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INVESTIGATION OF THE ABRASION RESISTANCE OF ALUMINUM COPPER MAGNESIUM ALLOY

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ABSTRACT
Aluminum copper magnesium (Al-Cu-Mg) alloys have been widely used in aerospace industries and defense products because of their unique properties that satisfy the requirements of that industries. Tribological properties play significant role in understanding the lifetime of the materials and prediction of materials failure. In this study, unique Al-Cu-Mg alloys was prepared by heat treatment process. Earth elements yttrium (Y) and erbium (Er) as well as zirconium (Zr) were added into the alloys for enhancing their mechanical properties. It was found that the effect of Zr on the wear of Al-Cu-Mg-Y alloys was insignificant. While, the effect of Zr was clearly observed in alloys that contain Er, where the value of scratch width drastically decreased in presence of 0.3 wt. % Zr at relatively higher loads. Based on the experimental observations, it can be concluded that the presence of Er in alloy C.4 and Y in C.2 are responsible for the enhanced wear resistance.

KEYWORDS
Aluminum based alloy, scratch width, zirconium, yttrium, erbium.

INTRODUCTION
Al-Cu-Mg alloys are known for uses in aerospace and defense applications because they possess high mechanical strength, outstanding thermal stability, [1] superior fatigue resistance and acceptable creep resistance, [2]. However, with expansions of aerospace needs, it is necessary for enhancing the mechanical properties of AL-based alloys in order to satisfy the demands of the applications. Rare earth element reveal promising direction at enhancing the mechanical properties of Al-based alloys provide extended alloying capabilities, [3]. Al-Cu-Y and Al-Cu-Er are quasi-binary alloys establish a significant base in order to create novel cast alloys besides high thermal stability the intermetallic phases, low solidification range and perfect mechanical properties because of the heat treatment, [4]. Increasing element yttrium (Y) element could develop the strength properties at 300 °C. Moreover, the tensile strength of 0.32Y alloy at 300 °C reaches 232 MPa, with increasing about 8% higher

than that of Y-free alloy, [5]. Researchers have interests in element Erbium as an alternative element because of low price. Moreover, it ply significant role in refiner in Al-based alloys. Furthermore, the Al3Er phase, which possesses the same L12 structure as the Al_3Sc phase precipitated in aluminum alloy, can also be considered a main strengthening phase, [6].

The adding of zirconium on Al-Cu-Mg alloys could enhance the microstructure of the proposed alloy, inserting 2 wt. % Zr to base Al-Cu-Mg powder could decrease and restrict the cracks formation during formation the alloy by selective laser melted (SLM) method. Moreover, the presence of Zr could support Al_3 Zr precipitates and grain refinement that eliminate the propagation of cracks. Addition of zirconium could raise the yield strength from 253 ± 9.8 MPa to 446 ± 4.3 MPa, and ultimate strengths rise from 389 ± 20 MPa to 451 ± 3.6 MPa, [7].

Term tribology focuses on friction, wear, and lubrication of sliding surfaces in relative conduct, was explained in 1967 by a commission. Tribology plays significant role in the daily life, from the wear of simple case such as one's teeth to the design of complex, high-speed bearings for the space shuttle, [8]. Thus the study of the tribological properties for the proposed materials exhibits vital demand.

L.U. Gezici et al., [9], created new Al-based alloy by reinforcing B_4C and Sic hybrid into Al-Cu-Mg-Si alloy. The composite produced is fabricated by a microwave sintering technique at a sintering temperature of 550 °C for 60 min. It is demonstrated that agglomeration increasing with SiC reinforcement rate, delamination wears increased in 12 wt. % SiC reinforced hybrid composite. Hence, the lowest value of wear rate was measured as 0.3374 × 10−3 mm^3 $(Nm)^{-1}$ in the 3 wt. % B_4C + 9 wt. % SiC reinforced sample. Whereas, R. Chebolu et al., [10], evaluated the tribological properties of Al-based alloy hybrid metal composite beside the investigation of TiB_2 weight percent and its effect on the Al-based alloy.

