www.tubiad.org
ISSN:2148-3736
El-Cezerî Fen ve Mühendislik Dergisi
Cilt: 4, No: 1, 2017 (127-134)

El-Cezerî Journal of Science and Engineering
Vol: 4, No: 1, 2017 (127-134)

ECJSE

Research Paper / Makale

A Comparative Study of Thermal Sprayed AISI 316L Stainless Steel Coatings

Harun MINDIVAN[1,*], Adnan KALE[2], Umit BERSE[3], Ramazan SAMUR[4]

[1]Bilecik Şeyh Edebali University, Engineering ,Faculty, Department of Mechanical and Manufacturing Engineering,, 11210 Bilecik/TURKEY
[2,3]Marmara University, Ministry of National Education, Technical Teacher, 34730 Istanbul/TURKEY
[4]Marmara University, Faculty of Technology, Department of Materials and Metallurgy, 34730 Istanbul/TURKEY
[1,*]harun.mindivan@bilecik.edu.tr, [2]adnankale@mynet.com, [3]umitberse@hotmail.com, [4]rsamur@marmara.edu.tr

Abstract: In this study, austenitic stainless steel (316L) coatings were formed using both Wire Flame Spray Forming (WSF) and High Velocity Oxy Fuel (HVOF) deposition processes after a NiCr bond layer was deposited on low carbon steel substrate. The coatings were characterized by light optical microscope (LOM) and microhardness measurements. Corrosion resistance of 316L austenitic stainless steel coatings applied onto low carbon steel via WSF and HVOF spray processes was analyzed by using the potentiodynamic polarization scanning (PDS) technique. The wear behaviour of the coatings against Al_2O_3 ball was investigated with a reciprocating tester under dry friction conditions. It was found that the HVOF sprayed coating showed higher hardness and better wear resistance than the WSF coating. However, the overall corrosion resistance of the HVOF deposited coating was inferior to that of the WSF coating.

Keywords: Austenitic stainless steel; Corrosion; High velocity oxy fuel; Wire flame spray; Wear.

Termal Püskürtme Yöntemi ile Üretilmiş AISI 316L Paslanmaz Çelik Kaplamaların Karşılaştırmalı İncelenmesi

Abstract: Bu çalışma kapsamında, düşük kabonlu çelik üzerine NiCr bağlayıcı tabaka uygulandıktan sonra alevle tel püskürtme (WSF) ve yüksek hızlı oksijen yakıt (HVOF) gibi iki farklı termal püskürtme işlemi ile östenitik paslanmaz çelik kaplamalar oluşturulduktan sonra optik mikroskop ve mikrosertlik ölçümleri ile yüzey özellikleri ve performansları karşılaştırılmıştır. 316L paslanmaz çelik kaplamaların korozyon direnci potansiyodinamik polarizasyon tarama (PDS) teknik ile belirlenmiştir. Aşınma deneyleri ise salınım hareketli aşınma test cihazında karşı malzeme olarak Al_2O_3 bilye kullanılarak kuru ortamda gerçekleştirilmiştir. HVOF püskürtme ile elde edilen 316 L paslanmaz çelik kaplama, alevle te püskürtme yöntemi ile elde edilen 316 L paslanmaz çelik kaplamaya göre daha yüksek sertlik ve aşınma direnci sergilemiştir. Ancak, korozyona karşı alevle tel püskürtme yöntemi ile elde edilen 316 L paslanmaz çelik kaplamanın daha koruyucu olabileceği görülmüştür.

Anahtar kelimeler: Ostenitik paslanmaz çelik; Korozyon; Yüksek hızlı oksijen yakıt; Tel püskürtme; Aşınma.

