INVESTIGATION OF THE EFFECT OF ADDING CU ON AL ALLOYS FOR WEAR AND FRICTION PROPERTIES

Murat Colak[1], Gürhan Deniz[2], Fehim Findik[3], Salih Hakan Yetgin[4]

[1]Bayburt University, Department of Materials Sci. and Nanotechnology Eng., Bayburt/TURKEY
[2]Sakarya University, Department of Technical Education, Sakarya/TURKEY
[3]Sakarya University, Department of Metallurgy and Materials Engineering, Sakarya/TURKEY
[4]Dumlupınar University, Department of Manufacturing Engineering, Kütahya/TURKEY

Abstract

In this study, Cu alloys in different ratios (2, 4, 6 and 8%) were added into the commercial purity (99.8% Al) aluminum alloys and Al-Cu alloys were prepared by sand mold casting method. In the current study, chemical composition is determined by spectrometer, density and hardness are measured, the wear and friction behavior are investigated, and finally microstructure of Al-Cu alloys is examined by optical microscopy. Wear tests were made under dry sliding, at pin-on-disk wear device and against X40CrMoV5-1 steel disc. In wear tests, 20, 40 and 60N loads, 0.5-1.5 m/s sliding speed were used, respectively. As a result, coefficient of friction of pure Al and Cu filled Al alloys increased by load and sliding speed. Wear ratio decreased with load while increased by the sliding speed. Wear rates of Cu filled Al alloy were determined about 10^{-13} m^2/N.

***Keywords:** Aluminum, Al-Cu alloy, Wear, Friction*

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1. INTRODUCTION

Heat treatability of alloy increases with copper. The melting point and eutectic temperature of the alloy is significantly decreased by addition of copper. For this reason, the solidification range of the alloy rises when copper adding [1-4], and simplify the situation of porosity formation [5]. Aluminum–Copper (Al-Cu) cast alloys have high strength and hardness properties in the as-cast state, and low corrosion resistance, low fluidity and ductility. Therefore, they have been widely used in different industrial applications.

Small amounts of Cu, Mg, Mn, Zn or Ni are added to Al-Si alloys for strengthening and furthermore the existence of Si provides helpful casting properties. On the other hand, ductility such as mechanical properties increases when adding of copper to Al-Mg-Si alloys. If Cu is added to Al-Si alloys, the creation of Al_2Cu phases and different intermetallic component are obtained, that affect the strength and ductility [5-9]. If Mg is added to Al-Si alloys, it raises the strength of matrix, reduces then ductility [6, 10]. Joenoes and Gruzleski [10] reported, when higher amount of Mg was added to Al-7%Si alloy, Mg_2Si phase was formed and the structure take place a fine lamellar and even possibly a fibrous structure [11]. Due to increased needs and quality expectations studies are continuing. The effect of different alloying elements on the micro structural, mechanical and wear properties of the Al alloy were reported [12-18]. Microstructure and wear behavior of Zn–27%Al–(2-4)%Cu alloys was reported by Mojaver and Shahverdi [12]. Ardakan [13] was investigated tribological properties of A390 (Al–17Si–4.5Cu–0.5Mg) hypereutectic Al–Si alloy and, 6 and 10 wt% Mg filled alloys. The tribological test results indicated that wear rate of Al–Si alloy improved when Mg content increased. The effect of Cu content on the microstructure and hardness of near-eutectic Al-Si-(*2-5%)*Cu were examined [14]. Results of this study represent that as Cu content increase in the alloy, the hardness also increases. Al–40Zn–3Cu and Al–40Zn–3Cu–(0.5–3)Ni alloys were fabricated by permanent casting [15]. After determination of microstructural and mechanical properties, their wear and friction behavior were analyzes with block-on-disc device. Al–4.5Cu alloy and Al–4.5Cu-TiB2 alloy have been compared and wear surfaces and the debris were examined by Herbert [16].

The purpose of this study is investigation of microstructural, mechanical and tribological behavior of Al and Al-Cu alloys, and determination of their most suitable chemical composition for friction coefficient and wear ratio.

2. MATERIALS AND TEST CONDITIONS

2.1 Preparations of Alloys

99.8% commercially pure Al alloy in the form of primary ingots and alloys containing 2%, 4%, 6% and 8% Cu were used in the experiments to investigate the effect of Cu addition to aluminum alloys. Melting operations were performed in the electrical resistance furnace within a carbide-based pot with the capacity of melting 8 kg of aluminum. The chemical composition of pure Al is given in Table 1.

Table 1. Chemical composition of pure Al alloy (%Weight)

Al	**Fe**	**Si**	**Cu**	**Zn**	**Ti**	**Mn**
99,78	0,07	0,11	0,02	0,02	0,01	0,01

2.2 Model Design

The measures of the prepared model and the solid model image are given in Figure 1. Castings were performed into sand molds prepared in accordance with the model design shown in the figure, and tests were carried out on the specimens obtained. Double-sided plates prepared as a model, type rating in the polls, in the preparation of sand molds with CO_2 gas hardening resin sand (2.5% resin + dry silica sand) were used. After the molding process, mold degree and models were prepared with the taper, the model could be separated easily. After the centering cores were ready for casting which placed on the prepared molds and degrees to each other. Figure 1 shows design of model and sizes. Liquid metal, with the purpose of purification of hydrogen gas dissolved immersed graphite crucible of about 750 °C, was followed by washing with liquid nitrogen held constant with the aid of the lance. Thereafter, a liquid flux over metal powder was cleaned and casting was operated. For control of compliance with the quality of the liquid metal before casting, solidification made vacuum RPT (reduced pressure test) was collected. RPT samples were analyzed cross-sectional images of the surface, the liquid metal was determined to be suitable for the casting after the cleaning process.

