www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES of FOUNDRY ENGINEERING

DOI: 10.1515/afe-2017-0111

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 17
Issue 3/2017

168 – 174

Friction and Wear Properties of Plasma Sprayed YSZ/Ni-Cr-Al Coated 6063-T6 Aluminum Alloy

E. Erzi *, D. Dispinar, S. Yilmaz
Metallurgical and Materials Engineering Department, Istanbul University,
34320, Avcilar, Istanbul, Turkey
*Corresponding author. E-mail address: eerzi@istanbul.edu.tr

Received 25.02.2017; accepted in revised form 05.05.2017

Abstract

In this study T6 heat treated 6063 aluminum alloys were used as substrate material. In order to form a bond between the substrate and the main coating, all samples were coated with Ni-Cr-Al powders. 8 wt% Yttria Stabilized Zirconia powders (YSZ) were coated with plasma spray technique. Thickness of YSZ was 150 µm and bond coating was 36 m. XRD and SEM-EDS analyses were performed to characterize the coating layers. These YSZ coated and uncoated samples were subjected to wear testing under different spindle speed, loading and working distance. Wear test results were compared with the kinetic friction coefficients and weight loss values. Wear marks on YSZ coated and uncoated samples were investigated by SEM analysis. By coating with plasma spray technique, the wear resistance of Al alloys was increased without changing the friction coefficient. It was found that spindle speed had significant effect over the wear properties than the load applied. By YSZ coating, wear properties were increased 10 times.

Keywords: Mechanical properties, Abrasive wear, Plasma spraying, YSZ coating, 6063 aluminum alloy

1. Introduction

Metals such as aluminum and its alloys are extensively used today due to their low weight and energy saving. Because of its low ductility and tribological properties, aluminum tends to show low wear resistance. Numerous researchers are studying to improve and vary the usage areas of aluminum. However, aluminum has to show better mechanical strength and resistance to high temperatures to be used in applications such as moving machine parts. Coating aluminum surface with hard ceramic is a way to increase these properties [1-8]. Ceramic materials have high hardness and high resistance to thermal and corrosive conditions. Alumina, titania, chromia and silica have been widely used as surface coating materials to improve the resistance of Al to wear, erosion, cavitation, fretting and corrosion [9]. Zirconia ceramics were also extensively studied as wear resistant materials for the engineering applications. Zirconia as a structural ceramic material has good physical, chemical and mechanical properties [10-13]. Zirconia is used as 6-8 wt% Yttria Stabilized Zirconia (YSZ) by air plasma spray technique with a bond coating which is made of MCrAlY where M stands for Ni or Co [11]. Plasma spraying is a thermal spraying method for the ceramic or composite coatings to improve the wear, corrosion resistance and the performance parameters of the metallic substrate materials [9, 10]. Having high thermal and wear resistance, these coatings can be used in the internal combustion engine parts such as piston crowns and cylinder heads. With the harder coatings, soft materials tend to wear less as long as the coating surface exists. Life cycle of coatings can be easily measure by wear tests. Thus, the complex parts can be produced for a lower cost owing to the design flexibility of the soft materials [12-20]. In this study, 8 wt.% Y_2O_3 stabilized zirconia powders (YSZ) were coated onto T6 heat treated aluminum alloys surface with plasma spraying method and the wear resistance values of these coated samples were compared with the uncoated ones.

2. Experimental

2.1 Preparation of 6063-T6 samples

The chemical compositions of 6063 Al alloy used in the experiments is given in Table 1. The samples were produced from extruded 30 mm rods. They were subjected to T6 aging process: heated up to 480˚C for 20 minutes and water quenched to room temperature. Finally, the samples were heated to 180˚C and held for 7.5 hours for artificial aging. Heat treatments were carried out at Lenton UAF 15/10 model laboratory furnace.

Table 1.
Chemical composition of the 6063 Al alloy (wt.%)

Cu	Fe	Si	Zn	Mn	Mg	Ti	Cr	Al
0.10	0.30	0.40	0.10	0.20	0.40	0.10	0.05	Rem.

