Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 5, pp. 01-07
Published Year 2020

Metal-ceramic Composite to Improve Wear Resistance of Aluminum Alloys Surface by Nanoceramic Electroplating

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ABSTRACT: The improvement of aluminum alloys surface according to the industrial applications was achieved by many techniques. Including increase of hardness, that lead to improve wear resistant of aluminum alloys surface, for that purpose the electroplating was used. Electroplating by composite of hard chromium-Nanoceramic Co-deposit was conducted in this paper. Nanoceramic particles including Nanotitanium oxide (Nano-TiO_2), Nano-aluminum oxide (α-Nano-Al_2O_3) and Nanozirconia (Nano-ZrO_2) were used to hard chromium electroplating on 1050 aluminum alloy. For co-deposit analyses characterization were used scanning electron microscope (SEM) and- energy dispersive X-ray (EDX). The hardness was evaluated by Micro hardness tester, wear resistance was increased by increase the hardness with the presence of Nanoceramic particles in this process. The results showed the maximum hardness and minimum wear rate at the samples with Nanozirconium oxide particles were 1409MPa and ($0.003*10^{-8}cm^3*cm^{-1}$) respectively.

KEYWORDS: Index Aluminum-alloys, Wear resistance, hard chromium electroplating, Nanoceramic particles, co-deposit electroplating

INTRODUCTION

Aluminum alloys are used widely in industrial applications due to its many and special characteristics, including; high thermal and electrical conductivity, low density, magnetic neutrality, high ductility, etc. Despite these properties, some applications were require improved the surface of aluminum alloys, such as hardness increasing and wear resistance, that led to discover the best techniques to improve the surface of aluminum alloys [1, 2]

AA1050 alloy has low mechanical properties compared to other types of aluminum alloys, because it is not heat treatable alloy. Some solving to this problem was the strain hardening [3].

The composite Cr--Nanoceramics electroplating was used to improve the surface of aluminum alloys. Due to the many advantages of process that when used can be achieved such as; any shape and size can be used. The uniform distribution of particles, with low temperatures, the deposition was achieved. More coating rates and low energy losses, not required into industrial equipment [4, 5]. The ceramic particles were used with composite coatings by the electroplating process, because of the high corrosion resistance, and at same time is used with the reduced metal ions were precipitated [6, 7].

To improve the surface of aluminum alloys, the Plasma electrolytic oxidation was used to increase the wear resistance and coefficient of friction, for that process, the basalt mineral powder with a silicate-alkaline solution were achieved to make slurry electrolyte [8]. The Al_2O_3 was deposited on electrochemical responses by aluminizing method, that for produce the single layer coatings of copper and alumina, also double layers Cu/Al_2O_3 that by reverse pulsed current electroplating [9].

Lately, the ionic solutions electroplating process was used to improvement layer of light metals to resist the wear, including Nanoceramic particles with chromium electroplating by forming co-deposit coating processes were used to improve the wear resistance. Also Hard chromium-Nanoceramic co-deposit processes were used to increase the wear resistance of metals surface [10, 11]. Many studies focused on the effect of electroplating on properties of metals that reinforced by nanoceramic particles, such as study the effect of Nanoalumina on the corrosion resistance of cupper surface [12]. The pulse electroplaplating of Ni-Co coatings which reinforced by Nano and micro ZnO and its effect on properties of the copper substrate surface was achieved. The NanoZnO improves the wear resistance. Most previous studies concluded the Co-deposition of cr-Nanoalumina process lead to improve the deposit thickness and the efficiency of the current [13].

In this work, the main objective was to improve the surface by co-deposit of Cr-Nanoα-Al_2O_3, Cr-NanoZrO_2, and Cr-NanoTiO_2 to treat the surface of 1050 aluminum alloy. In addition, a comparison of the effect of these Nanoceramics materials on the surface properties of 1050 Al alloy when added to hard chromium electroplating bath.

MATERIAL AND MEHODS

Samples preparation

The samples of Aluminum alloy (1050 Al-alloy) were machined with finishing cutting conditions by lathe machine at cutting speed 450 m/min, depth of cut 0.5 mm, feed 0.1 mm/rev and dry cutting, the dimensions of samples were diameter 25 mm and 3 mm thickness. Then, the grinding, polishing, zincate and electroplating processes were conducted. Electroplating was including hard chromium according to ASTM B177 / B177M - 11(2017) standard [14].

