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Characteristic of MAO coatings formed on $CuAl_2$ in-situ reinforced Aluminum Matrix Composites

D.I. Mafouz [a,b], A.H. Paksoy [a], F. Muhaffel [a], O. Tazegul [a], H. Cimenoglu [a,*]
[a] Department of Metallurgical and Materials Engineering, Istanbul Technical University, Istanbul, Turkey,
[b] Department of Mechanical Engineering, Institute Polytechnic of Paris, France
* Corresponding e-mail address: cimenogluh@itu.edu.tr

ABSTRACT

Purpose: The aim of this study was to examine the structural and mechanical properties of coatings formed on $CuAl_2$ in-situ reinforced aluminium matrix composites (AMCs) by micro arc oxidation (MAO) process. AMC, which were fabricated by powder metallurgy method upon addition of copper powder into aluminium powder at different percentages (0%, 15 wt.% and 30 wt.%), were exposed to MAO after sintering at 550°C for 6 h. During sintering process $CuAl_2$ type intermetallic was precipitated in the microstructure of copper containing compacts. MAO caused covering of the surfaces of AMCs with an oxide layer mostly consisting of mullite and alumina. Mechanical performance of the coatings were determined by hardness measurements and wear tests. In summary, the oxide layers formed on the AMCs exhibit a reduction in hardness and tribological performance with increasing copper content of the AMC.

Keywords: Aluminium Matrix Composite; Intermetallic; Micro arc oxidation; Mullite; Wear

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PROPERTIES

1. Introduction

Aluminium is one of the most attractive materials for structural applications, where high strength to weight ratio is critical. Nevertheless, the traditional aluminium alloys recently cannot satisfy the requirement of high technology used industries such as aerospace, chemical, and transportation etc. In this respect, reinforcing of aluminium with ceramic particles (i.e production of aluminium matrix composite, AMC) and/or surface modification have been extensively investigated in recent years in order to widen the use of aluminium components [1-4]. Among the surface modification techniques, micro arc oxidation (MAO), has appeared as an environmentally friendly and relatively simple electrochemical coating technique. MAO forms oxide layer which sustains anti-corrosion and anti-wear properties on the surfaces of aluminium and its alloys [5-8].

In this study, MAO treatment was applied on copper-free aluminium and $CuAl_2$ reinforced AMCs as the continuity of our previous study [9]. The aim was to analyse the influence of $CuAl_2$ reinforcement of AMC on the mechanical properties of the oxide layer formed on the surface of AMCs by MAO process.

2. Material and method

In the present study, AMCs were produced by powder metallurgy method. Mixtures of aluminium and copper (0, 15, and 30 wt.% copper) powders were compacted at room temperature. Afterwards, compacted samples were sintered at 550°C for 6 h. Prior to MAO treatment, all the samples were ground by SiC abrasive paper up to ♯1200, washed with the ethanol and distilled water and completely dried at room temperature. MAO treatment applied by using 30 KW DC power supply and stainless steel container served as cathode during the process. Samples treated in an electrolyte containing 10 g/l sodium silicate (Na_2SiO_3, Merck) and 3 g/l of sodium phosphate (Na_3PO_4, Alfa Aesar) for 15 min with the applied voltage of 520 V in the positive half cycle and 100 V in the negative half cycle. MAO coated samples were coded as Cu-0, Cu-15, Cu-30 according to copper contents of the compacts.

After the MAO treatment, structural examinations were made by utilizing scanning electron microscope (SEM, Hitachi TM-1000) and X-Ray diffractometer (XRD, GBC MMA). XRD analyses were executed with in 2θ range from 20° to 80° using Cu-Kα radiation. SEM examinations were conducted on the surface and cross-sections of the compacts. For the cross-sectional investigation, coated samples were gently cut and then ground and polished by following standard metallographic procedures. Additionally, hardness of the oxide layers were measured from the polished cross-section. Hardness measurements were made by Shimadzu micro hardness tester under the load of 25 g.