1. Introduction

Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Coating materials available for thermal spraying include metals, alloys, ceramics, plastics and composites. They are fed in powder, wire or rod form, heated to a molten or semi-molten state and accelerated towards substrates in the form of micrometer-size particles. Combustion or electrical arc discharge is usually used as the source of energy for thermal spraying [1-3]. By using different coating processes, coating materials and the process parameters,

How to cite this article
Mindivan, H., Kale, A., Berse, Ü., Samur, R., "*A Comparative Study of Thermal Sprayed AISI 316L Stainless Steel Coatings*" El-Cezerî Journal of Science and Engineering, 2017, 4(1); 127-134.

the resulting coating properties may differ. In the practice, it is not possible to achieve defect-free thermal spray coatings, which induce weak wear and corrosion resistance. In the industrial applications, coating quality is usually assessed by measuring its porosity, oxide content, macro and microhardness, adhesion strength and surface finish. The wire flame spray deposition method provides distinguishing advantages, such as its being more economical, easier to handle and more adaptable to manufacturing processes with short series or recovery of pieces, while the HVOF technique requires special installations and equipment which utilize confined combustion and an extended nozzle to heat and accelerate the powdered coating material [2, 3].

In this work, stainless steel alloys were sprayed by WSF and HVOF techniques to produce coatings with great wear and corrosion resistance. It must be mentioned that the thermal sprayed stainless steel coatings obtained by both processes have not yet been fully examined. This work therefore can provide useful information for fabrication of thermal sprayed stainless steel coatings using two techniques.

2. Experimental Details

The substrate material was the low carbon steel. The spayed materials were AISI 316L stainless steel. Before the spraying process, the surface of the carbon steel was roughened by sand blasting and then coated with an intermediary Ni-Cr layer. The coatings were sprayed by WSF and HVOF, respectively. The thickness of WSF sprayed coating was about 290 μm. The thickness of the HVOF sprayed coating was about 350 μm.

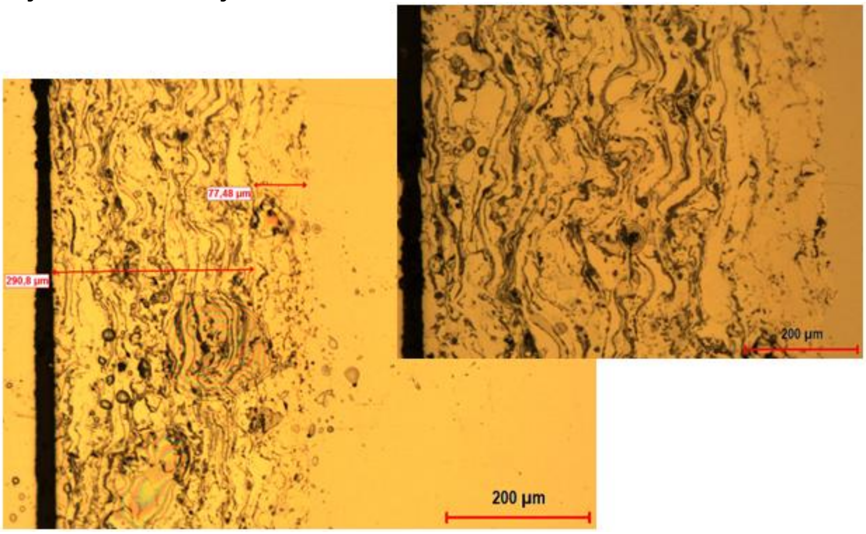
Cross-sectional morphology of the coatings was characterized by using a Light Optical Microscopy (LOM) and Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-Ray Spectroscopy (EDS). Mechanical properties of the coatings were examined by microhardness measurements and dry sliding wear tests. Microhardness tests were conducted on polished surface of the coating with a Vickers indenter under a load of 500 g for a dwell time of 10 s. Three microhardness measurements were obtained for each coating, and the average value was recorded. Dry sliding wear tests of the coatings were performed on a reciprocating wear tester operating in ball-on-disc configuration at room temperature. In this configuration, an Al_2O_3 ball with a diameter of 10 mm was sliding forward and backward against the coatings with a sliding speed of 1.7 cm s^{-1}. Normal load of the test, sliding amplitude (wear track length) of the reciprocating motion and overall sliding distance were 5 N, 10 mm and 50 m, respectively. During the wear tests, the temperature and the relative humidity were maintained as 18 ± 2 °C and 34 ± 2 %, respectively. The friction coefficient force was continuously recorded during the tests. Width and depth of the wear tracks were measured by a surface profilometer (Surftest SJ 400) to calculate wear performance of the coatings. Following the wear tests, wear tracks were examined by LOM and SEM examinations.