Electroplating process

The composition of bath was (300g/l of Cr_2O_3, 3g/l of concentrated H_2SO_4), also the anodes were from lead-7Sn alloy. The samples were cathode in the electroplating cell. The Nanozirconium oxide (ZrO_2), Nanoaluminium oxide (Al_2O_3), and NanoTitanium oxide (TiO_2) with particle size (20-30 nm) were used in the unit cell each individually. The parameters of electroplating as in table 1.

Table 1. parameters of hard chromium electroplating

Sample No.	S0	S1	S2	S3	S4
CrO_3	0	300 g/L	300 g/L	300 g/L	300 g/L
H_2SO_4	0	3 g/L	3 g/L	3 g/L	3 g/L
Voltage(V)	0	6	6	6	6
DC current (A)	0	20	20	20	20
Time (Min.)	0	30	30	30	30
Temperature (C ^{o})	0	50	50	50	50
Mixing Velocity (rpm)	0	800	800	800	800
Nano ZrO_2	0	0	0	6 g/l	0
Nano TiO_2	0	0	6 g/l	0	0
α-Nano Al_2O_3	0	0	0	0	6 g/l

For mixing and heating the electroplating bath, magnetic stirrer with hot plate were used, the temperature for all experiments was 45ºC. Table 1 showed the parameters of the chromium electroplating processes. Deposit thickness and composition of deposit layers was evaluated using scanning electron microscope (SEM) and-dispersive X-ray (EDX).

The samples were prepared according to ASTM E3—11(2017) preparation standards for microstructure, hardness and dry sliding wear resistance. Micro Vickers hardness was carried out using the Vickers hardness test with (0.4N) testing load and (15 sec.) testing time as in table 2.

Table 2. Micro-hardness results

Sample No.	Test 1 (Hv MPa)	Test 2 (Hv MPa)	Test 3 (Hv MPa)	Mean value MPa
S0 (Without electroplating)	33	37	36	35.5
S1(Hard chromium deposit)	890	880	920	897
S2 (Chromium with TiO_2)	1220	1240	1250	1237
S3 (Chromium with ZrO_2)	1410	1408	1410	1409
S4(Chromium with α-Al_2O_3)	1090	1080	1098	1086

The wear rate was carried out by dry sliding wear resistance using universal wear resistance pin-on-disc machine. The parameters were, load (500g), speed (200 rpm), diameter of disc (30mm), and the time of sliding (5, 10, 15, 20 min.). The diameter of samples was (6mm) and (15mm) length. The wear rate was as in table 3

Table 3. the wear rate

Sample No.	Wear rate (cm^3*cm^{-1}) at 5 min.	Wear rate (cm^3*cm^{-1}) at 10 min.	Wear rate (cm^3*cm^{-1}) at 15 min	Wear rate (cm^3*cm^{-1}) at 20 min
(S1)	$1.62*10^{-8}$	$0.95*10^{-8}$	$0.674*10^{-8}$	$0.53*10^{-8}$
(S2)	$0.05*10^{-8}$	$0.05*10^{-8}$	$0.06*10^{-8}$	$0.06*10^{-8}$
(S3)	0	0	$0.003*10^{-8}$	$0.005*10^{-8}$
(S4)	$0.03*10^{-8}$	$0.03*10^{-8}$	$0.02*10^{-8}$	$0.015*10^{-8}$

RESULTS AND DISCUSSION

SEM Image

Fig.1 showed the chemical composition of the first layer. Figure 1A, presents the microstructure of SEM image at spectrum 3. As appear in fig.1B the EDS graph showed the chemical composition of the first layer on the aluminum substrate. This layer deposited on aluminum surface to activate the aluminum surface for electroplating. While Figure 2 shown the SEM image and EDS paragraph on spectrum 23.

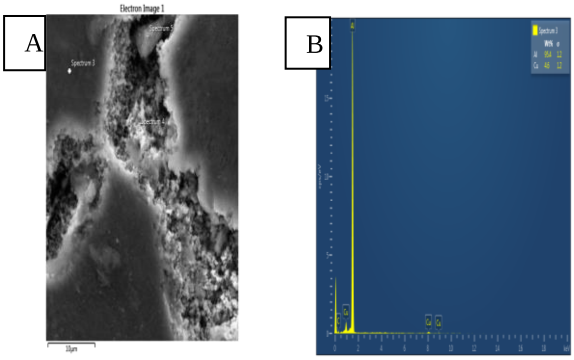

Figure 1. The SEM image and EDS at the first layer which represents the copper layer.

It appeared clearly from figure 2 the composition of spectrum 23 consisted of Al and Ti. This image was at the surface of sample S2.