Composites were produced by ultrasonic assisted stir casting with 5 wt. % silicon carbide (SiC) and varying X wt. % (0, 5, 10) of TiB_2. R. Yamanoglu et al., [11], studied the influence of heat treatment on the Al-Cu-Mg alloy tribological properties that reinforced with 4 wt.% SiC particles with 650 nm average particle size. It is demonstrated that produced material revealed enhancing on ageing response in comparing to the unreinforced material in the same heat treatment conditions.

The Al-based alloys have the enormous studies on the effect of various properties, however the studying of tribological properties for different percentage wt. % of Zr on the Al-Cu-Mg alloy had not enough attention. Thus in the present wok, tribological properties of Al-Cu-Mg alloy with Y and Er elements besides the different effect of Zr wt. % were investigated.

EXPERIMENTAL

Resistance furnaces Nabertherm S3 laboratory furnace (Nabertherm, Lilienthal, Germany) is used for melting the different elements of alloys. Four alloys with different chemical composition as shown in table 1 were investigated and prepared with the previous furnace. The different alloys were melted in the furnace with degrees varies from 750 to 830 ºC. Aluminum with purity 99.99% was casted with other aluminum alloys such as (Al–51.7Cu,

Al – 10 Er, and Al - 5 Zr) and (Al - 51.7 Cu, Al - 3.5 Zr, Al – 10 Er, and Al – 10 Mn) as master alloys. The casting was carried out into a water-cooled copper mold with an internal cavity 40 mm wide, 20 mm thick, and 120 mm high. The cooling rate was approximately 15 K/s. The Nabertherm and SNOL furnaces with a fan were used for heat treatment with accuracy of 1K maintaining the temperature. Then the produced ingots rolled at 440°C to 10 mm and 1 mm thickness at room temperature.

Fig. 2 shows the specimen after applied experiments.

