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Evaluation of Wear and Corrosion Resistances of Oxide Coatings Formed on Magnesium Alloys by Micro Arc Oxidation

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Abstract. In the present study, wear and corrosion resistances of magnesium alloys were analyzed after coated by micro arc oxidation (MAO) process for potential protection of gear component, which is the most wearing part of a conventional bicycle. Two of the most common magnesium alloys (AZ31 and AZ91) were used in the study and they were oxidized in three different electrolytes (aluminate-, silicate- and phosphate-based). Scanning electron microscopy (SEM) was utilized in order to analyze the coating morphology and wear tracks obtained during wear tests. Energy dispersive X-ray spectroscopy (EDS) analyses were implemented to determine the elemental composition of the coatings. Wear and corrosion tests were applied to compare the performances of the coatings. Experimental results showed that wear and corrosion resistances of the samples generally increased after coated by MAO process and the best protection against wear and corrosion related failures, was achieved by utilizing silicate-based electrolyte for MAO process of magnesium alloys under selected process parameters.

Introduction

Bicycle is one of the most efficient solutions for continuously increasing transportation problems and luckily, they seem to be getting more attraction since past decade. Lightness of a bicycle is the key specification when you as a consumer, consider the energy saving and easy usage. It is possible to observe that less energy can be spent including several parameters, such as weight of rider, distance, and riding style [1]-[5].

Light bicycles are able to accelerate rapidly considering the respond the force that applied on treadle and they are less tiring at low speed by owing to have inertia and capability of vanquish the gravity with less power. These types of bicycles have very special skills as having acceleration and deceleration in shorter time, having better control in hard grounds, and consuming less energy in longer paths. In brief, light bicycles provide more work with the same power or supply the same work with less power. While bicycles mainly made from metallic materials, magnesium was considered in the present study because of their beneficial properties as being light and having high specific strength. However, insufficient wear and corrosion resistances are the main disadvantages of magnesium alloys, which limit the area of applications [5]-[10].

The steps of this study were firstly to characterize the coatings formed by micro arc oxidation (MAO) on magnesium alloys (AZ31 and AZ91) and secondly to analyze the wear resistance against ceramic counter-material and corrosion resistance in a salt solution environment. By courtesy of ensuring benefits just as easier pre-treatment, higher hardness, faster practice and non-toxic working environment; MAO is chosen as a coating process. Magnesium alloys were coated in aluminate-, silicate- and phosphate-based electrolytes. Microstructures of the samples were examined by a scanning electron microscope (SEM) and elemental analyses were determined by an energy dispersive X-ray (EDS) spectrometer. Wear tests were implemented to the samples to compare the wear resistance of different coatings produced with different electrolytes. Corrosion test was performed with the NaCl solution by immersing the samples for 4 days.

Experimental Method

MAO Process. AZ31 and AZ91 quality magnesium alloys were coated by utilizing DC bipolar-pulsed MAO device in silicate-, aluminate- and phosphate-based electrolytes. For experimental studies, circular AZ91 samples having 5 mm thickness and 20 mm diameter were divided into the two pieces. AZ31 samples with dimension of 10 x 10 x 5 mm prepared for MAO process. Samples were ground with silicon carbide sandpapers up to #1200. MAO process carried out at 400 V positive and 80 V negative voltages, 500hz in frequency for 5 min. As it is illustrated in Fig. 1 that samples were coded as related to the electrolytes used for MAO process; aluminate-AZ31, aluminate-AZ91, phosphate-AZ31, phosphate-AZ91, silicate-AZ31 and silicate-AZ91.