The electrochemical corrosion tests were performed utilizing a typical three electrode potentiodynamic polarization test unit in the corroding media of aerated solution of 3.5 wt. % NaCl at room temperature. The exposed area of the coatings was about 0.2 cm^2. Before potentiodynamic polarization measurements, the coating surfaces were ground using 1200 grit SiC paper and mechanically polished with a fine grade Al_2O_3 paste to achieve a certain surface uniformity. The coatings were immersed into the solution and allowed to be stabilized for 45 min in order to ensure a steady open circuit potential (OCP). Potentiodynamic polarization curves were generated by sweeping the potential from cathodic to anodic direction at a scan rate of 1 mVs^{-1}, starting from – 0.25 up to + 0.25 V. Corrosion potentials (E_{corr}) and corrosion current densities (i_{corr}) were calculated using a Tafel type fit in the software. Finally, the surface images of the corroded coatings were examined using a SEM.

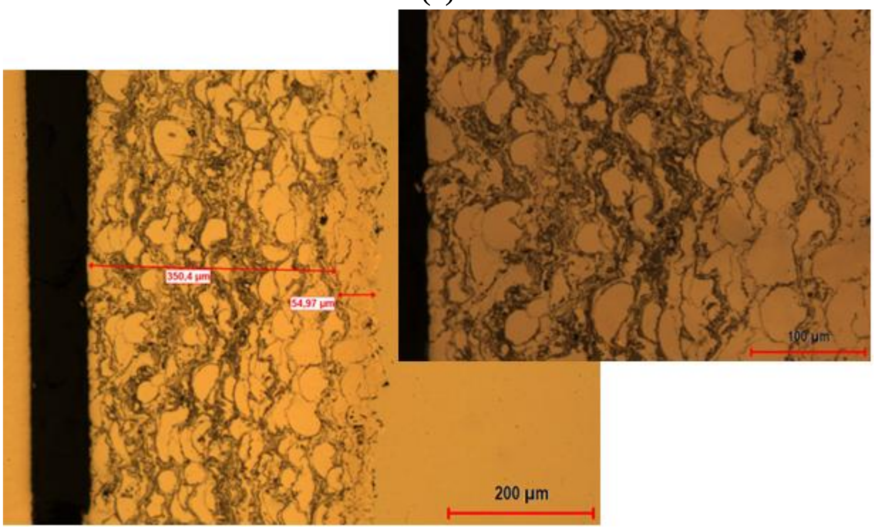
3. Results and Discussion

The microstructures of WSF and HVOF 316L coatings are shown in Figure 1. The coating microstructure in Figure 1 (a) shows splats on top of each other separated by alternating oxide layers due to the lower temperature and velocity associated with WSF spraying. Different from the WSF coating, the HVOF coating has melted, unmelted and semi-melted particles in the coating structure (Figure 1 (b)). The two coatings are well combined with the substrate. The dense and compact HVOF sprayed structure is resulted due to higher velocity that causes both, mechanical bonding between the splats and metallurgical bonding due to partial melting [2].

Figure 2 illustrates representative surface SEM micrographs of the deposited coatings along with the typical chemical composition of different places inside the coatings analyzed by EDS. It has been found that the coatings are composed of two different brightness contrast microzones that represent the different constituent phases marked as X and Y in Figure 2. In general, the bright-colored (marked as X) microzone contains elements such as Fe, Cr and Ni depending on the used process, while the presence of Fe, Cr, O elements in the gray-colored (marked as Y) microzone is clearly identified by the EDS analysis.



(a)



(b)

Figure 1. LOM micrographs showing cross-section microstructure of (a) WSF and (b) HVOF sprayed coatings.