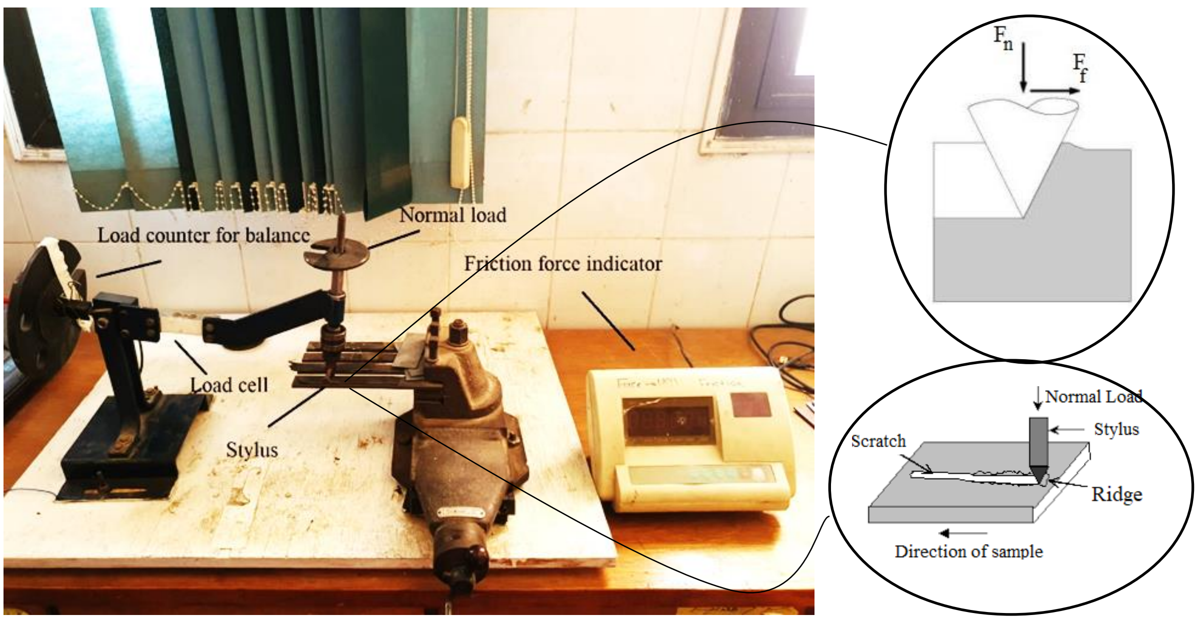
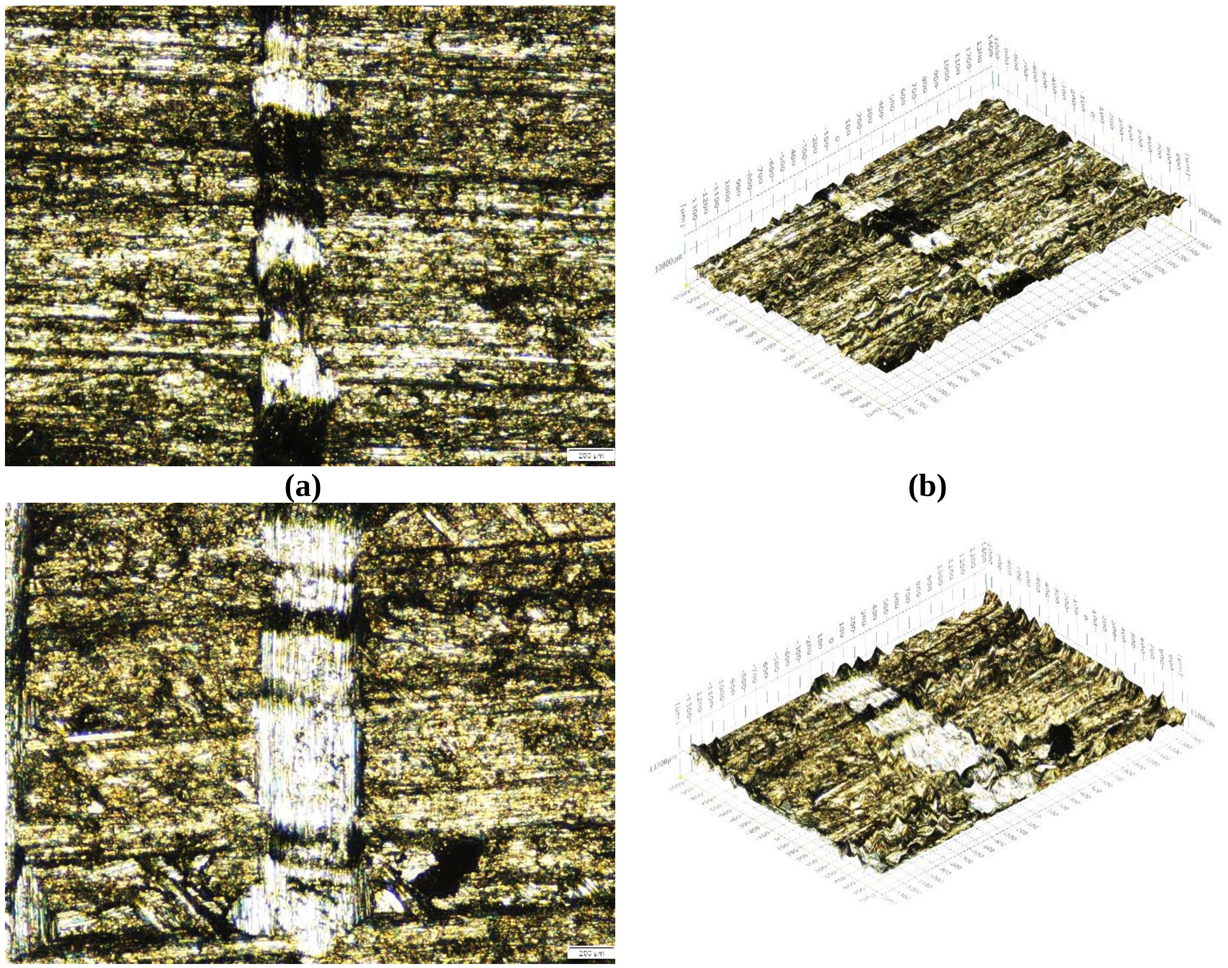


