JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 18, No. 11-12, November - December 2016, p. 1052 - 1056

The microstructure and hardness properties of plasma sprayed Cr_2O_3/Al_2O_3 coatings

S. ÖZEL*, E. VURAL
Bitlis Eren University, Faculty of Engineering Architecture, Dept. of Mechanical Eng., 13000-Bitlis, Turkey

In this study, the surface of aluminum alloy was coated with and without bond coat with Cr_2O_3/Al_2O_3 powders by using plasma spray technique. The coating layers were examined with optical microscopy, SEM, EDS and XRD analysis. The microhardness of specimens was measured. In XRD studies, such compounds as α-Cr_2O_3, Cr_2O_3 and Al_2O_3 have been identified on coating layers. The maximum hardness value has been determined in the sample coated with Cr_2O_3.

(Received November 26, 2015: accepted November 25, 2016)

Keywords: Plasma Spray Coating, Al alloy, Cr_2O_3/Al_2O_3

1. Introduction

Thermal barrier coatings (TBCs) is a process used commonly for coating gas turbines' inner parts of gas turbines exposed to high temperature to reduce the damages caused by combustion and make them last longer [1, 2, 3]. A plasma spray coating is one of the thermal barrier coating methods. For the last 30 years, plasma spraying coating has gained high importance for the industrial and technical technologies. Plasma sprayed coatings exhibit highly anisotropic microstructure with a large content of amorphous phase and small content of recrystalled phase. Generally the deposits are composed of crystallographic phases different from the original feedstock materials. They have high thermal conductivity rates which make them unique for applications at higher temperatures. They have been employed to deposit various materials for different performance requirements.

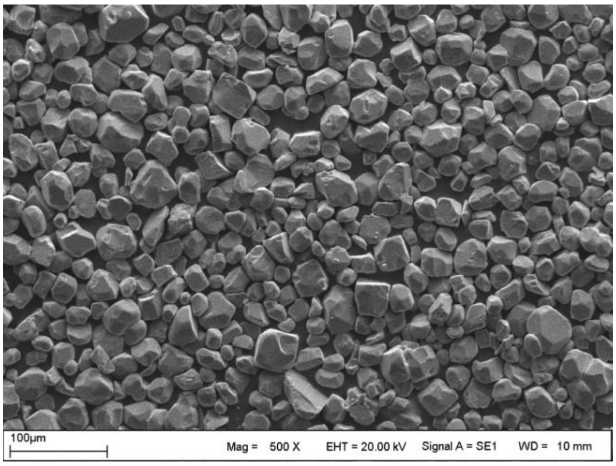
Atmospheric plasma spraying (APS) is one of the methods provides protective coating layer for wide range of application. Various types of wear and corrosion are the severe condition for facilities that surface coatings have to deal with [4-7]. There are several ceramic coatings especially metal oxides such as Al_2O_3, Cr_2O_3, ZrO_2, TiO_2, etc. Such coatings have complex phase composition and microstructure. Therefore, they exhibit distinctive and unusual properties. Those are highly effective coatings to improve wear, cavitation, fretting and corrosion resistance especially where high temperature is required [4, 6, 8]. Bond coatings have specific properties. the bond coatings are used to bind layers that have different thermal coefficent and provide a good thermal expansion match between the layers.

Bond coating layers are thinner with respect to main coatings [9, 10]. For the last few decades, as chromium oxide coatings (Cr_2O_3) exhibit excellent wear resistant and friction characteristics, they have increasing potential for the usage of aerospace and automobile applications. Atmospheric plasma spray (APS) widely used to deposit Cr_2O_3 coatings as it has high deposition efficiency, low-cost and high flexibility values. APS coating has porous structures which might show favorable tribological behavior. Ease of lubrication owing to the oil storage of the pores in the coating could improve the service life of Cr_2O_3 coating. Porous structures might also have unfavorable effects for the structure and properties of the deposits. For a better protection porosity of the coating should be well controlled [11, 12].