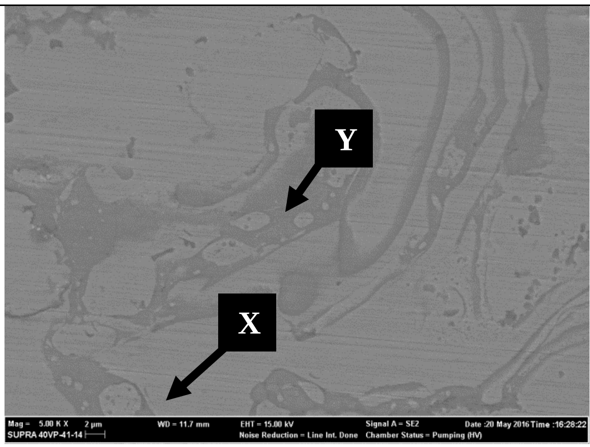
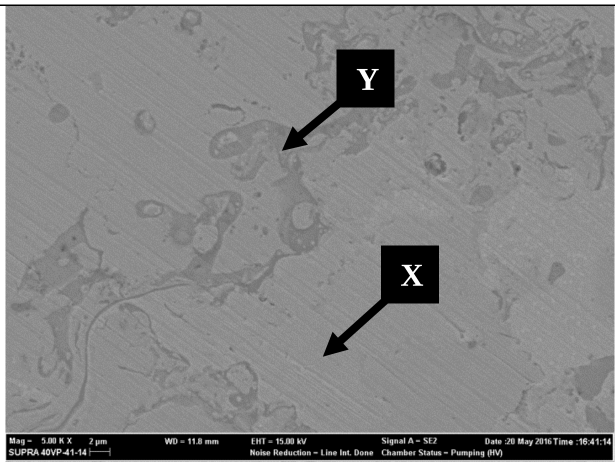
<table>
<tr><td rowspan="5">WSF</td><td rowspan="5"></td><td>Element (wt. %)</td><td>X</td><td>Y</td></tr>
<tr><td>Fe</td><td>71,69</td><td>52,70</td></tr>
<tr><td>Cr</td><td>15,65</td><td>20.27</td></tr>
<tr><td>Ni</td><td>12.66</td><td>-</td></tr>
<tr><td>O</td><td>-</td><td>27,03</td></tr>
<tr><td rowspan="5">HVOF</td><td rowspan="5"></td><td>Element (wt. %)</td><td>X</td><td>Y</td></tr>
<tr><td>Fe</td><td>6,46</td><td>48,81</td></tr>
<tr><td>Cr</td><td>1,99</td><td>21,39</td></tr>
<tr><td>Ni</td><td>91,56</td><td></td></tr>
<tr><td>O</td><td>-</td><td>29,81</td></tr>
</table>

Figure 2. SEM micrographs along with EDS analysis results in the stainless steel coatings deposited with both WSF and HVOF processes. Arrows indicate the location of EDS analyses.

The XRD examinations shown in Figure 3 demonstrate the transformation of the phases present in the WSF and HVOF sprayed 316L coatings. The results show that the dominant phases in the surface layer of the WSF and HVOF sprayed coatings were α-Fe, γ-Fe and Fe_3O_4CrO. However, 316L coating obtained by WSF spraying exhibited higher amount of Fe_3O_4CrO than that of the ones obtained by HVOF spraying (Figure 3).

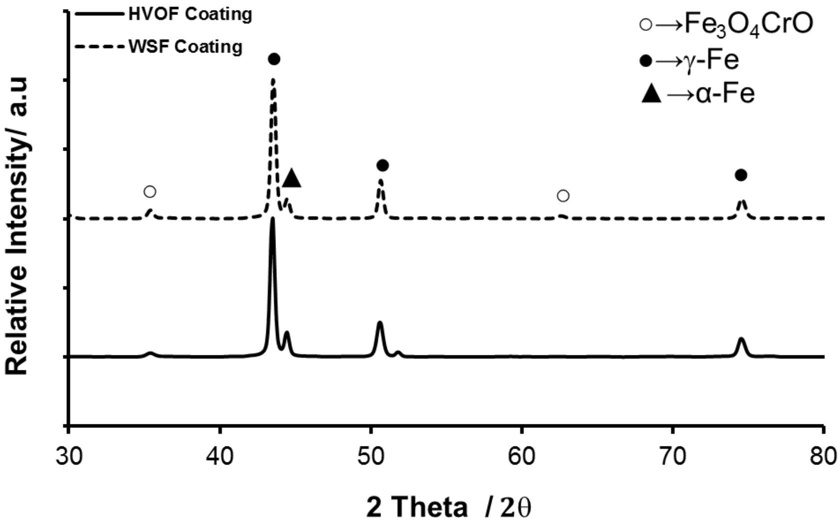


Figure 3. XRD patterns of the WSF and HVOF sprayed stainless steel coatings.