Fig. 3 shows the scratch device.

For setting the device of scratch the counter weights were used in the one side of the device for balancing the device parts and neutral weight of the device and ready for applying normal force for precision effect measurement as shown in figure 3. The specimen were exposed to 5 normal loads 2, 4, 6, 8 and 10N on the lever of the device in order to accomplish tribological scratch tests. The device is attached to load cell for obtaining the friction force hence it enabling calculating the coefficient of friction and monitoring the behavior of friction force through the movement of the scratch tip on the surface of the specimen. The scare widths were investigated with optical microscope as shown figure 4.



(a) (b)

(C) (D)

Fig. 4 The microscopic views for different scratch shape; a) View of scratch specimen C1 with 4N normal force, b) 3D view for scratch specimen C1 with 4N normal force, c) View of scratch specimen C1 with 6N normal force, d) 3D view for scratch specimen C1 with 6N normal force.

Table 1 shows the chemical composition of different Al-Cu-Mg alloys in wt. %.

	Cu	Y	Er	Mg	Mn	Zr	(Ti-Si-Fe)	Ti	(Fe-Si)
C.1	5.4	-	3	1.1	0.9	0.3	0.15	-	-
C.2	5.6	2	-	1	0.8	0.3	0.15	-	-
C.3	4.5	1.6	-	0.9	0.6	0.2	-	0.1	0.15
C.4	4	-	2.7	0.8	0.8	0.2	-	0.1	0.15

RESULTS AND DISCUSSION

As shown in Fig. 5, the relationship between the normal force and scar width is proportional. For sample C.1 the scar width increases with increasing of normal force, where the scar width is about 260 µm when 2N normal force is applied. The increase of scar width is monitored up to 365 µm at 10 N normal force. The relatively lowest values of wear scar width are observed for C.4 with about 110 µm at 2 N normal force and ended with about 300 µm

at 10 N. The proportional behavior could be logically explained as the normal force increases, the scratch tip has more load that is obtained the ability to deeply penetrate the surface of specimen. As a result, the scratch width increased with increasing load. However, it is noticed that the alloys C.2 and C.3 that contains yttrium (Y) shows the same trend and the differences between results through the normal force are very low even the values of resulted scratch width are almost identical when the specimen are loaded with 4, 6, and 8N. In contrary to the case of the alloys that contain Er, the effect of Zr is significant. Based on the experimental observation, it is found that C.4 specimen that contained Er had the highest wear resistance compared to the other three tested specimens followed by C.2 that contained Y, C.3 and C.1. It seems that the presence of Er in alloy C.4 and Y in C.2 are responsible for the enhanced wear resistance.