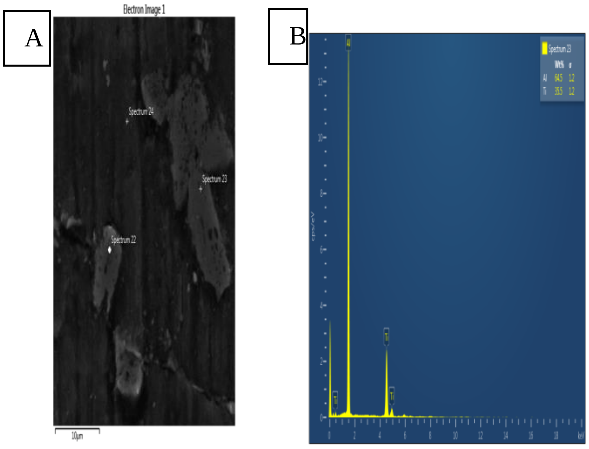

Figure 2. SEM image at spectrum 23 which shows the Nano TiO^2 particles at the deposit.

As well as the Figure (3) shown the SEM images appeared the thickness of codeposit layers. Image at fig.ure 3A appear only the chromium deposit (sampe S1). Figure 3B reveals two layers, the fist layer 3.73µm the copper layer and the co-deposit of cr-Nano$TiO_{2.}$ The thickness of this layer is 6.67 µm.

Fig. 3C represented the deposit Cr-$ZrO_{2,}$ the first layer is the copper layer, the thickness of this layer is 5.16 µm. The second layer is co-deposit is Cr-ZrO_2 and its thickness is 12.3 µm. The thickness of Copper layer and co-deposit of Cr-$Al_2O_{3,}$ is 6.81 µm, and 4.14 µm respectively, these layers at figure 3.D. these result may be regarded to the thickness of Cr-NanoZrO_2 was two and three times the thickness of Cr-NanoTiO_2 and Cr-Al_2O_3 respectively.

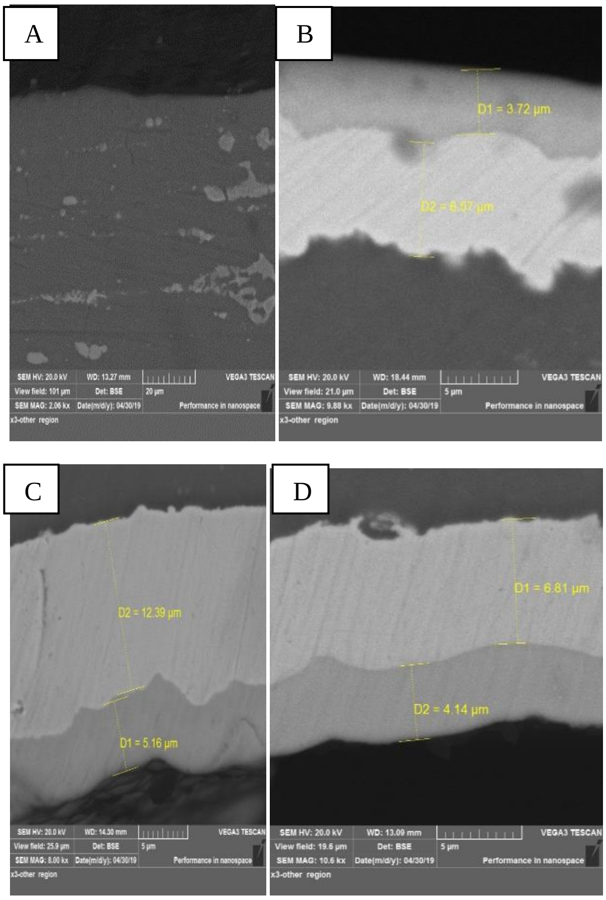

Figure 3. (A, B, C, and D): The SEM images showed the thickness of deposit layers.

Micro hardness

As appeared from the image in fig.3B, there are two layers, the upper one represent the Ti deposit and the lower showed chromium deposit. The thickness of TiO2 was 3.72 µm and 6.57 µm the thickness of chromium (sample S2). Fig.3A, B,C, and D represent sampleS0, aluminum substrate without plating, Sample S2,codeposit of Cr-NamoTiO$_2$, Sample S3, codeposite of Cr-NanoZrO$_2$, and sample S4, codeposite of Cr-NanoAl$_2$O$_3$, respectively. Fig. 3C showed the layers of codeposit at sample S3. This consists of the ZrO$_2$ at the upper with thickness 12.39 µm and Cr deposit at lower has 5.16 µm. The upper layer of sample S4 at fig.3D was Al$_2$O$_3$, the thickness of alumina deposit was 6.81 µm,

The hardness test was done using micro-hardness machine. Three tests for each sample, were done, the testing load and testing time was (30 gr., and 30 sec. respectively) as in table 2.

