml/min)	3.5
Feed rate (l/min)	38
Spray distance (mm)	250
Spray angle (deg)	90

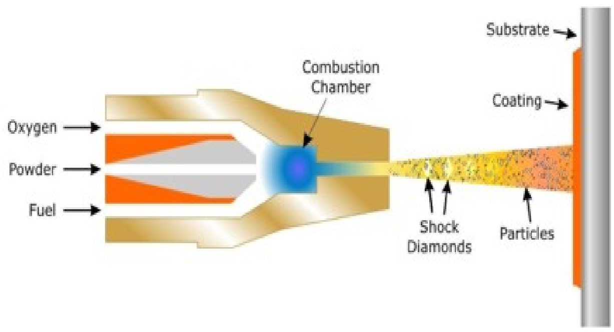

Fig. 1 HVOF thermal spray process

III. Results and Discussion

A. Crystallographic characterization

Fig. 2 illustrates the XRD pattern of WC-12Co powder. As it can be seen from the patterns the peaks are attributed to WC and Co. Fig. 3 illustrates the XRD pattern of the coating. As it can be seen the patterns correspond to presence of WC, W_2C and W_3Co_3C. The presence of W_2C and W_6Co_6C are thought to be due to decomposition of WC at high temperature of flame jet and abundant amount of oxygen when the powders are accelerated. Decarburization of WC has been reported in the literature to affect the coating hardness and wear resistance [2]. In the work of Stewart et al. [4], it has been established that the formation of W_2C upon splat quenching is caused by dissolution of WC in Co matrix whereas the formation of elementary W depended on the composition of the starting powder. Yang et al. [5] showed that larger degree of WC decomposition is correlated to a smaller carbide grain size in the starting powder. Other forms of W-Co-C may also be present in the matrix in the form of $W_xCo_yC_z$ which are not detected by the XRD method due to their low content or high dispersion in the coating.

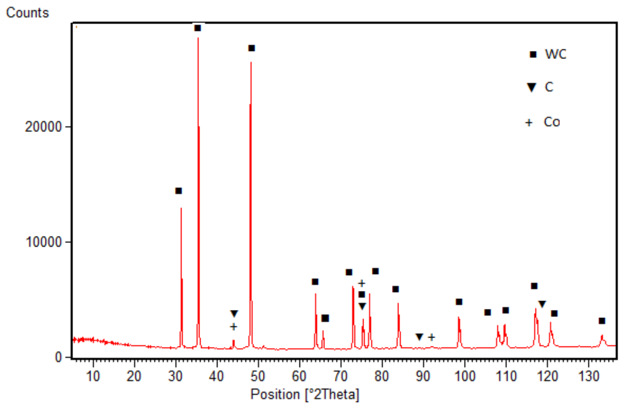

Fig. 2 XRD pattern of WC-Co powder

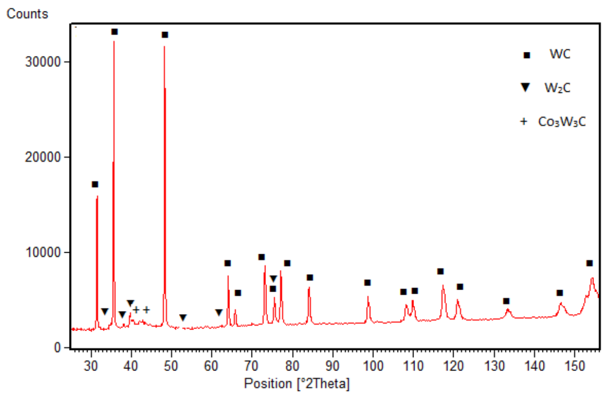

Fig. 3 XRD pattern of WC-12Co coating

B. Residual Stress

For WC-12Co multiphase coating, the determined stresses by X-ray diffraction concern only the dominant phase(WC), which can be taken as the residual stresses on the surface of the coating [5]. The strains in the samples were measured using peak position (2θ~133.48°) of WC. Positive and negative tilts were applied over the full range for $\sin^2\psi=0$ up to 0.8 with step of 0.1.

The analysis results of the residual stresses in the WC phase at the surface of the as-coated and ground samples indicated a linear dependency of strains and d-spacing versus $\sin^2\psi$. Thus, it was assumed that the coating is under an equibiaxial stress state with $\sigma_{22}=\sigma_{33}$ and $\sigma_{11}=0$. Because the penetration depth of X-ray in WC-Co is very small (~2-5μm) [5] the resulting measurements refer specifically to surface of WC-Co coating thus only plane stresses were measured. As the measured strains for (ψ<0 and ψ>0) is linear function of $\sin^2\psi$, the shear stress components were negligible. So the residual stress can be obtained from the slop of strain-$\sin^2\psi$ plot:

$$\sigma_\phi = \frac{mE}{(1+\nu)} \tag{1}$$

The stresses were measured in different thickness after layer removal by grinding. The results show the similar values for different layers seem to be independent of coating residual stress state. Fig. 4 shows the ε-$\sin^2\psi$ for different thickness. Residual stress through the coating thickness is showed in Fig. 5 the average of residual stress generated by grinding thickness was -400 MPa.

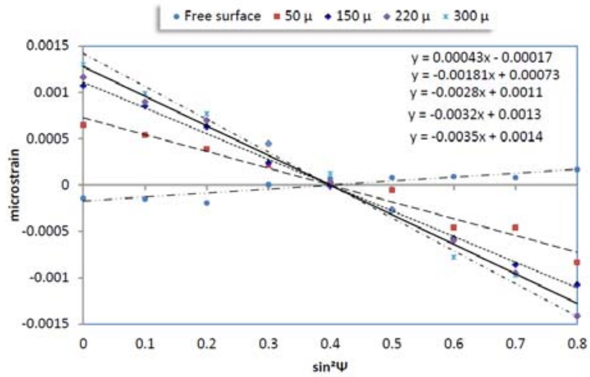

Fig. 4 Micro-strains vs. $\sin^2\psi$

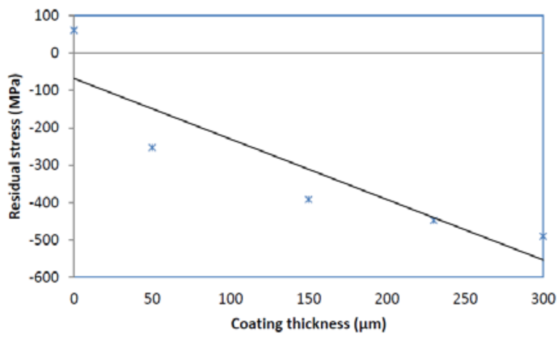

Fig. 5 Residual stress vs. coating thickness

IV. Conclusion

Specification, composition and present phase samples coated using high velocity oxy fuel thermally spraying process has been investigated. Metallurgical and mechanical investigations were employed for this purpose. The results show the huge compressive residual stress which seems independent from residual stresses exists in as coat material

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