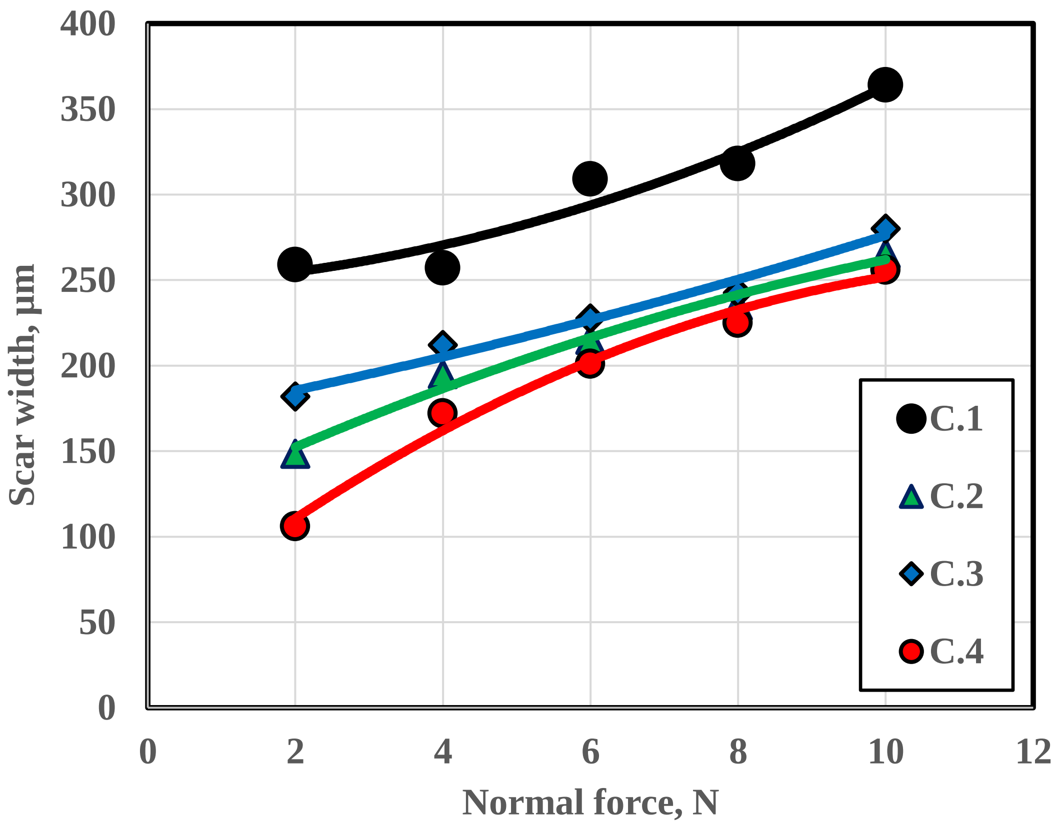


Fig. 5 The effect of normal force on the scar width of scratch.

As observed in Figs. 6, 7, 8 and 9, it is noticed that the friction force behavior has uniform distribution and sometimes it seems to nearly a line in low load such as 2 and 4 N in all specimens, whereas with increasing of normal load, the behavior of friction forces showed high distraction. With relatively higher loads, the ability of penetration is high, thus the opportunities of front and lateral ridges formations are high because of the sticking and slipping of the stylus on the surface of specimen. However, at low loads, that phenomenon could not be detected. Moreover, it explains the uniform distribution of friction force through long time whereas the friction forces through high normal loads showed short effective scratching time.