The microhardness values of WSF and HVOF coatings are 190 ± 58 $HV_{0.5}$ and 270 ± 30 $HV_{0.5}$, respectively. The reasons why HVOF coating has higher microhardness than WSF coating may be that the former has more compact microstructure (Figure 1) and cohesive strength of the individual splats as a result of the high impact velocity of the coating particles as suggested by Sidhu et al [2].

Figure 4 denotes wear rate values. The HVOF sprayed coating has lower wear rate than that of the WSF coating, which can be attributed to the higher hardness as well as the better bond both in the coating and in the coating/substrate zone.

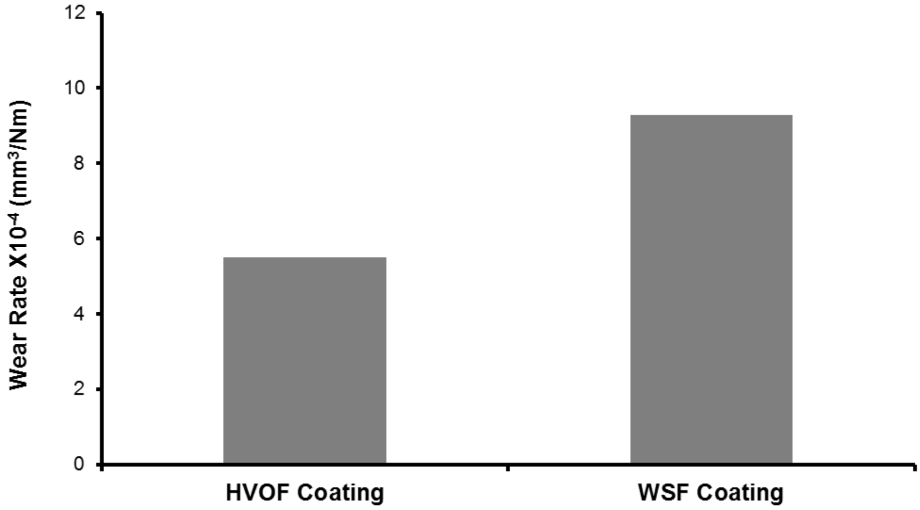


Figure 4. Wear rates of coatings.

Friction coefficients measured at room temperature of WSF and HVOF coatings were ~1.27 and ~1.08, respectively. These values were determined from the average values of the stable friction period based on the plot of friction coefficient evolution as a function of number of cycles as shown in Figure 5. These observed friction coefficient values were in agreement with their wear behaviors. The surface micrographs of wear tracks after 50 m sliding distance are shown in Figures 6 and 7 Microstructural investigation within wear scars revealed a smoother damage surface of the HVOF coating compared to a more severe worn surface of the WSF coating as illustrated in Figures 6 and 7. The superior wear resistance in the HVOF coating was solely attributed to an increase in hardness and a decrease in friction force.