Tribological investigations of the samples were examined by the ball-on disc type tribotester (CSM) against WC ball having 6 mm diameter. Wear tests executed under the load of 2 N, linear sliding velocity of 5 cm/s and a total sliding length of 200 m under controlled atmosphere (23 ± 1°C and 30 ± 3% humidity). Friction coefficients of the samples were recorded during the tests. While wear rates were determined by measuring the width and depth of the wear track utilizing a contact profilometer (Veeco Dektak 6M), worn surfaces were examined by SEM.

3. Results and discussion

The XRD spectra of the MAO applied samples are shown in Figure 1. From the XRD spectra, it is clearly observed that γ-Al_2O_3 (γ-alumina) and $2Al_2O_3.SiO_2$ (mullite) were formed during MAO process. The growth mechanism of the oxide layers (containing mullite and γ-alumina) on the samples can be explained by the electrochemical reactions taking place between aluminium from the substrate, silicon and oxygen from the electrolyte. Aluminium and $CuAl_2$ peaks were also detected on the XRD spectra. It is interesting to note that the intensity ratios of $CuAl_2/Al$, $CuAl_2/Al_2O_3$ and $CuAl_2/2Al_2O_3.SiO_2$ tended to increase with increasing copper content of the substrate. This suggests existence of $CuAl_2$ in the MAO layers of Cu-15 and Cu-30 samples.

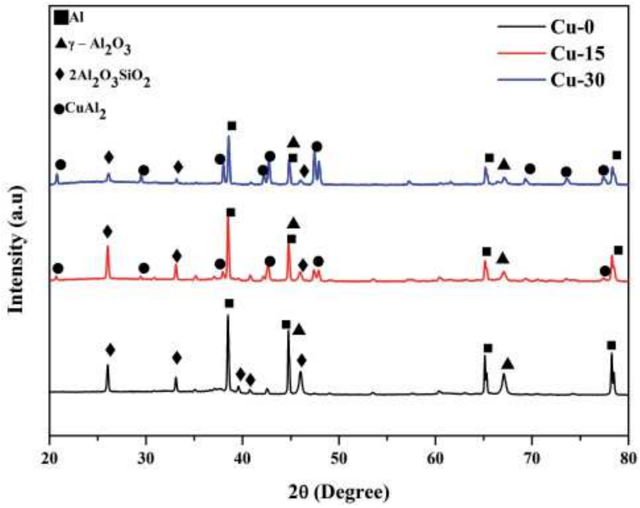

Fig. 1. XRD spectra of the Cu-0, Cu-15, and Cu-30 samples

The surface and cross-sectional SEM micrographs of the coatings are shown in Figure 2. Surfaces of the examined samples exhibited typical appearance of MAO coatings consisting of micro cracks, volcano like crater shaped structures as the result of the formation of discharge channels.

Numbers and the sizes of the micro pores in the MAO coatings tended to increase with increasing copper content of the substrate. Cross-section examination revealed that, the thickness of the MAO coatings, which were in good adhesion with the substrate, were about 30 μm. It should be noted that, $CuAl_2$ particles existing in the MAO coatings of the Cu-15, and Cu-30 samples appeared in relatively light colour.

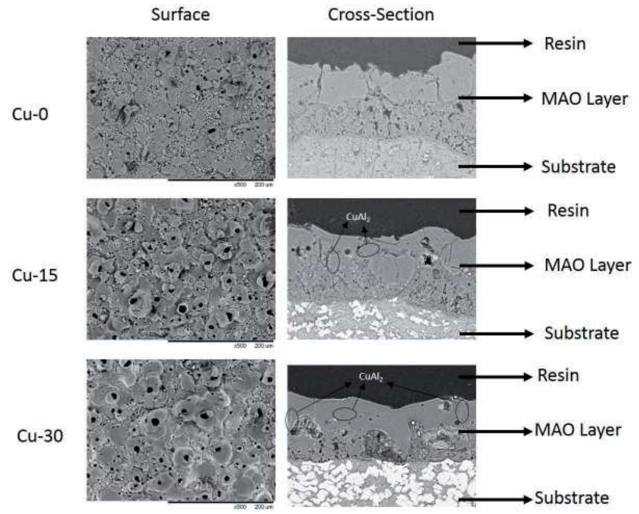

Fig. 2. SEM micrographs of the surface and cross-section of the samples

Hardness values of the coatings tended to decrease with increasing copper content of the substrate. Thus, the average hardness of the MAO coatings formed on Cu-0, Cu-15, and Cu-30 samples were measured as 385, 262 and 170 $HV_{0.25}$, respectively. Remarkably lower hardness values of the MAO coating with increasing of the copper content can be related to the lower hardness of the $CuAl_2$ phase in the substrates. Additionally, increasing of pore concentration with increasing of copper content can be reduced the hardness of the MAO coating.

