

A. ÖZ, R. SAMUR, H. MINDIVAN, A. DEMİR, S. SAGIROGLU, A. K. YAKUT

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## EFFECT OF HEAT TREATMENT ON THE WEAR AND CORROSION BEHAVIORS OF A GRAY CAST IRON COATED WITH A COLMONOY 88 ALLOY DEPOSITED BY HIGH VELOCITY OXYGEN FUEL (HVOF) THERMAL SPRAY

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Preliminary Note – Prethodno priopćenje

The present work has been conducted in order to determine the influence of heat treatment on the wear and corrosion behaviours of a gray cast iron substrate coated with a Ni base coating deposited by HVOF thermal spray. The wear resistance of the coatings was obtained using a reciprocating wear tester by rubbing a 10 mm diameter steel ball on the coatings at normal atmospheric conditions. Corrosion tests were performed using potentiodynamic polarization measurements in a 3,5 % NaCl solution. It was observed that the corrosion and wear resistance of the coatings increased along with the reduction of porosity and roughness by the heat treatment.

**Key words:** Corrosion, HVOF, Ni-based coating, post-heat treatment, wear.

### INTRODUCTION

Thermal-sprayed coatings are surface coatings engineered to improve component performance relative to the bulk material used as substrate [1]. However, corrosion resistance is important as well as the mechanical properties, adhesion and metallurgical stability must be considered when designing a coating by means of different thermal spraying systems. Coatings applied using the HVOF technique have a high mass density and produce good adhesion and mechanical strength. However, even with the choice of this deposition technique, it is not possible to achieve defect free thermal spray coatings. Difficulties arise due to the mismatch in elastic modulus, thermal expansion coefficients, hardness between the surface layer and the substrate material, substrate compatibility, inter-diffusion, adhesion and porosity of the coatings [2-5]. The best performing and most suitable properties for a given application can in principle be achieved by a microstructural optimization. Post treatment of thermal spray coatings could potentially be an effective practice to improve or change the coating microstructure, thus avoiding some or all of the limitations of sprayed coatings.

Therefore, the present work was undertaken with the aim of determining the influence of the post-heat treatment on the microstructure, wear and corrosion behaviour of an HVOF nickel-based alloy.

### EXPERIMENTAL DETAILS

Samples of 20 mm diameter gray cast iron were HVOF coated at industrial level with a commercial alloy of NiWCrBSi powder (Colmonoy 88). Prior to spray coating, an intermediary Ni-Cr layer was applied as a bonding coat to enhance adhesion and reduce thermal expansion mismatch between the substrate and coating layer. The thickness of the bond coating was less than 50  $\mu\text{m}$ . The as-deposited samples without the Ni-Cr layer were post-heat treated by using oxyacetylene flame. The post-heat treatment was performed at 1050 °C.

The characterization of each of the as-deposited and the heat-treated coatings was made by microscopic examinations, thickness, porosity, roughness and hardness measurements. Microstructural evaluation of the coatings was carried out by using an Optical Microscopy (OM). Apparent porosity of the coatings was determined by linear intercept method on the polished cross-sections of all samples. Surface roughness of the coatings was determined by a stylus profilometer. Hardness measurements in the cross-section were conducted on a Wolpert HMV2 microhardness tester by applying an indentation load of 200 g with a Vickers indenter. The reported Vickers microhardness ( $HV_{0.2}$ ) values were based on the average value of ten readings on the coating surface.

Wear tests were carried out under normal atmospheric conditions ( $20 \pm 2$  °C and  $40 \pm 5$  % RH) on a reciprocating wear tester. All experiments were carried out under a constant normal load of 2 N using a 10 mm diameter steel ball, and sliding speeds from 0,0128 to 0,0567  $\text{ms}^{-1}$  with increments of 0,014  $\text{ms}^{-1}$ . After the wear tests, the wear tracks formed on the coatings were detected by a stylus profilometer using the software ver-

A. Öz, Mehmet Akif Ersoy University, Burdur, Turkey; R. Samur, Marmara University, İstanbul, Turkey; H. Mindivan, Ataturk University, Erzurum, Turkey; A. Demir, Marmara University, İstanbul, Turkey; S. Sagioglu, Karabuk University, Karabuk, Turkey; A. K. Yakut, Suleyman Demirel University, Isparta, Turkey.