2.2. YSZ coating of 6063-T6 samples by using plasma spray technique

YSZ ceramic powder was provided from PAC (Powder Alloy Corporation) as ZrO_2 powder which was partially stabilized with Y_2O_3 ($YO_{1,5}$). XRD and SEM/EDS analyses of this powder are given in Fig. 1.

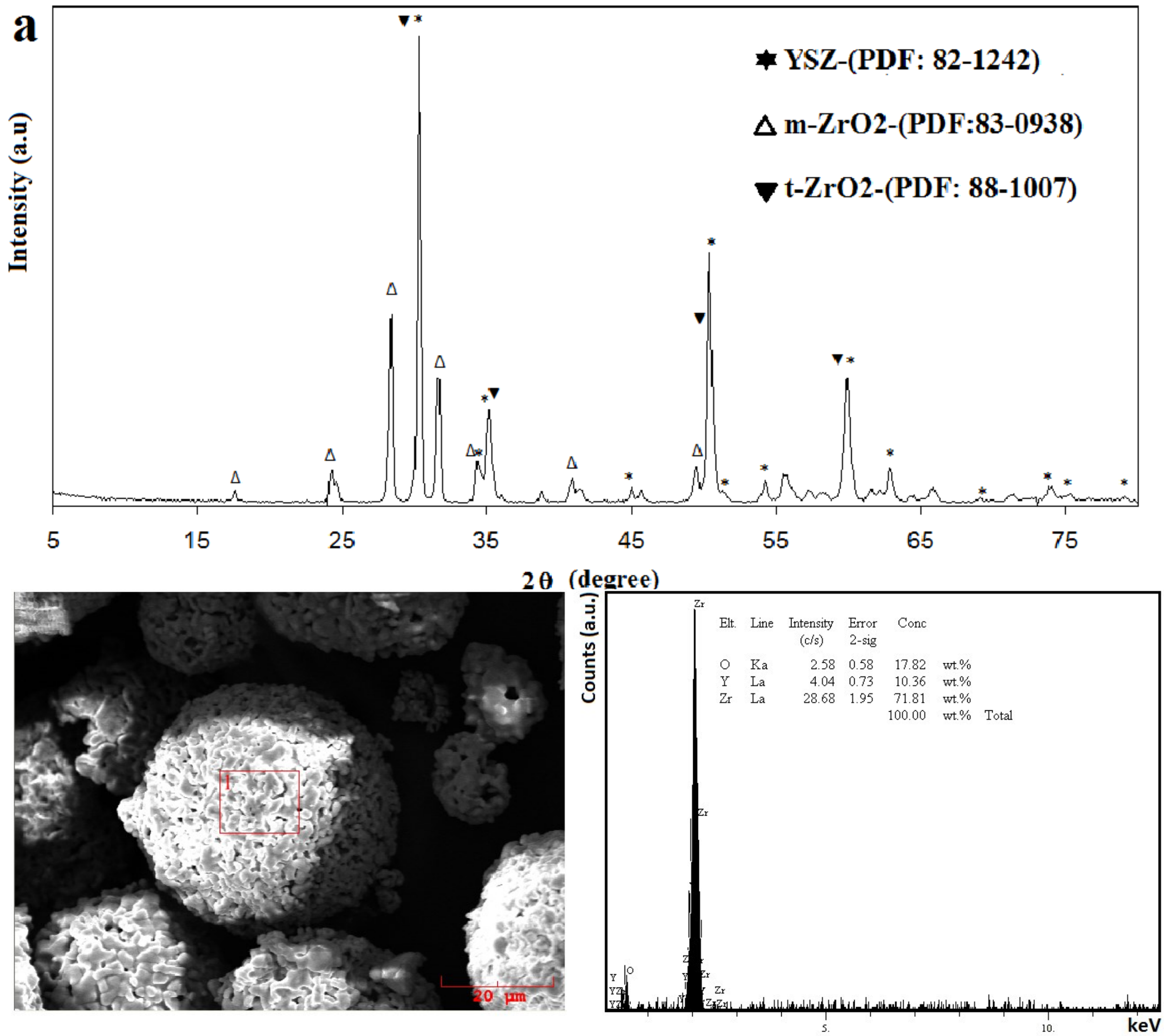

Fig. 1. a) XRD diagram of YSZ ceramic powders which were used as coating material, b and c) SEM and EDS analysis of YSZ ceramic powders which were used as coating material