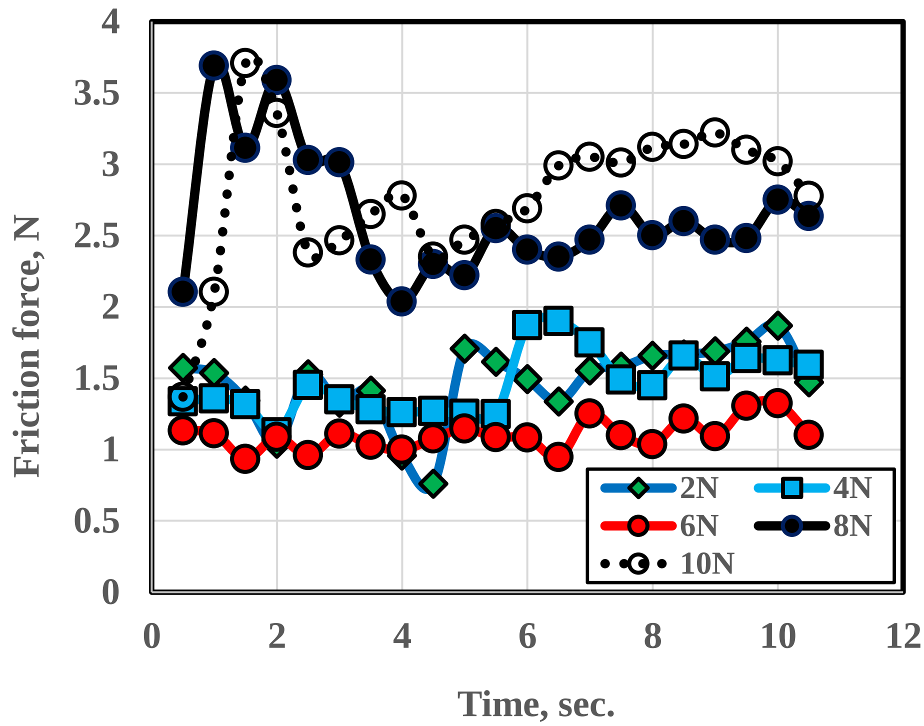


Fig. 6 Friction force versus time of C.1.

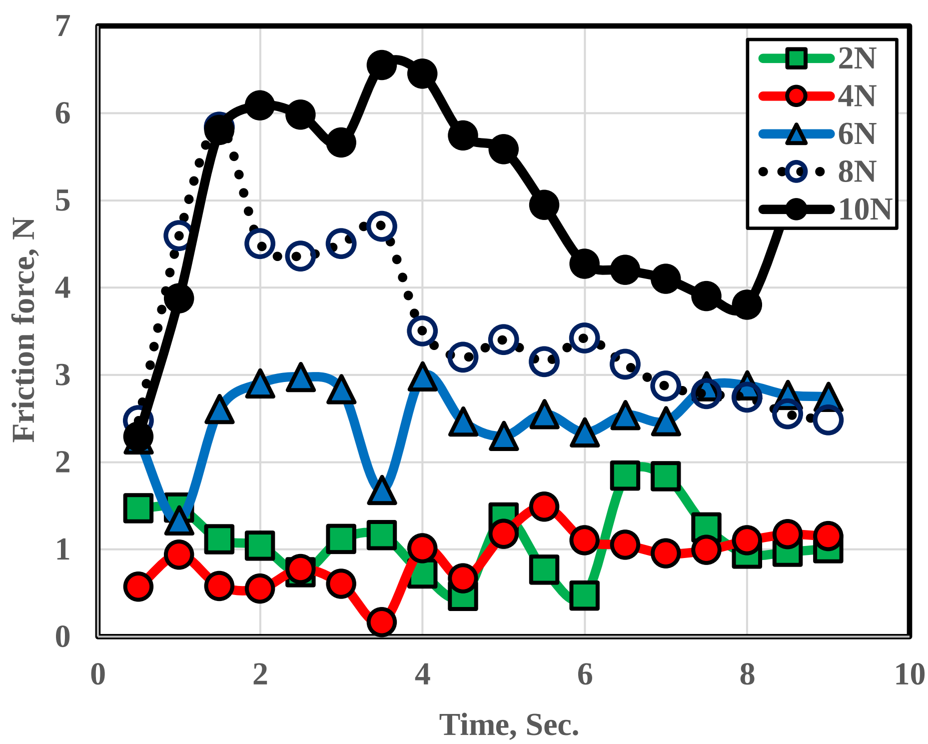


Fig. 7 Friction force versus time of C.2.