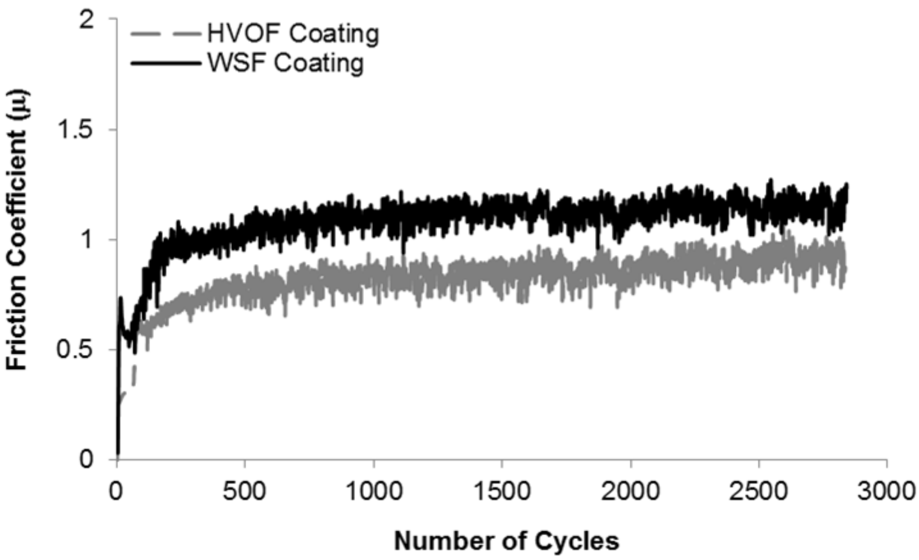
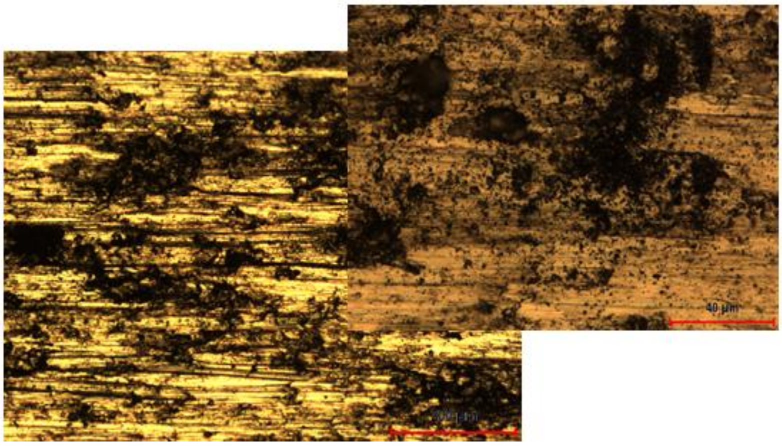
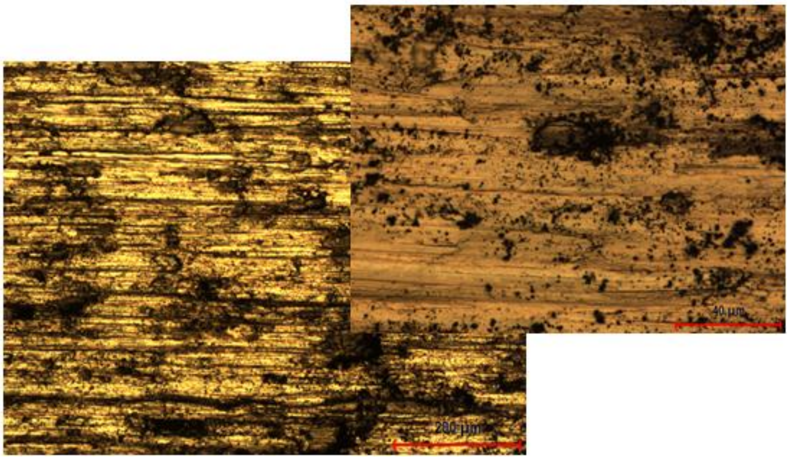


Figure 5. Friction coefficient curves recorded during wear tests.