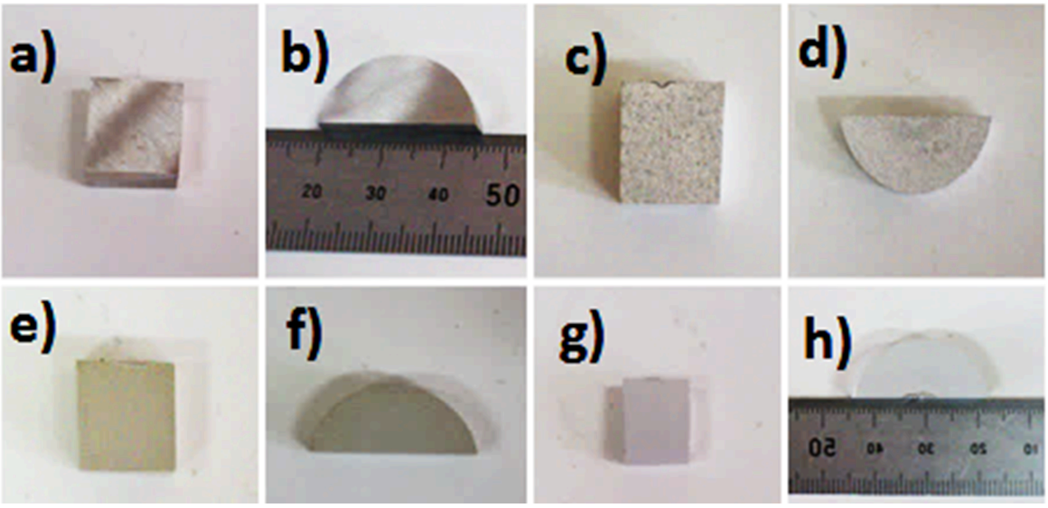

Fig. 1. Images of uncoated and coated samples as a) Uncoated-AZ31, b) Uncoated-AZ91, c) Aluminate-AZ31, d) Aluminate-AZ91, e) Phosphate-AZ31, f) Phosphate-AZ91, g) Silicate-AZ31 and h) Silicate-AZ91.

Characterization of Coatings. Coated magnesium alloys were investigated by SEM (Hitachi TM-1000) with different magnifications (2000X and 5000X). For determining the composition of the coatings, EDS analyses were also utilized to the surface of the samples.

Wear and Corrosion Tests. Dry sliding wear tests of MAO coated samples were performed on a reciprocating wear tester (Tribotech Oscillating Tribotester) at room temperature. In this configuration, an alumina ball with a diameter of 6 mm was sliding forward and backward on the samples with a sliding speed of 4 mm/s. Normal load of the test, sliding amplitude (wear track length) of the reciprocating motion and overall sliding distance were 2 N, 4 mm and 25 m, respectively. Width and depth of the wear tracks were measured by a surface profilometer (Veeco Dektak 6M) to calculate worn volumes of the samples and relative wear resistances. Following the wear tests, wear tracks were examined by SEM. In order to compare the corrosion resistances, MAO coated and uncoated samples were immersed into a 10 wt.% NaCl solution for 24, 48, 72 and 96 hours at 20°C. Samples were then taken out from the NaCl solution and weighed at 24-hour intervals.

Results and Discussion

Characterization Tests. SEM micrographs of the coated samples are illustrated at Fig. 2. For silicate-based coating, it was seen that pores and cracks were in micron range and cracks occur between the pores. Phosphate-based coating images demonstrated thumping pores and cracks among these pores. The reason of crack formation was influenced by thermal shock of melted layer owing to rapid cooling. Phosphate-AZ31 sample contained more cracks compared to phosphate-AZ91 sample. It is suggest that presence of higher aluminum in the alloy resulted less cracky surface appearance.

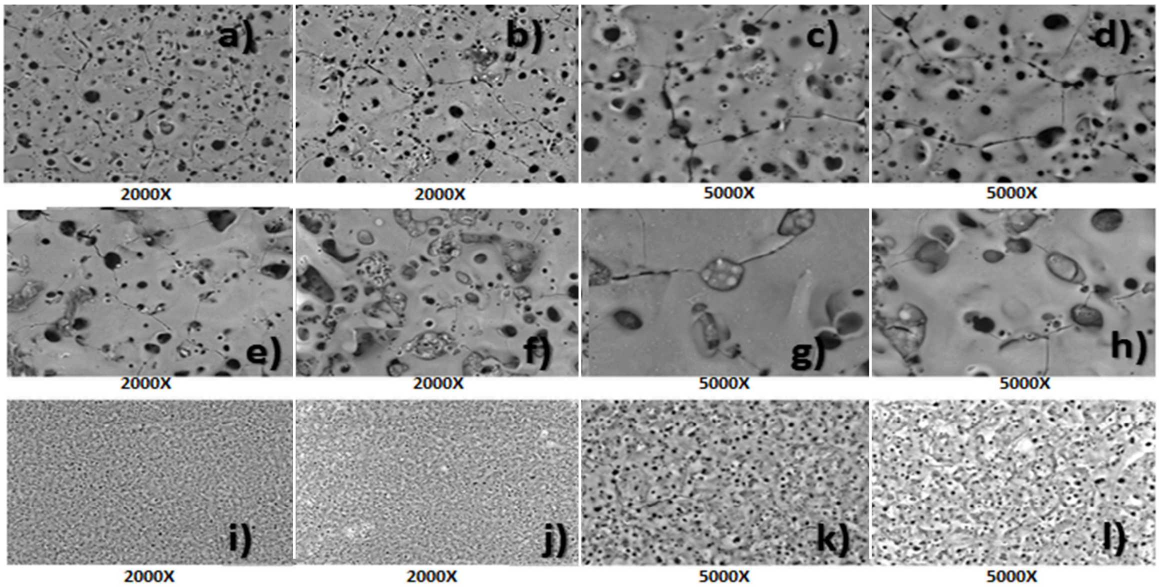

Fig. 2. SEM images of coated samples as a) Silicate-AZ31 b) Silicate-AZ91 c) Silicate-AZ31 d) Silicate-AZ91 e) Phosphate AZ31 f) Phosphate-AZ91 g) Phosphate-AZ31 h) Phosphate-AZ91 i) Aluminate-AZ31 j) Aluminate-AZ91 k) Aluminate-AZ31 l) Aluminate-AZ91.