As shown in figure 4 the hardness of samples increased after hard chromium electroplating. The hardness of sample S0 was 35.5 MPa, but in hard chromium deposit at the sample S1 the hardness increased to 879Mpa. The effect of Nano ceramic particles increased the hardness of co-deposit, to the maximum hardness about 1237 MPa at the Cr-TiO$_2$ composite layer at the sample S2. The hardness of Cr-ZrO$_2$, and Cr-Al$_2$O$_3$ were 1409 and 1186MPa respectively. The hardness of co-deposit in Cr-ZrO$_2$ increased about 60% compared with only hard chromium deposit. The reason for that is the high hardness of NanoZirconia particles.

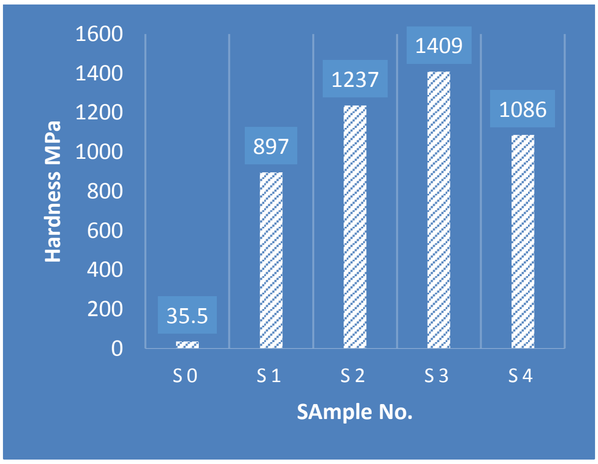

Figure 4. Effect of Nanoceramic particles on micro hardness of hard chromium deposit

Wear rate

The effect of Nanoceramic particles on the wear rate of the hard chromium electroplating codeposit. Clearly reveals from fig.5 the effect of Nanoceramic addition to the hard chromium path. The wear rate of sample S1 started with high value (1.62*10^{-8}cm3*cm^{-1}) at 5 min., and decreased with the time increasing to (0.35*10^{-8}cm3*cm^{-1}) at 20min. That was a result of the rising of temperature which help in decrease the friction between the sample surface and the rotating disc of the wear machine as in figure 5.

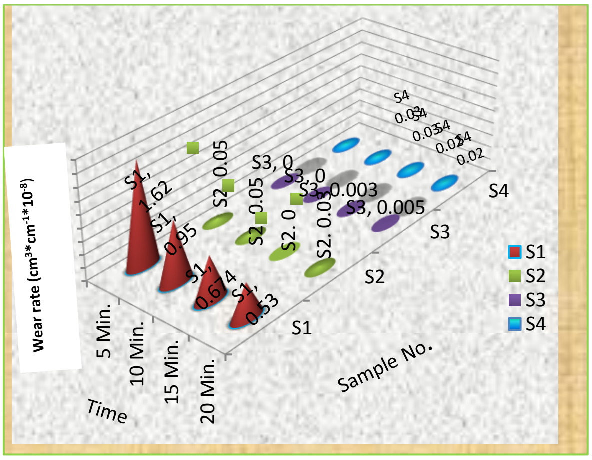

Figure 5. Wear rate of hard chromium-Nanoceramic particles as a function of time.

The same mechanism happens with the other samples. The lowest wear rate was with the sample (S3) which was electroplated with hard chromium-ZrO_2, between (zero and ($0.005*10^{-8}$ cm^3*cm^{-1}) at (5and 20 min.) respectively. These results were because the highest wear resistance of NanoZrO_2.

CONCLUSIONS

The effect of the codeposite of Cr-Nanoα-Al_2O_3, Cr-NanoTiO_2 and Cr-NanoZrO_2 on the hardness and wear dry sliding wear rate of 1050 Al-alloy electroplated by hard chromium deposit was achieved. The following conclusions have been drawn:

- The highest thickness was at the sample (S3) electroplated by hard chromium with NanoZrO_2.
- The highest value of hardness was at the surface of sample co-deposit of CR-NanoZrO_2.
- The best wear rate was at the Cr-ZrO_2 codeposit on the surface of Sample (S3).
- The wear rate decreased with wear time increasing of most of samples.
- The hardness value increased about 60% at co-deposit of Cr-NanoZrO_2

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