Firstly, 6063-T6 samples were sand blasted to roughen the surface in order to achieve a better grip for the coatings. A bond coating was applied between the ceramic coating and the metal surface. Coatings were applied by Sulzer-Metco model 3MB branded plasma spray gun. The bond coating was made of Amdry 956 of Metco which has 45 µm grain size. Over the bond coating, 8 wt % YSZ powders were plasma sprayed to the surface. These powders were PAC powders with 50 µm grain size (Fig. 1). Both the coated (top) and the uncoated (bottom) samples can be seen in Fig. 2.

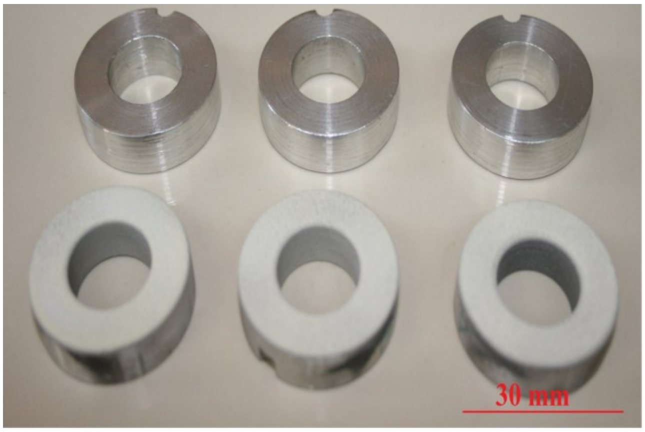

Fig. 2. YSZ coated and uncoated wear test samples

3. Material and Methods

In order to investigate the coating's structure of YSZ coated Al alloy, samples were cut by using a diamond cutter. The cut surfaces were then polished and finally analyzed by SEM (Jeol 5600), EDS and I-XRF to determine the surface characteristics.
Hardness test of the coated and the uncoated samples were performed by ZWICK/ROELL branded ZHU 8187.5 LKV model hardness test device.
Wear tests were done according to the "Pin-on-Disc" test method and the weight loss values were calculated. In order to calculate the weight loss values, ±0.0001 precision scales were used. Weight of each sample was measured before and after the experiments according to this method and in this way the weight loss values were calculated.
By using the densities and the weight loss values, volume differences were also calculated according to Equation 1;

$$\Delta V = \Delta G / \rho \quad (1)$$

where ΔV: volume loss (cm^3), ΔG: weight loss (g), ρ: density (g/cm^3)

Jinan branded MMW-1A model computer-controlled wear test device was used for the wear tests. Pure alumina (corundum) abrasive "pin" was connected to the bottom of the upper head and the samples were fixed on the top of the bottom set.