Aluminate-based coatings also displayed pores and cracks in micron range and can be observed under 5000X magnification. EDS analyses given at Table 1 showed approximately the same results which mean there is no different phase forming on coatings of AZ31 and AZ91 alloys.

Table 1. EDS analyses of coated samples (without oxygen due to the incapability of EDS equipment).

	Elements	AZ91(wt.%)	AZ31(wt.%)
Silicate	Mg	25.38	32.28
	Na	6,.4	5.46
	Al	1.04	3.86
	K	10.82	7.12
	Si	56.2	51.3
Phosphate	Mg	28.58	30.58
	Na	4.86	3.48
	Al	2.88	4.46
	P	59.32	59.78
	K	4.36	1.72
Aluminate	Mg	46.48	47.88
	Na	0.22	0.18
	Al	51.8	51.56
	K	0.6	0.38

Wear Tests. Width and depth of the wear tracks were measured by the surface profilometer. Relative wear resistance values are calculated related to these data and given in Table 2. MAO samples showed higher values of relative wear resistance.

Table 2. Wear track measurements of coated and uncoated samples.

	Width of track (µm)	Depth of track (µm)	Cross-sectional area (μm^2)	Relative wear resistance
Uncoated AZ91	1224 ± 8.16	64 ± 1.05	28250	1.75
Uncoated AZ31	1464 ± 15.71	86.93 ± 5.04	49442.5	1
Aluminate AZ31	961.33 ± 26.95	43.64 ± 0.78	16227.5	3.04
Aluminate AZ91	229.67 ± 13.06	1.28 ± 0.34	89.95	549.7
Silicate AZ31	219.67 ± 15.82	0.933 ± 0.61	80.23	616.25
Silicate AZ91	277.67 ± 17.89	1.55 ± 0.145	169.02	292.52
Phosphate AZ31	414 ± 6	4.18 ± 0.08	679.57	72.75
Phosphate AZ91	370 ± 38.15	2.78 ± 0.165	406.85	121.54

SEM micrographs of phosphate-AZ91 and phosphate-AZ31 showed that coatings protected the base material. It can be seen in Fig. 3 that aluminate coatings did not protect the base material and were removed from the surface during the test. Therefore, abrasive ball of wear test machine reaches the alloy. Residues of the coating were observed at SEM images of aluminate AZ31. Silicate coatings displayed the best resistance to wear. It is shown in Fig. 3 that SEM images of silicate-AZ31 and silicate-AZ91 indicated that abrasive ball of the tester did not surpass the coating and attain the base material.