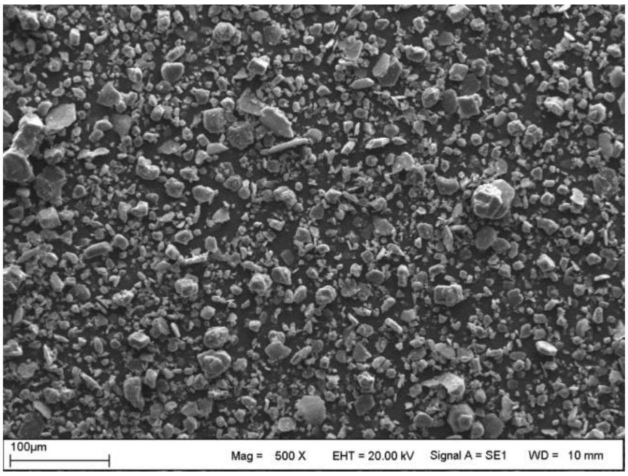
In this study, the surface of aluminum alloy was coated with and without bond coat using Cr_2O_3 and Al_2O_3 powder mixed into Cr_2O_3 at different rates (25%, 50, 75) by using plasma spray technique. Optical microscopy, Scanning Electron Microscopy (SEM), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD) analysis of samples, microhardness test and the effect of added Al_2O_3 have been examined after the coating process.

2. Materials and method

The coatings were carried out on aluminum alloy plate by using plasma spray technique. The chemical composition of aluminum alloy used as substrate material was given in Table 1. The surface procedure was realized with NiCr bond coat and without bond coat using Cr_2O_3 and Al_2O_3 powder mixed into Cr_2O_3 at different rates (25 %, 50 %, 75 %) powders. Powders have been mixed for 45 minutes at 45 rpm in the mechanical powder mixing apparatus. The SEM images of Cr_2O_3 and Al_2O_3 powders are given in Fig. 1. The plasma spray technique is schematically shown in Fig. 2. The Cr_2O_3/Al_2O_3 powders were sprayed by plasma spray technique with a 3 MB torch from Sulzer Metco, using plasma composed of argon and hydrogen. In order to produce a rough surface for good bonding, the aluminum alloy plate substrate of 100 mm x 20 mm x 5 mm in dimension were grid-blasted with alumina grits prior to the coating technique. The parameters of the plasma spray condition are summarized in Table 2.



a



b

Fig. 1. The SEM photo of a) Cr_2O_3 and b) Al_2O_3 powders.

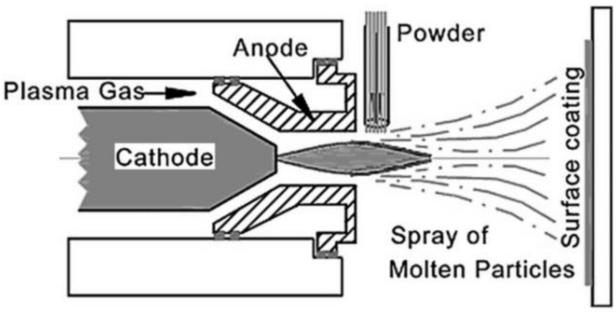


Fig. 2. Schematic cross-section of a typical plasma spray [13].

.

Table 1. The chemical composition of the substrate material to the aluminum alloy

Weight (%) Composition					
Al	Si	Ni	Cu	Mg	Fe
Balance	12,6	1,96	0,88	0,60	0,5

Table 2. Plasma spray coating parameters of the NiCr bond coat and the Cr_2O_3/Al_2O_3 coatings

Parameters	NiCr Bond Coat	Cr_2O_3 and Cr_2O_3/Al_2O_3 Coatings
Plasma Gun	3 MB	3 MB
Current (A)	500	500
Voltage (V)	64	70
Primary Gas-Ar (l/min)	150	80
Secondary Gas-H_2 (l/min)	5	15
Spray Distance (mm)	100-150	64-90
Nozule Diameter (mm)	7,6	7,6

The cross-sectional surface for metallographic examination of the coated surface were wet-ground with 400, 600, 800 and 1200 grit SiC paper and polished with diamond paste. The microstructures of the specimens were investigated by optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD) analysis. Microstructure measurements were carried out by Qness-10M microhardness tester.