4. Results and Discussion

SEM micrograph was taken from the cross-section of the coated 6063 sample. The substrate and the thickness of the coating layers can be seen in Figure 3. According to the figure, the thickness of the bond coating obtained by thermal spraying is 36 µm and the YSZ thickness of the coating varies between 140-155 µm. As can be seen in Figure 3a, b and c which belong to SEM/EDS analyses from outside to inside, the coating material (YSZ) and the intermediate layer (Ni-Cr-Al) with the substrate alloy of 6063 were characterized by layers. As can be observed from SEM image, the surface of the YSZ coating is rough and porous. It is seen that pore sizes are 25 µm. This porous structure (coated with YSZ) is compatible with the low density of 6063 aluminum alloy.
30 N load was applied for Vickers hardness tests and the average hardness values were obtained by making measurements from 5 different zones of both the coated and the uncoated samples. 80 HV3 ± 3 was measured for the uncoated samples and 266 HV3 ± 5 for the coated samples. It can be determined that the coating has increased the overall hardness almost 3 times more than the uncoated ones.
For the wear tests, samples were divided into groups to investigate the effect of different speed, loading and working distance. By doing so, while investigating the wear resistance of the coating, effects of other different parameters on the coating were also studied. These combinations were applied to both the coated and the uncoated samples so that 14 combinations in total were created. Test values for all these combinations were calculated by performing pre-tests and the determined values are summarized in Table 2. The comparison of the test results of the coated and the uncoated samples can be seen from Figures 4 to 6.
For all the test conditions, YSZ coated 6063 aluminum alloy samples showed better wear resistances than the uncoated ones. With the increase of the speed, the working distance and the loading values, the weight loss of the samples was increased. However, YSZ coated 6063 samples exhibited again better wear resistance than the uncoated ones (Fig. 4-6). As a result, it can be concluded that 140 µm YSZ coating increased the overall wear resistance of 6063 aluminum alloy. If the wear resistances are compared, it is understood that the coated samples had performed almost 10 times better than the uncoated ones in terms of the test parameters used in this work. By increasing the working distance, the spindle speed and the loading values, the wear rates of both samples (YSZ coated and uncoated) were increased. The lowest weight loss was measured at 10 N loading, 60 rpm spindle speed while the highest weight loss was measured at 10 N load and 240 rpm speed.