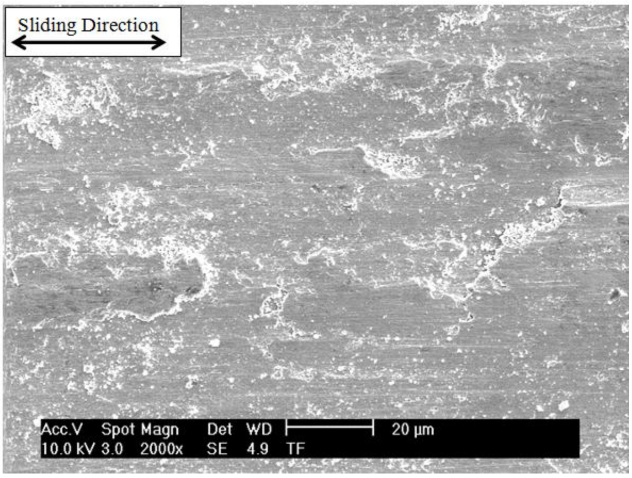


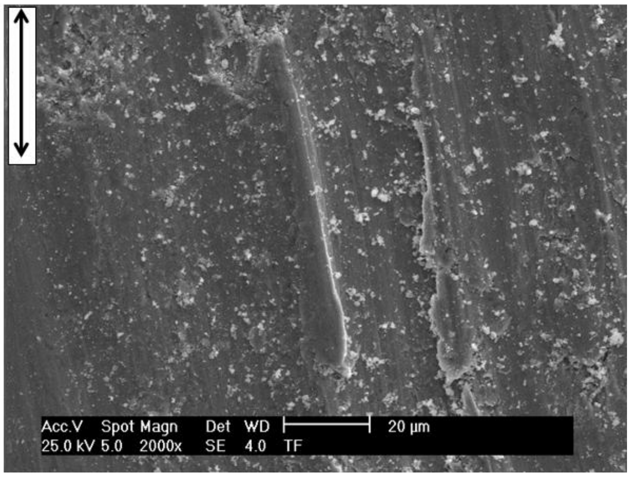
(a)



(b)

Figure 6. LOM micrographs of the wear tracks formed on the (a) WSF and (b) HVOF coatings.





(a) (b)

Figure 7. SEM images of the wear tracks formed on the (a) WSF and (b) HVOF coatings.

Figure 8 shows the polarization curves recorded on 316L stainless steel coatings obtained by WSF and HVOF spraying processes. The corrosion potential E_{corr} of the WSF coating is -476 mV and the corrosion current density i_{corr} is 6.3 x 10^{-6} A/cm^2. Meanwhile, the corrosion potential E_{corr} and corrosion current density i_{corr} of the HVOF coating are about -613 mV and 10.2 x 10^{-6} A/cm^2, respectively. Analyzing the curves (Figure 8) and corrosion surfaces (Figure 9), it can be noticed a better corrosion behavior of WSF coating in comparison with HVOF coating, since the distance from the coating surface to the coating/substrate interface along the alternating oxide layers is very long [4].