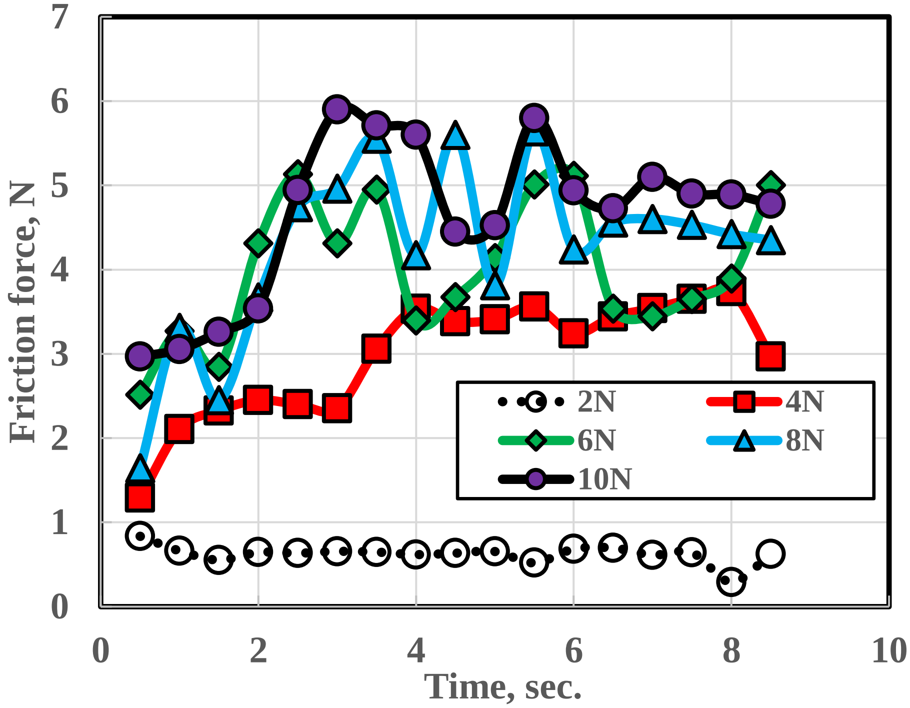


Fig. 8 Friction force versus time of C.3.

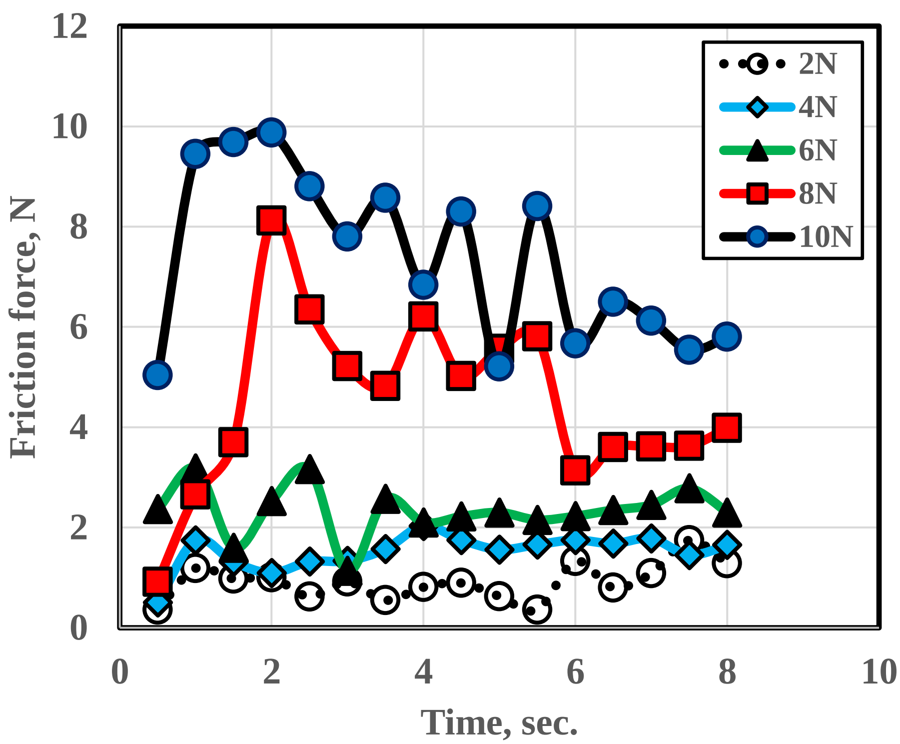


Fig. 9 Friction force versus time of C.4.