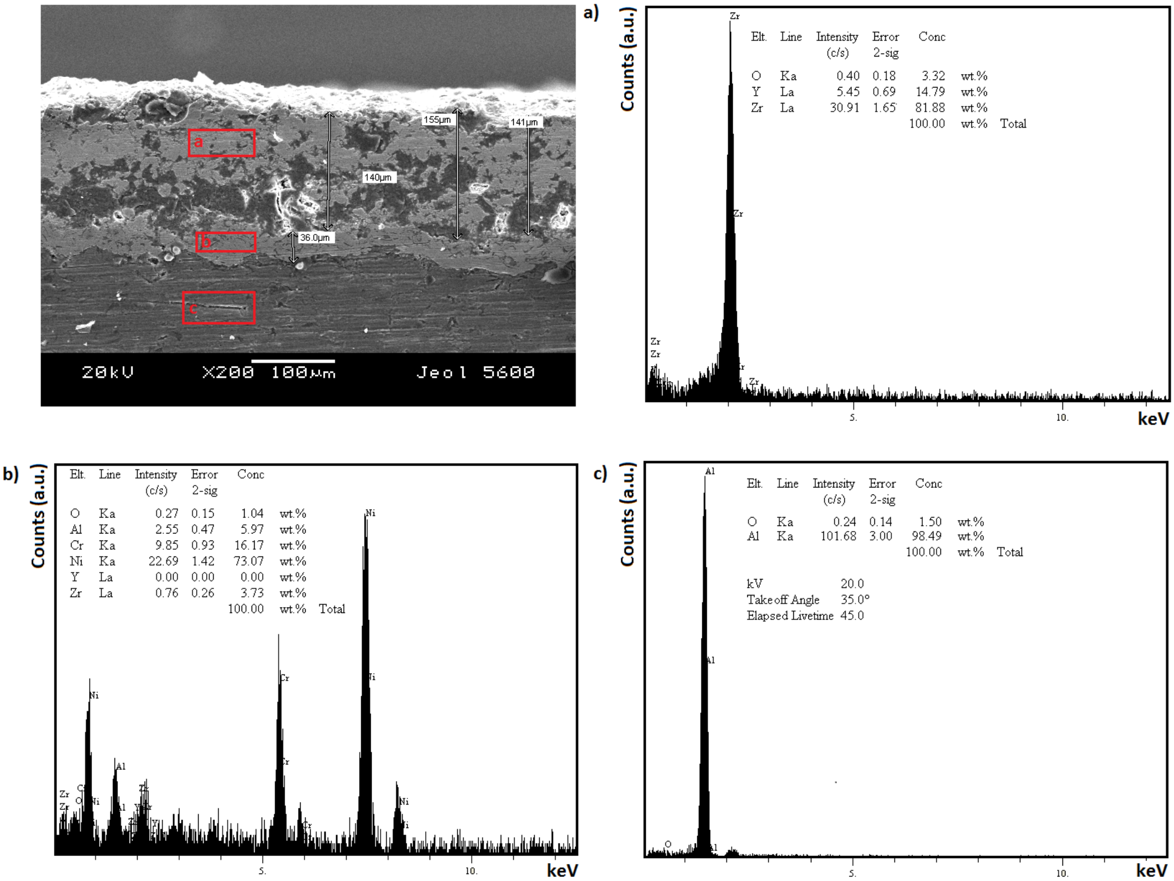

Fig. 3. Layers and their thicknesses
a, b and c) EDS analysis of YSZ coating, Ni-Cr-Al bond coat and 6063-T6 Al substrate

Table 2.
YSZ coated and uncoated 6063 samples weight loss values

YSZ ⇓	Working Distance (m)	Applied Load (N)	Spindle Speed (rpm)	Weight loss ΔG (g)
UNCOATED	7.23	10	60	0,00300
	14.46	10	60	0,00780
	28.92	10	60	0,01350
	14.46	20	60	0,01060
	14.46	40	60	0,01730
	14.46	10	120	0,01000
	14.46	10	240	0,02250
COATED	7.23	10	60	0,00005
	14.46	10	60	0,00005
	28.92	10	60	0,00005
	14.46	20	60	0,00150
	14.46	40	60	0,00245
	14.46	10	120	0,00270
	14.46	10	240	0,00295

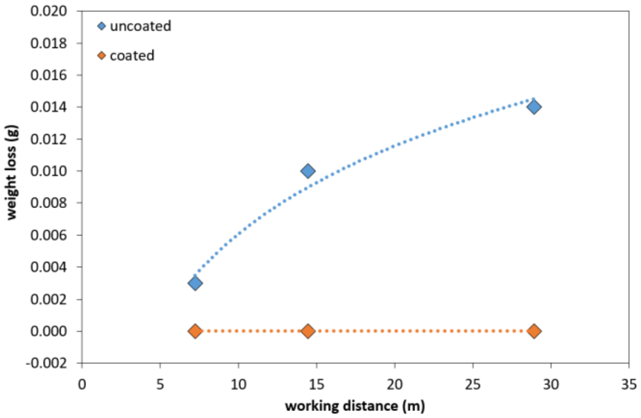

Fig. 4. YSZ coated and uncoated 6063-T6 aluminum alloys weight loss values for different working distances

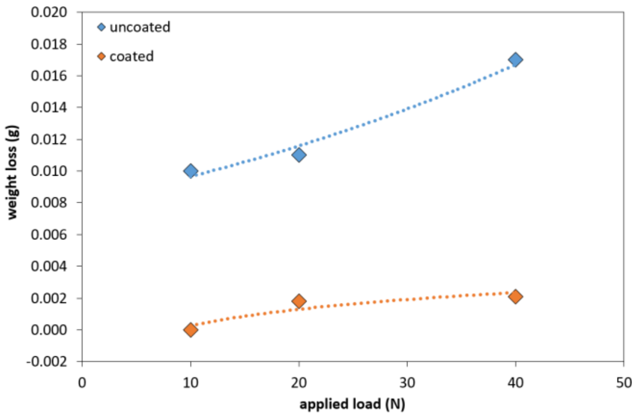

Fig. 5. YSZ coated and uncoated 6063-T6 aluminum alloys weight loss values for different loading parameters

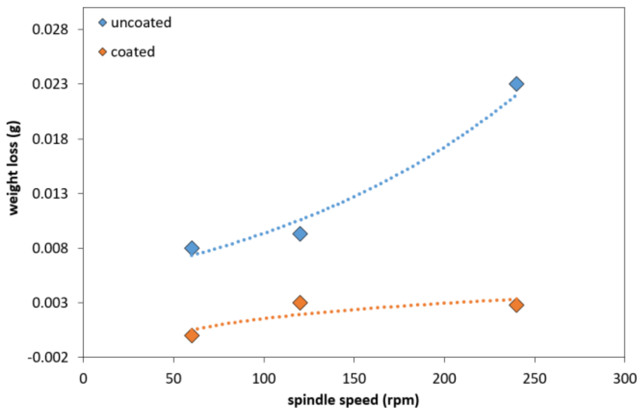

Fig. 6. YSZ coated and uncoated 6063-T6 aluminum alloys weight loss values for different speeds