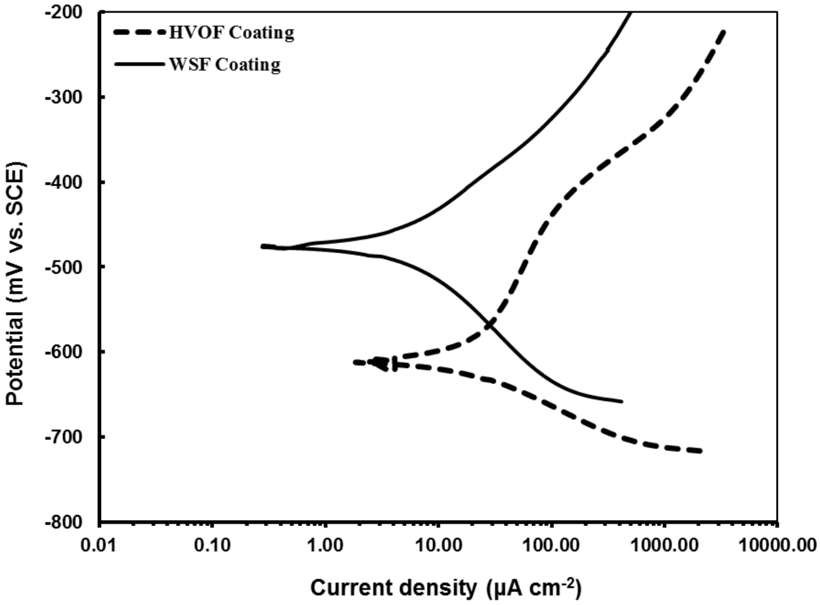
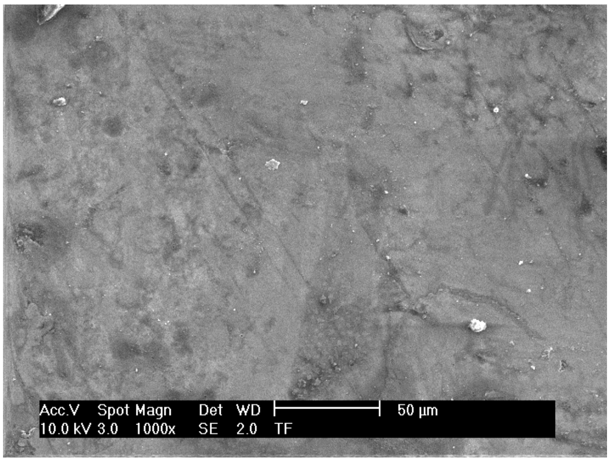
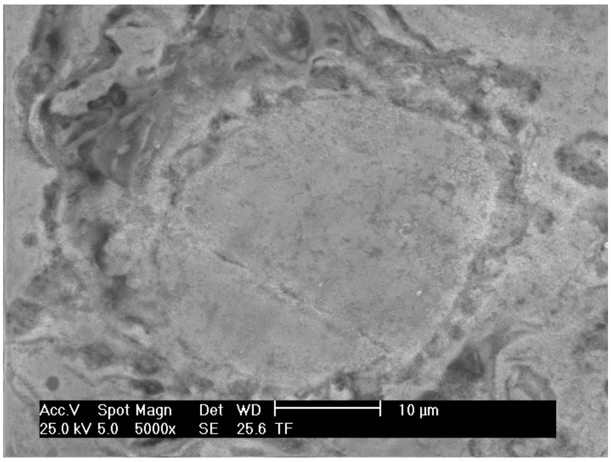


Figure 8. Polarization curves of the coatings.



(a)



(b)

Figure 9. SEM surface morphologies of the (a) WSF and (b) HVOF coatings after potentiodynamic polarization.

4. Conclusion

The AISI 316L coatings were thermally sprayed by WSF and HVOF processes. The microstructure, hardness, wear behavior and corrosion resistance of the coatings were investigated. The results can be summarized as follows:

1. The coating made of HVOF is more compact than that of WSF.
2. The hardness was improved by 40 % in HVOF coating compared to WSF coating and that had great influence on its wear properties.
3. WSF coating had outstanding corrosion resistance compared with the HVOF deposited coating. Further study is necessary to understand the mechanism behind such marked difference in the corrosion performance between the two coatings.

5. Acknowledgement

The financial support of the research foundation of Bilecik S.E. University (Project No.: 2015-01. BSEU.03-04) is gratefully acknowledged. The authors are grateful to the Central Research Laboratory and Mechanical and Manufacturing Engineering Department of Bilecik S.E. University for the use of their instruments facilities.

Asst. Prof. Dr. SAMUR acknowledges the support by Marmara University, Scientific Research Projects Department (BAPKO), Project FEN-C-YLP-080715-0344.

References

[1] Huang, P-K., Yeh, J-W., Shun, T-T., Chen, S-K.,“Multi-principal-element alloys with improved oxidation and wear resistance for thermal spray coating”, Advanced Engineering Materials, 2004, 6: 74-78.

[2] Sidhu, T. S., Prakash, S., and Agrawal, R. D., “Studies on the properties of high-velocity oxy–fuel thermal spray coatings for higher temperature applications”, Materials Science, 2005, 41 (6): 805-823.

[3] Uyulgan, B., Dokumaci, E., Celik, E., Kayatekin, I., Ak Azem, N.F., Ozdemir, I., . Toparli, M., “Wear behaviour of thermal flame sprayed FeCr coatings on plain carbon steel substrate”, Journal of Materials Processing Technology, 2007, 190: 204–210.

[4] Dobler, K., Kreye, H., and Schwetzke, R., “Oxidation of stainless steel in the high velocity oxy-fuel process”, Journal of Thermal Spray Technology, 2000, 9(3): 407-413.