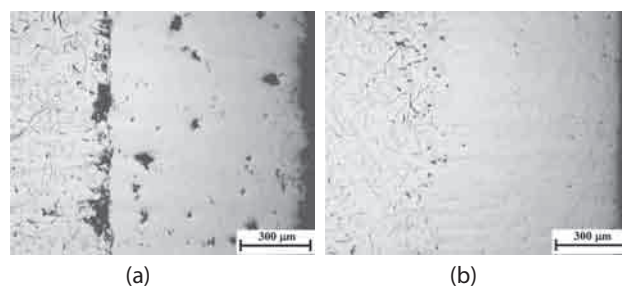
sion of MarSurf PS1 Explorer to quantify the test results in terms of the wear track area. Wear track area values of the coatings were then converted into Relative Wear Rate (RWR) by assuming the RWR of the as-sprayed coating under a sliding velocity of 0,0375 m/s to be 100. After the wear test, wear tracks formed on the surfaces of the coatings were examined using a Scanning Electron Microscope (SEM).

Evaluation of the corrosion was determined by potentiodynamic polarization measurement. For the potentiodynamic polarization measurement, machined samples (square cube shaped samples with an average size of 2 mm x 2 mm) were mounted on copper rod using epoxy resin for electrical connection, and open surfaces of all samples were ground with 1 200 mesh SiC abrasive paper and then cleaned with deionized water followed by rinsing with methanol and then dried. The potentiodynamic polarization measurement was carried out using a Gamry model PC4/300 mA potentiostat/galvanostat controlled by a computer with DC 105 Corrosion analysis software. All the corrosion experiments were performed at the room temperature in a glass cell containing 3,5 % NaCl solution. Each polarisation experiment was carried out holding the electrode for 45 minutes at open circuit potential ( $E_o$ ) to allow steady-state to be achieved. Potentiodynamic polarization curves were generated by sweeping the potential from cathodic to anodic direction at a scan rate of  $1\text{ mVs}^{-1}$ , starting from  $-0,25$  up to  $+1$  V. Each data point for potentiodynamic polarisation tests represents at least an average of three different measurements.

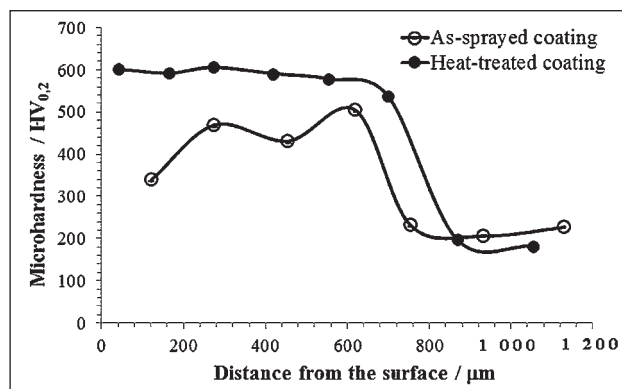
## RESULTS & DISCUSSION

Figure 1 shows the cross-section of the coatings sprayed on gray cast iron substrates for comparison. When compared with the heat-treated coating, relatively coarse pores were formed in the as-sprayed coating. Quantitative metallographic studies revealed that the porosities of the as-sprayed and heat-treated coatings are 2,5 % and 0,1 %, respectively. Porosity is completely eliminated after the heat treatment. Furthermore, no evidence of delamination or spalling has been detected along the interface of the heat-treated coating (Figure 1 b). This is an indication of the formation of a metallurgical bond between the coating and substrate. The diffusion process, which has occurred for the heat-treated coating, will assure a better bond between the coating and substrate. The final coating thickness for all samples was controlled at  $\sim 800\ \mu\text{m}$ . Roughness value in the as-sprayed condition ( $6,06\ \mu\text{m}$ ) is lower than that obtained in the heat-treated coating ( $1,15\ \mu\text{m}$ ). Coating melted by the heat treatment strongly decreases the roughness parameters achieving, a final hard surface.