According to the results obtained from the micrographic examination of SEM analysis of the wear surface, it was determined that the marks on the surface which belong to the uncoated sample of 6063 are deep and have a distinctive wear shape due the ductile behavior of aluminum (Fig. 7a and b). Random placement of the sprayed zirconia particles on the surface of the coated 6063 substrate creates a hard ceramic structure so that brittle fractures were detected on the wear marks. Condensed wear can be seen at the higher parts of the surface morphology. However, in spite of the porous and rough surface of the coated YSZ, the wear lines on the surface of the coated 6063 samples still do not have significant wear marks (Fig. 8a and b). Therefore, it is understood that the coated samples which were exposed to abrasion will demonstrate much higher performance at the operating conditions.

The kinetic friction coefficient values obtained from the tests are given in Table 3. According to the results, the friction coefficients were found to be between 0.1-0.2 for both of the material groups.

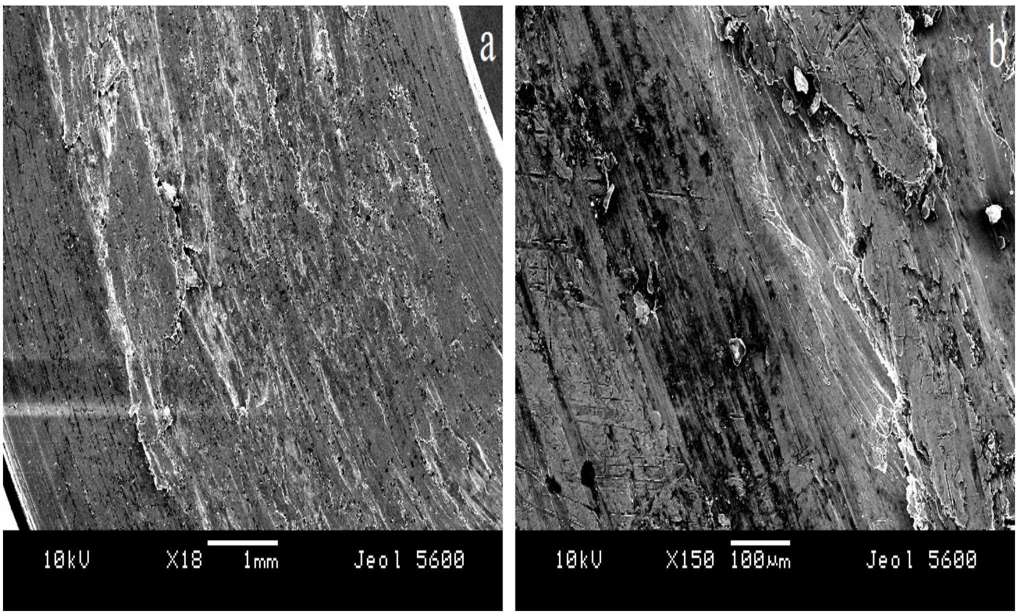

Fig. 7. SEM analysis of uncoated 6063-T6 samples dry sliding wear marks

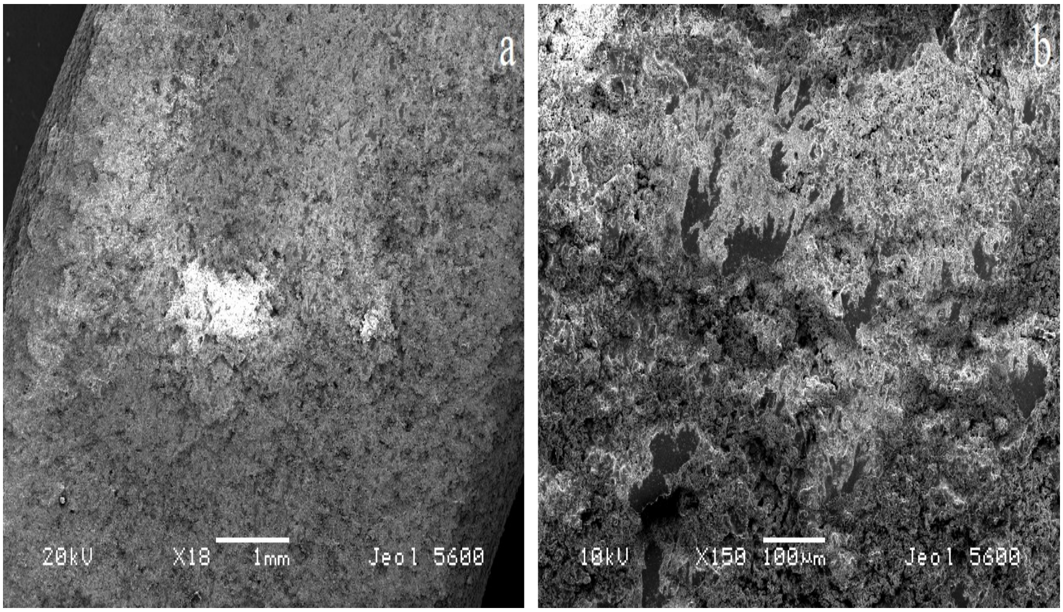

Fig. 8. SEM analysis of wt% 8 YSZ coated 6063-T6 samples dry sliding wear marks

Table 3.
Measured kinetic friction coefficients from the wear tests

	Working distance (m) / applid load (N) / spindle speed (rpm)						
	7.23/10/60	**14.46/10/60**	**28.92/10/60**	**14.46/10/120**	**14.46/10/240**	**14.46/20/60**	**14.46/40/60**
6063-T6	0.158	0.135	0.122	0.165	0.235	0.124	0.114
YSZ coated 6063-T6	0.218	0.148	0.101	0.2	0.208	0.145	0.162

5. Conclusion

By coating 6063-T6 aluminum alloy with 8 wt% YSZ ceramic material, higher wear resistance can be achieved. According to the test conditions studied in this work, the difference was found to be 10 times higher.