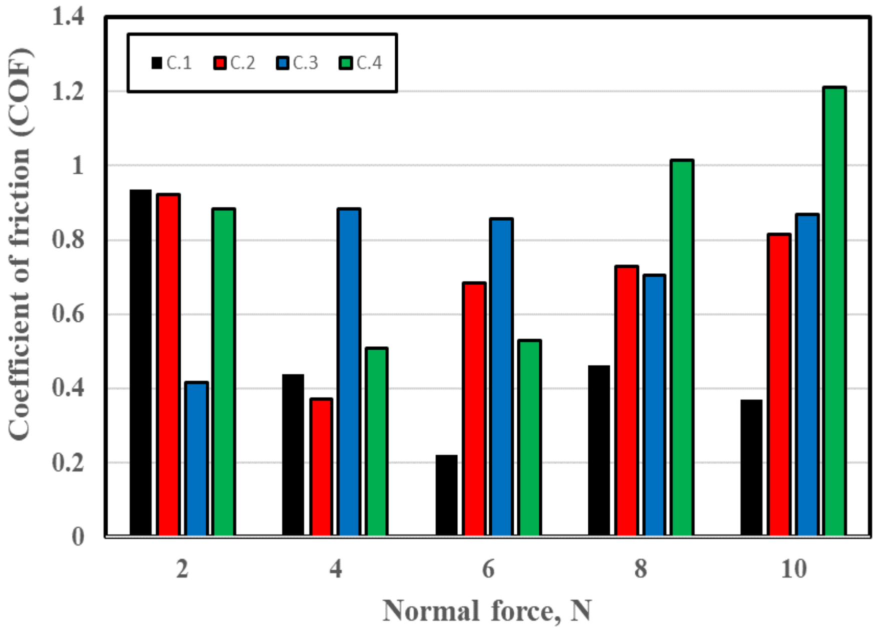


Fig. 10 Relationship between the normal force and coefficient of friction.

From Fig. 10, it is concluded that COF is almost the same with value reached 0.9 in case of samples C.1, C.2 and C.4. COF showed high values of 1 and 1.2 with sample C.4 at 8 and 10 N. At relatively higher loads, the ability of penetration increased, while specimens fabricated from Al-based alloys have high ductility, thus the stylus could stuck deeply in the material. As result of that, the stylus needs higher force in order to overcome the sticking restriction then high friction force produced leading to the increase of COF.

CONCLUSIONS

Tribological properties of Al-5.4Cu-3Er-1.1Mg-0.9Mn-0.3Zr-0.15 (Ti-Si-Fe), Al-5.6Cu-2Y-1Mg-0.8Mn-0.3Zr-0.15 (Ti-Si-Fe), Al-4.5Cu-1.6Y-0.9Mg-0.6Mn-0.2Zr-0.1Ti-0.15 (Fe-Si) and Al-4Cu-2.7Er-0.8Mg-0.8Mn-0.2Zr-0.1Ti-0.15 (Fe-Si) were investigated. Y and Er were added to enhance the mechanical properties. Effect of Zr content was studied. It is concluded that the effect of Zr on the wear of Al-Cu-Mg-Y alloys is insignificant. Besides, the major effect of Zr is clearly in alloys that contain erbium, where the value of scratch width at 2N normal load increases up to 140 %, while in presence of 0.3 wt. % Zr scar width increases up to 23 % at 10 N normal load. It seems that the presence of Er in alloy C.4 and Y in C.2 are responsible for the enhanced wear resistance.

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