Results of the wear tests are listed in Table 1 in terms of wear rate (volume loss per unit sliding length) and steady state friction coefficient, where friction curve remained at a constant value. Wear rate and steady state friction coefficient of the MAO coating increased with increasing of copper content of the substrate. This observation revealed the interaction of the coating and counterface is directly related to the wear performance of the coatings. Additionally, hardness of the coatings are also directly related to the wear resistance of the coatings.

Table 1.
Wear rate and steady state friction coefficient of the MAO coatings

Sample	Wear Rate, mm^3/m	Steady state friction coefficient
Cu-0	$1.27x10^{-4}$	0.60
Cu-15	$1.67x10^{-4}$	0.78
Cu-30	$2.31x10^{-4}$	0.82

Worn surface appearances of the MAO coatings are depicted in Figure 3. Worn surface of the MAO coating formed on the Cu-0 sample (Fig. 3a) can be characterised by tensile cracks perpendicular to the sliding direction and micro groves aligned on the sliding direction. Small delamination zones were also identified on the worn surface. When the Cu-15 and Cu-30 samples are of concern, coarse delamination zones were dominant on the worn surfaces of their MAO coatings (Figs. 3b and c), unlike Cu-0 sample. This suggested poor binding of $CuAl_2$ intermetallics with the surrounding oxides so that pull out of the $CuAl_2$ intermetallics from the MAO coating during the rubbing action of the counterface accelerated the wear loss.

4. Conclusion

MAO of the samples coded as Cu-0, Cu-15 and Cu-30 with respect to their copper content in 10 g/l Na_2SiO_3 and 3 g/l Na_3PO_4 containing electrolyte generated about 30 µm thick coating mainly consisted of alumina and mullite.

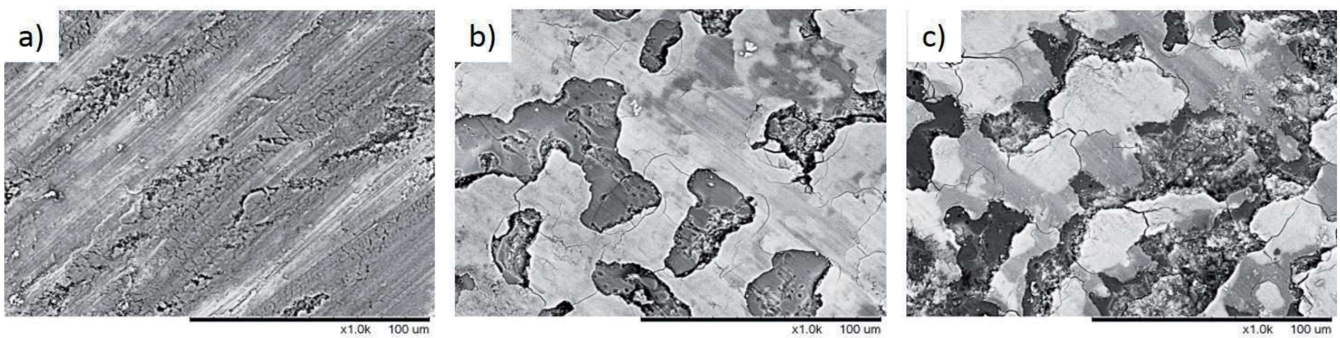

Fig. 3. Worn surface of the MAO coating formed on the a) Cu-0, b) Cu-15, c) Cu-30 substrate

The MAO coatings exhibited different structural and mechanical characteristics with respect to the copper content of the substrate. In general higher copper content of the substrate caused generation of a coating with higher porosity, lower hardness and poor tribological performance.

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