Figure 2 shows the variation of the microhardness through the thickness for each coating. Microhardness value of an average of  $435 \pm 75\ \text{HV}_{0,2}$  was measured for the as-sprayed coating. For the heat-treated coating, mi-



**Figure 1** Optical micrographs of the a) as-sprayed and b) heat-treated coatings



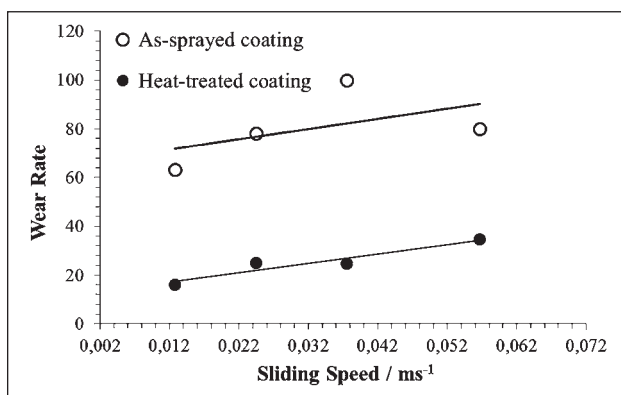
**Figure 2** Variation of coating microhardness with the distance from the coating surface

crohardness value of  $585 \pm 20\ \text{HV}_{0,2}$  was obtained. This latter value shows an increase of 35 % when compared to the microhardness value obtained for the as-sprayed coating, representing the consequence of the homogeneous distribution of hard phases and a decrease of both the porosity and the number of un-melted particles induced by heat treatment. The non-uniformity of the composition of the as-sprayed coating was confirmed by the standard deviation of the Vickers microhardness value. The results of the measurements performed on the substrate, in the close vicinity of the interface with the bottom layer, show a lower level of microhardness of the gray cast iron substrate after the heat treatment.

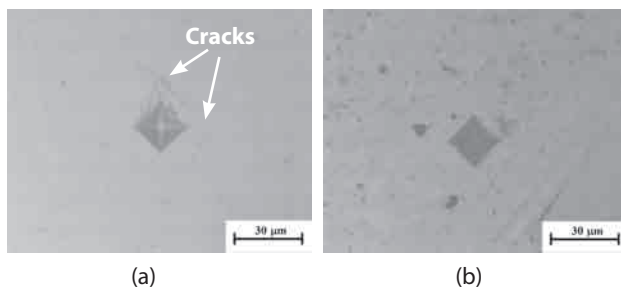
Figure 3 shows the influence of sliding velocity on the wear rates of the coatings. With an increase in sliding velocity, the wear rate for the coatings increased. The heat-treated coating exhibits a lower wear rate than the as-sprayed coating at sliding velocity of  $0,0128$  to  $0,0567\ \text{ms}^{-1}$ . The coating melted by the heat treatment shows an enhanced wear resistance in comparison to the as-sprayed coating when the applied sliding velocity ranges from  $0,0128$  to  $0,0567\ \text{ms}^{-1}$ .

Figure 4 illustrates the crack behaviour observed on the coatings. As indicated in Figure 4 a, the indentation performed on the as-sprayed coating is surrounded by cracks that originated either from the corners or along the sides of the indentation, propagating randomly around the indentation. Contrary to this, the indentation performed on the heat-treated coating did not show any visible cracks (Figure 4 b).