3. Results and discussion

3.1. Microstructure and XRD analysis

The optical microstructure images of the Cr_2O_3 and Cr_2O_3/Al_2O_3 coating produced by the plasma spray technique is shown in the Fig. 3 and 4. The thickness of the oxide coating layers without bond coat is approximately 300 μm, and that of the oxide coating layers with bond coat is approximately 250 μm at a thickness of the bond coat 70 μm. A lamellar structure can be seen in the coating layer of specimens. The porosity in generally present in the thermal sprayed coating and ranged between 6 and 9 %. [14, 15] The porosity amount was generally increased with increased of Al_2O_3.

The SEM image, EDS and XRD analysis taken from Cr_2O_3 coating specimen are shown in Fig. 5. The composition of the region 1 marked with circle consisted of 65wt.% Cr and 35wt.% O. The region 2 marked with circle consisted of 66.19 wt.% Cr and 33.81 wt.% O. Fig. 5d shows the XRD pattern of the coating layer. α-Cr_2O_3 and Cr_2O_3 compounds were formed in the coating layer. The porosity is very low in Cr_2O_3 coated specimen.

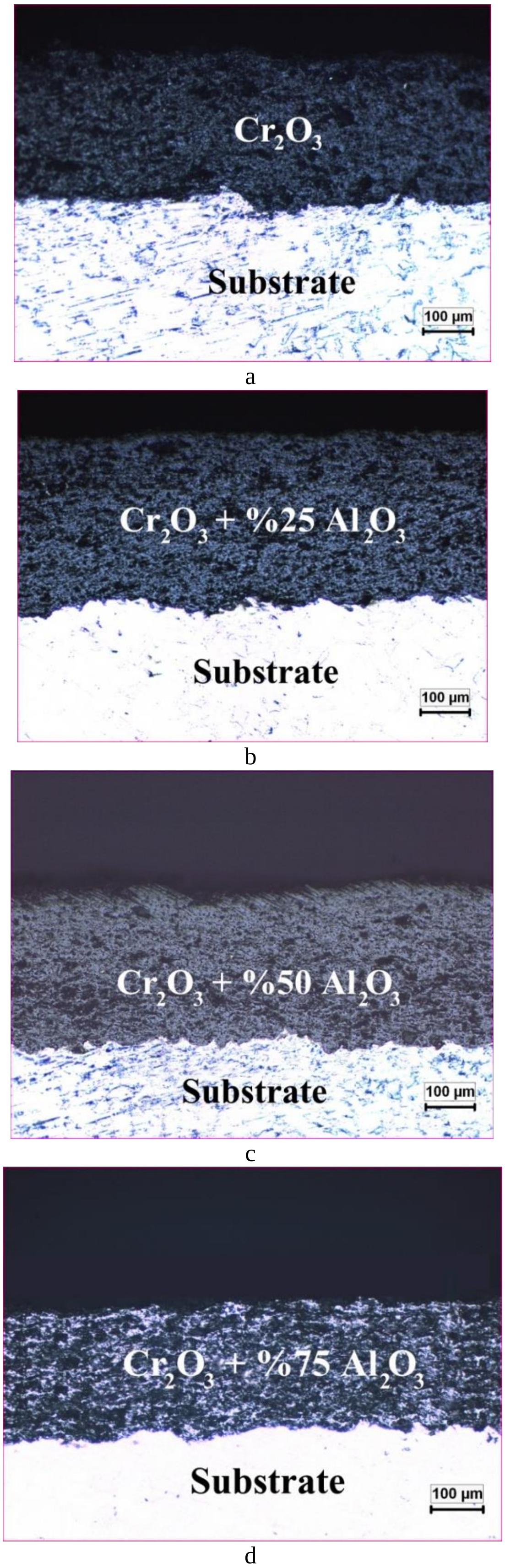


Fig. 3. Optical microstructure of Cr_2O_3/Al_2O_3 coatings without bond coat, a) Cr_2O_3 coated, b) 25 wt. % Al_2O_3 added, c) 50 wt. % Al_2O_3 added, d) 75 wt. % Al_2O_3 added.

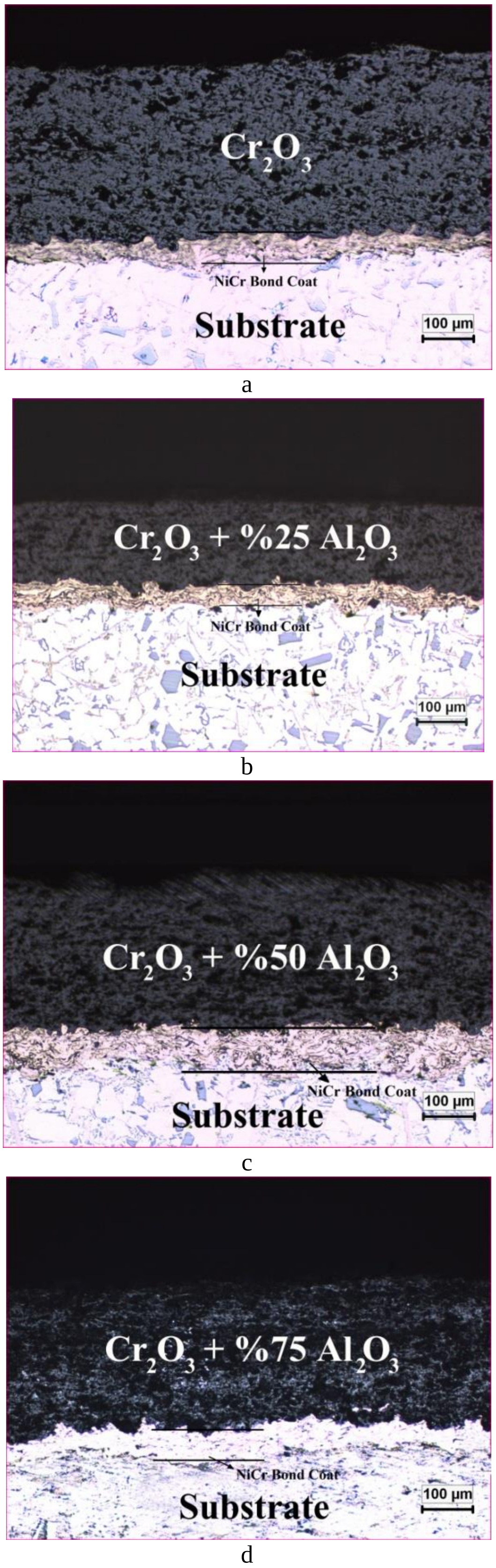
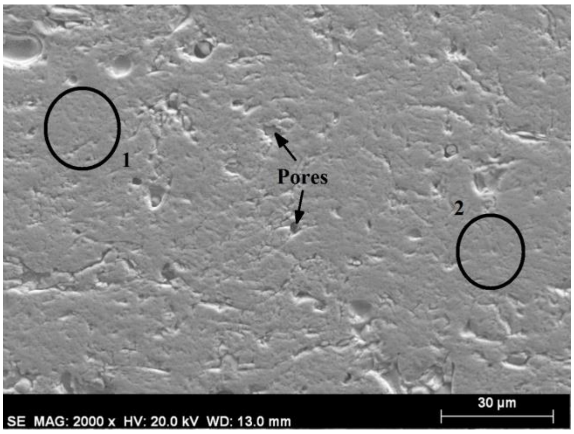
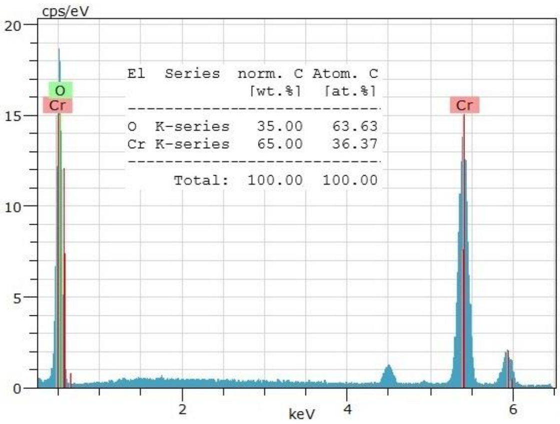