By increasing the applied load, spindle speed and travel distance, wear rates were increased in both coated and uncoated material groups. Increase in the wear rate of the coated samples with changing parameters was lower than the increase for the uncoated 6063-T6 samples. The most important parameter that increased wear rate was found to be the spindle speed rather than the load applied.

Zirconia coating has macro porosity. Although this situation has an enhancing effect on the surface roughness, it helps to keep the low density and the low weight advantages of the 6063 Al alloy.

Open pore structure is also an advantage especially in situations where a lubricant is used. The lubricant fills the open pores on the surface and this lubrication lasts for a longer time to decrease the wear resistance.

The friction coefficients were measured to be between 0.101 – 0.218 for YSZ coated material group and 0.114 – 0.235 for uncoated 6063-T6 aluminum alloy samples. There is no significant difference between the coated and the uncoated material groups. In the wear tests of YSZ coated samples, wear test device did not use higher torque values than the torque values used for the uncoated ones so that there was no excessive energy expenditure.

Even though aluminum has a low melting point and low mechanical strength, there is a high demand for aluminum due to its low density. Therefore, by coating aluminum alloy with YSZ, it can resist higher temperatures because of its thermal barrier properties and harder mechanical conditions for longer service time.

Acknowledgement

This work was supported by Research Fund of Istanbul University with Project Nr.: 515/05052006

References

[1] Wang, L. & Nɪe, X. (2006). Silicon effects on formation of EPO oxide coatings on aluminum alloys. *Thin Solid Films*. 494, 211.

[2] Xɪn S.G., Song, L.X., Zhao, R.G. & Hu, X.F. (2006). Composition and thermal properties of the coating containing mullite and alumina. *Materials Chemistry and Physics*. 97, 132.