Given the improvement in coating's hardness after the heat treatment, it was not surprising to see an im-



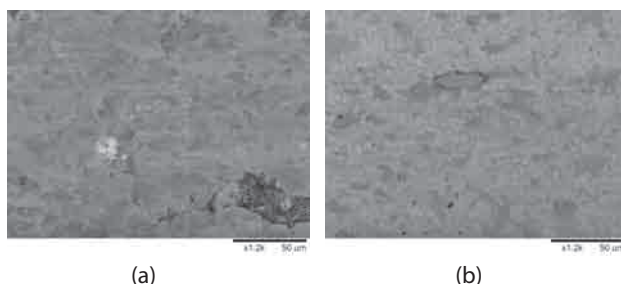
**Figure 3** Influence of sliding speed on the wear rates of the coatings



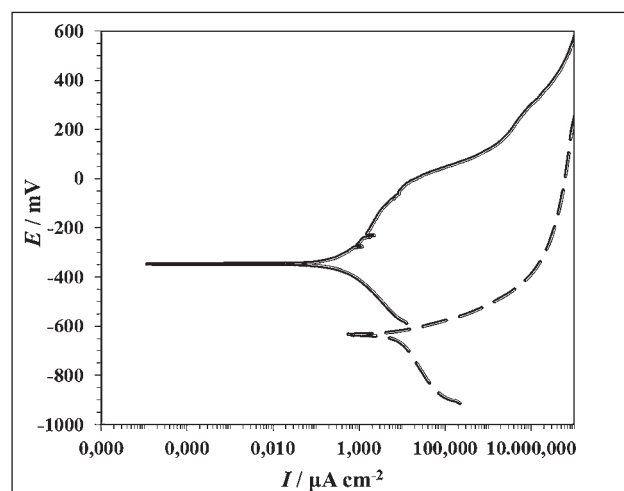
**Figure 4** Fracture toughness indentations on the a) as-sprayed and b) heat-treated coatings

provement in coating's wear resistance due to the influence of hardness, especially where plasticity was involved as a wear mechanism. However, hardness alone was not responsible for the improvements seen in coating's wear performance. There was an additional wear mechanism operational only when the as-sprayed coatings were tested, which increased the wear rate of the as-sprayed coatings with an increase in sliding velocity. This was microcracking and was caused by the relatively brittleness of the as-sprayed coating. It was confirmed by the study of the worn surfaces (Fig. 5a).

Figure 5 shows the worn surfaces of the coatings. Rubbing of steel ball caused worn surface of the heat-treated coating covered by dark black patches (Figure 5 b). Mindivan [5] identified the dark colored isolated islands as oxidized layer contained Fe and Cr detached from steel ball. On the other hand the worn surface of the as-sprayed coating appeared a pit where particle pull out had occurred (Figure 5 a). This is due to a relatively lower fracture toughness of the as-sprayed coating (Figure 4 a).



**Figure 5** SEM micrographs of the worn surfaces of the a) as-sprayed and b) heat-treated coatings



**Figure 6** Potentiodynamic polarization curves for the as-sprayed and heat-treated coatings

Clear decrease in porosity of the coating due to the heat treatment was observed in the potentiodynamic polarization measurements as shown in Figure 6. The heat treatment decreased the current density for as-sprayed coating from approximately 12,5  $\mu\text{A}/\text{cm}^2$  to 0,69  $\mu\text{A}/\text{cm}^2$ . At the same time, the heat treatment resulted in  $E_{\text{corr}}$  shifting positively by  $\sim 300$  mV.

## CONCLUSIONS

The microstructure-property relationships of the as-sprayed and heat-treated thermally sprayed NiWCrBSi coatings were established in order to investigate the potential of heat treatment for developing the coatings with excellent corrosion and wear protection. This investigation shows that not only the porosity of the coatings, but also the roughness, wear rate and corrosion loss decreased after the heat treatment.

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**Note:** The responsible translator for English language is Tureng Translation Company