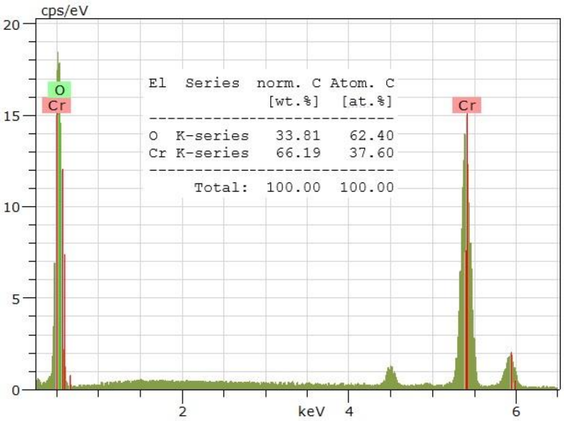
Fig. 4. Optical microstructure of Cr_2O_3/Al_2O_3 coatings with bond coat, a) Cr_2O_3 coated, b) 25 wt. % Al_2O_3 added, c) 50 wt. % Al_2O_3 added, d) 75 wt. % Al_2O_3 added.



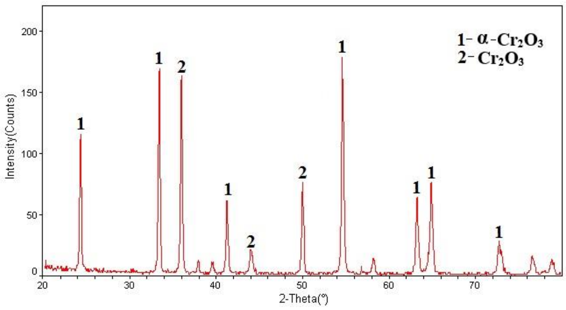
a



b

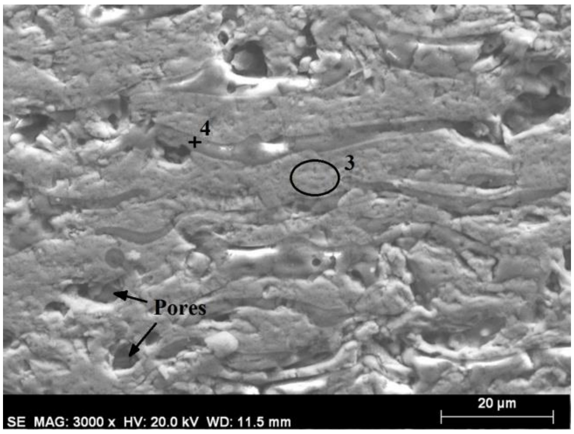


c

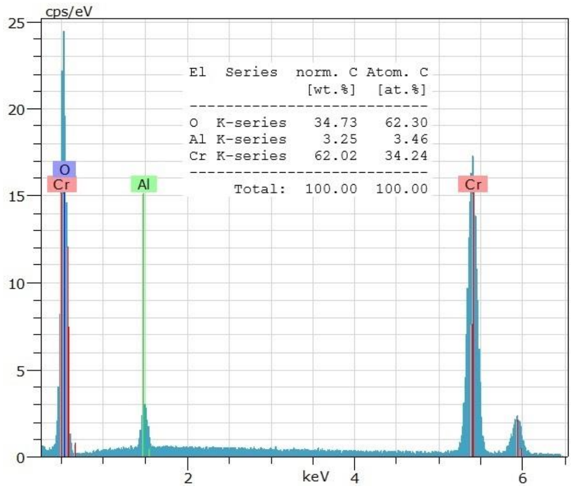


d

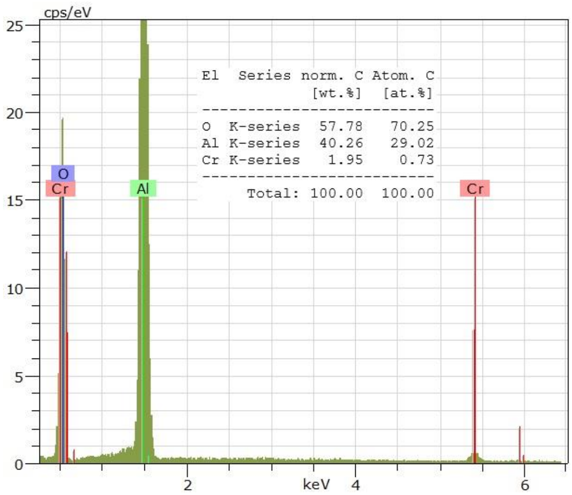
Fig. 5. SEM photo, EDS and XRD analyses of specimen coated with Cr_2O_3 powder.



a



b



c

Fig. 6. SEM photo, EDS and XRD analyses of specimen coated with Cr_2O_3+75 wt. % Al_2O_3 powder.

The SEM images, EDS and XRD analysis taken from Cr_2O_3+ 75% Al_2O_3 coating specimen applied NiCr bond coat are shown in Fig. 6. The composition of the region 3 marked with circle consisted of 62.02 wt.% Cr, 34.73 wt.% O and 3.25 wt.% Al. The marked spot 4 consisted of 40.26 wt.% Al, 57.78 wt.% O and 1.95 wt.% Cr. The dark grey lamella regions in the coating are attributed to Al_2O_3, while the grey ones are Cr_2O_3. Fig. 6d shows the XRD pattern of the coating layer. α-Cr_2O_3, Cr_2O_3 and Al_2O_3 compounds were formed in the coating layer. The porosity is increased in specimen coated with Al_2O_3 powder mixed into Cr_2O_3.

3.2. Microhardness

The microhardness measurement of the coatings layer and bond coats are shown in Fig. 7. It can be seen that the microhardness of the Cr_2O_3 coating without bond coat is 969 HV and with bond coat is 867 HV. The microhardness of the Cr_2O_3+25 wt.% Al_2O_3 coating without bond coat is 857 HV and with bond coat is 790 HV. The microhardness of the Cr_2O_3+50 wt.% Al_2O_3 coating without bond coat is 775 HV and with bond coat is 702 HV. Also, the microhardness of the Cr_2O_3+75 wt.% Al_2O_3 coating without bond coat is 664 HV and with bond coat is 528 HV. The hardness of the bond coat for the Cr_2O_3, Cr_2O_3+25 wt.% Al_2O_3, Cr_2O_3+50 wt.% Al_2O_3 and Cr_2O_3+75 wt.% Al_2O_3 coatings are 266 HV, 244 HV, 258 HV and 244 HV, respectively. These values are higher than that of the substrate. The maximum hardness was measured in the Cr_2O_3 coating layer. The figure 3 and 4 showed that the porosity was increased with increasing the Al_2O_3 content during the microstructural investigation. The minimum hardness was measured in the Cr_2O_3+75% Al_2O_3 coating layers.