[3] Sathish, S., Geetha, M., Aruna, S.T., Balaji, N., Rajam, K.S. & Asokamani, R. (2011). Sliding wear behavior of plasma sprayed nanoceramic coatings for biomedical applications. *Wear*. 271, 934.

[4] Bialucki, P. & Kozerski, S. (2006). Study of adhesion of different plasma-sprayed coatings to aluminum. *Surf. Coat. Tech*. 271, 2061.

[5] Dong, Z.L., Khor, K.A. & Gu, Y.W. (1999). Microstructure formation in plasma-sprayed functionally graded NiCoCrAlY/yttria-stabilized zirconia coatings. *Surf. Coat. Tech*. 114, 181.

[6] Khor, K.A., Gu, Y.W. & Dong, Z.L. (2001). Mechanical behavior of plasma sprayed functionally graded YSZ/NiCoCrAlY composite coatings. *Surf. Coat. Tech*. 139, 200.

[7] Lv, H., Zhao, W., An, Q., Nie, P., Wang, P., Wang, J. & Chu, P.K. (2009). Nanomechanical properties and microstructure of ZrO_2/Al_2O_3 plasma sprayed coatings. *Mat. Sci. Eng. A-Struct*. 518, 185.

[8] Tinquad, O., Bertrand, P. & Bertrand, G. (2010). Microstructure and tribological behavior of suspension plasma sprayed Al_2O_3 and Al_2O_3-YSZ composite coatings. *Surf. Coat. Tech*. 205, 1004.

[9] Ramachandran, C.S., Balasubramanian, V., Ananthapadmanabhan, P.V., Viswabaskaran. V. (2012). Understanding the dry sliding wear behaviour of atmospheric plasma-sprayed rare earth oxide coatings. *Mater. Design*. 39, 234.

[10] Brinkiene, K., Kezelis, R., Cesniene, J. & Mecius, V. (2009). Evaluation of wear resistace of plasma spray coatings. *Mater. SCI+*. 15, 302.

[11] Zhao, Y., Shinmi, A., Zhao, X., Withers, P.J., Van Boxel, S., Markocsan, N., Nylen, P. & Xiao, P. (2012). Investigation of interfacial properties of atmosheric plasma sprayed thermal barrier coatings with four-point bending and computed tomography technique. *Surf. Coat. Tech*. 206, 4922.

[12] Kato, K. (2000). Wear in relation to friction a review. *Wear*. 241, 151.

[13] Tucker, R.C., Pauleau, Y., Barna, P.B. (1997). *The use of thermal spray coatings for protection against wear and corrosion*. Kluwer Academic Publications.

[14] Picas, J.A., Forn, A., Rialla, R. & Martin, E. (2005). HVOF thermal sprayed coatings on aluminum alloys and aluminum matrix composites. *Surf. Coat. Tech*. 200, 1178.

[15] Barbezat, G. (2005). Advanced thermal spray technology and coating for lightweight engine blocks for the automotive industry. *Surf. Coat. Tech*. 200, 1990.

[16] Salman, S., Kose, R., Urtekin, L. & Findik, F. (2006). An investigation of different ceramic coating thermal properties. *Mater. Design*. 27, 585.

[17] Łągiewka, M. & Konopka, Z. (2014). The influence of graphite addition on the abrasive wear of AlMg10 alloy matrix composites reinforced with SiC particles. *Archives of Foundry Engineering*. 14(3), 51-54.

[18] Orłowicz, A.W., et al. (2015)Combustion Engine Cylinder Liners Made of Al-Si Alloys. *Archives of Foundry Engineering*. 15(2), 71-74.

[19] Piątkowski, J. Wieszała, R. & Gontarczyk, A. (2016). Influence of Casting Conditions on Tribological Properties of A390. 0 Alloy. *Archives of Foundry Engineering*. 16(3), 95-98.

[20] Konopka, Z. & Pasieka, A. (2014). Tribological properties of AlSi11-SiCp composite castings produced by pressure die casting method. *Archives of Foundry Engineering*. 14(3), 37-42.