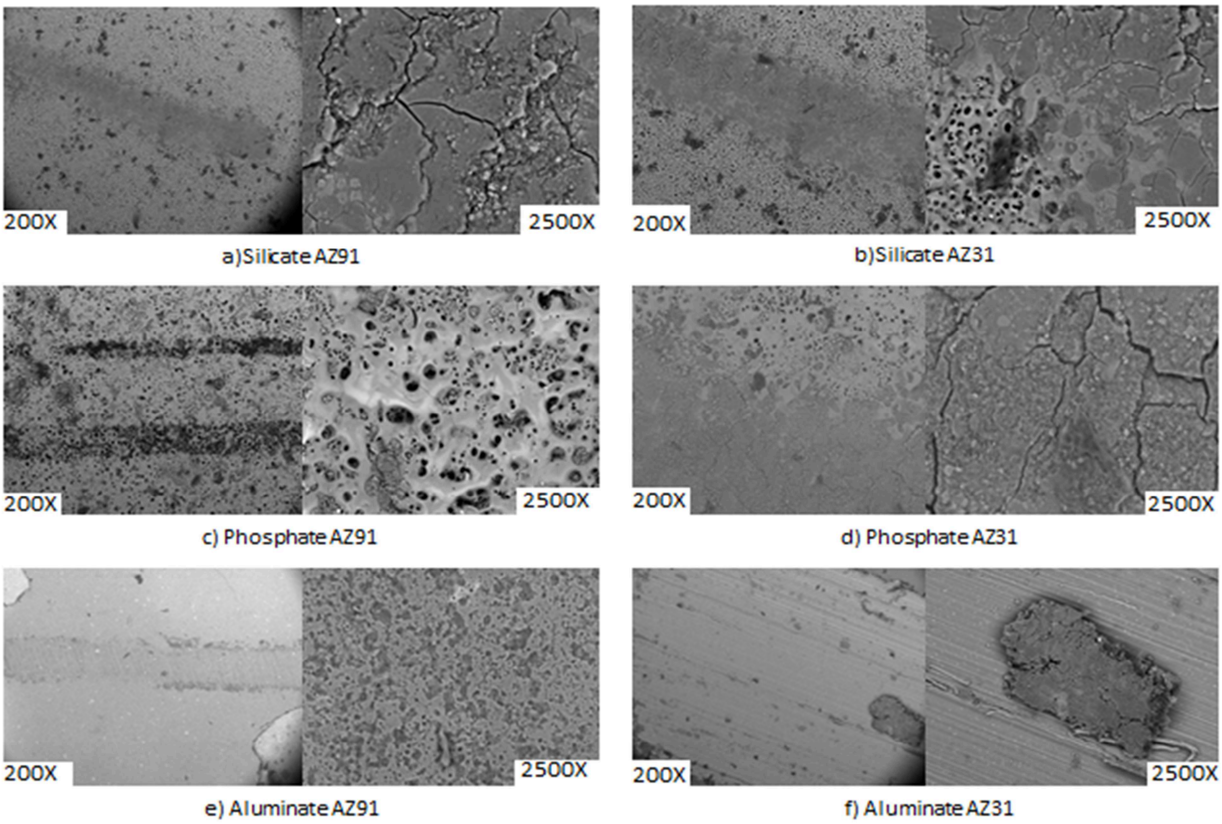

Fig. 3. SEM images of wear tracks of the coated samples.

Corrosion Tests. Fig. 4 gives the weight losses of coated and uncoated AZ31 and AZ91 samples after corrosion tests. Uncoated AZ31 and phosphate AZ91 samples show maximum values of weight losses. Increase of the amount of weight loss can be evaluated as a sign of weak corrosion resistance. It can also be understood from Fig. 4 that both silicate-AZ31 and AZ91 samples provided best corrosion resistance compared to other coatings and AZ91 sample.

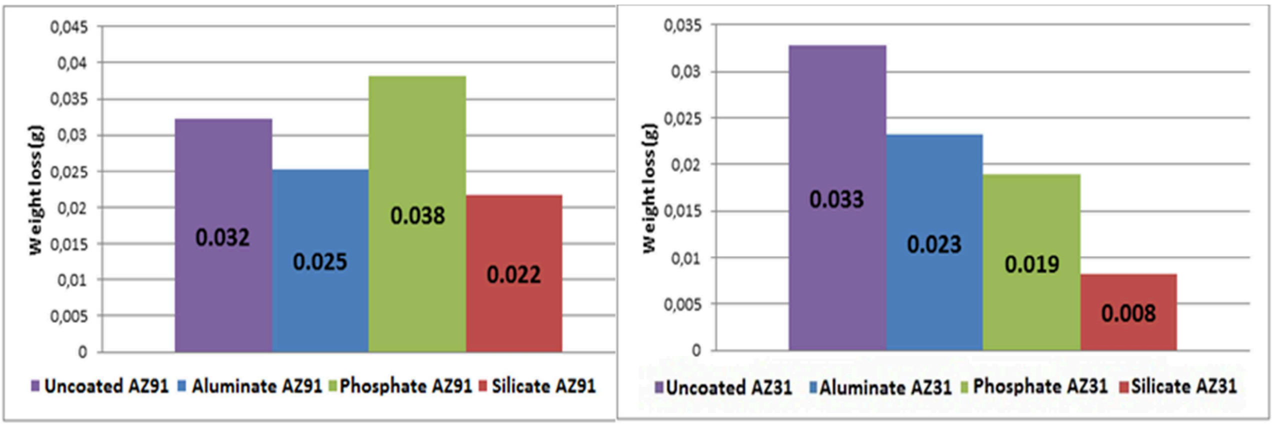

Fig. 4. Weight losses (g) of the AZ31 and AZ91 samples after 96 hours.

Conclusion

The results are as follows;

- Wear track was far larger on uncoated magnesium alloy surfaces as compared to silicate-, aluminate- and phosphate-based coated samples.
- According to corrosion test, visible damage was observed on uncoated samples. In addition, phosphate and aluminate coatings are affected more than silicate coating.
- After wear test, SEM images are taken under diverse magnifications show that silicate based coating is the optimal choice related to less pores and cracks.

After the experimental studies, silicate electrolyte was suggested for protection of wear and corrosion related applications.

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