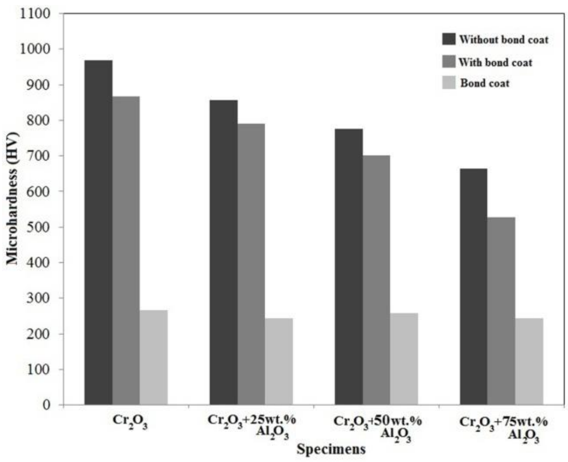


Fig. 7. Microhardness of plasma spray coatings

4. Conclusions

The surface of Al alloy has been coated with Cr_2O_3 and Cr_2O_3/Al_2O_3 powders by using plasma spray technique. The following results have been obtained after the microhardness tests, optical and SEM microstructure analysis, EDS and XRD analysis of the coated layers.

1- The porosity available in all coatings. The porosity is very low in Cr_2O_3 coated specimen. The porosity amount was increased with increased of Al_2O_3.

2- The mainly represented phase is Cr_2O_3 in all coatings. Also, Cr_2O_3 and Al_2O_3 phases were formed in specimen coated with Al_2O_3 powder mixed into Cr_2O_3.

3- The microhardness values were decreased with increasing the Al_2O_3 content in specimen coated with Al_2O_3 powder mixed into Cr_2O_3. The maximum hardness was measured in the Cr_2O_3 coating layer. Generally, The microhardness were decreased in the specimes coated with bond coat.

Acknowledgements

This work was supported by Scientific Research Project Unit of Bitlis Eren University under project-No: BEBAP-2014.15. The authors would like to thanks the Bitlis Eren University Science and Technology Research and Application Center for tests of specimens.

References

[1] Z. Zou, J. Donoghue, N. Curry, L. Yang, F. Guo, P. Nylén, X. Zhao, P. Xiao, Surface and Coatings Technology **275**, 276 (2015).
[2] K.A. Khor, Z.L. Dong, Y.W. Gu, Materials Letters **38**, 437 (1999).
[3] L. Wu, J. Zhu, H. Xie, Journal of Thermal Spray Technology **23**(4), 653 (2014).
[4] K. Neufuss, A. Rudajevová, Ceramics International **28**(1), 93 (2002).
[5] C.-J. Li, B. Sun, Materials Letters **58**, 179 (2003).
[6] F. Shao, K. Yang, H. Zhao, C. Liu, L. Wang, S. Tao, Surface and Coatings Technology **276**, 8 (2015).
[7] W. Haessler, R. Thielsch, N. Mattern, Materials Letters **24**, 387 (1995).
[8] E. Celik, E. Avcı, F. Yılmaz, Surface and Coatings Technology **97**, 361 (1997).
[9] G. Goller, Ceramics International **30**, 351 (2004).
[10] H. Chen, T.H. Hyde, K.T. Voisey, D.G. McCartney, Materials Science & Engineering A **585**, 205 (2013).
[11] S. Dong, B. Song, B. Hansz, H. Liao, C. Coddet, Surface & Coatings Technology **225**, 58 (2013).
[12] J.H. Ouyang, S. Sasaki, Wear **249**, 56 (2001).
[13] http://www.roymech.co.uk/Useful_Tables/ /Manufacturing/Surf_Eng.html(15.10.2015)
[14] S. Özel, H. Turhan, Materials Testing **52**, 4 (2010).
[15] V.Fervel, B. Normand, C. Coddet, Wear **230**, 70 (1999).

*Corresponding author: sozel@beu.edu.tr