Fig -1: The measurements of model used in casting experiments and 3D model image

2.3 Characterization Studies and Wear Test

Brinell hardness measurements were performed at room temperature using Struers Duramin-500 hardness meter at room temperature with a 2.5mm diameter ball and under 62.5kg load. Density measurements were done by an Archimedes kit connected to Dikomsan HT-SH 1500 model electronic scales with 0.02 g precision, in accordance with ASTM B595-11 standard. The microscopic examination of the surfaces prepared as metallographic was carried out using Clemex Vision Lite image analysis program based on images taken with a Nikon Eclipse L150 light microscopy and a connected Clemex digital camera. Wear tests were performed against X40CrMoV5-1 steel disc under dry conditions at room temperature with used pin-on-disc abrasion device. 6mm in diameter and 50mm length specimens were used for wear tests. Figure 2 represents the pin-disc abrasion device. Wear testing was done three times and the average was taken. Wear ratio (K_o) was calculated by using weight loss as down,

$$K_o = \Delta m / L \,.\, F \,.\, \rho \qquad (m^2/N) \qquad (1)$$

Where Δm: average weight loss (g), L: distance (m), F: the load (N) and ρ: density (g cm^{-3}).

Fig -2: Wear test machine

3. RESULT AND DISCUSSION

3.1 Chemical Analysis Results

Chemical analysis results of Al and its alloys are given in Table 2. When the results are examined, it is seen that the chemical composition range of prepared alloys to use in experiments is appropriate to the targeted values.

Table 2. The chemical analysis results of Al and its alloys (Wt %)

Alloy	Si	Fe	Cu	Mn	Mg	Al
Al	0,12	0,14	0,04	0,021	0,009	Rest
Al-2%Cu	0,12	0,22	2,03	0,022	0,011	Rest
Al-4%Cu	0,13	0,14	4,12	0,024	0,013	Rest
Al-6%Cu	0,11	0,16	6,15	0,018	0,014	Rest
Al-8%Cu	0,15	0,20	7,98	0,021	0,016	Rest

3.2 Microstructural Investigations

The microstructural images of Al and its alloys are presented in Fig. 3. Depending on chemical composition, the internal structures of cast samples of different alloys show different type of solidification. Microstructural images show that the structure contains varying amount of AlCu compounds depending on α master matrix and Cu content. By increasing the amount of Cu in the composition, more AlCu compounds are observed. The copper atoms in alloy are shared by α aluminum solid solution of aluminum and Al_2Cu intermetallic phase. Although the microstructure of Cu filled Al alloys varies with copper ratio, it is usually two-phase. The first phase is α aluminum solid solution phase, and the second one is Al2Cu intermetallic phase. The amount of intermetallic phase increases with increasing the copper ratio in the alloy. Since the Al-Cu binary system at a concentration of 33.2% Cu shows eutectic, the Al_2Cu phase solidify as lamellar eutectic structure between α aluminum dendrites. The eutectic structure consists of sequentially aligned Al_2Cu and α aluminum lamellas. The appeared phases and compositions during the solidification of Al-Cu alloy are given in Figure 3.

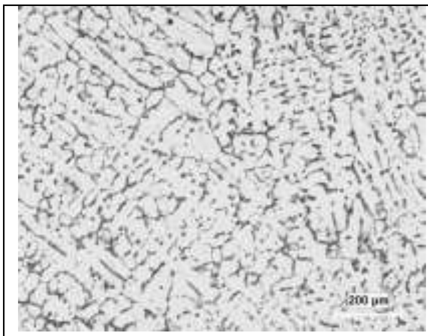
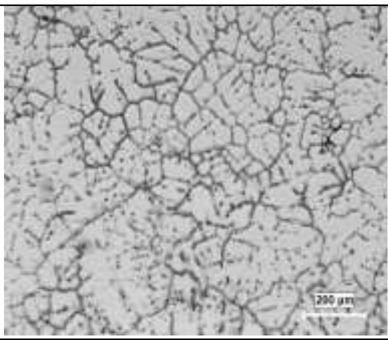
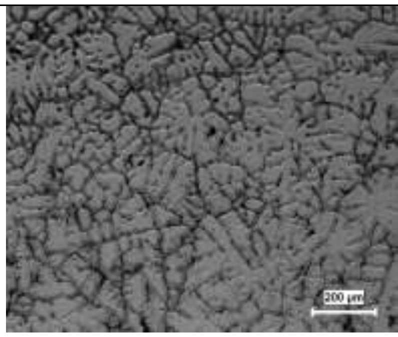
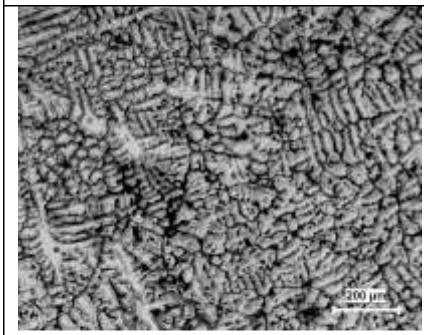
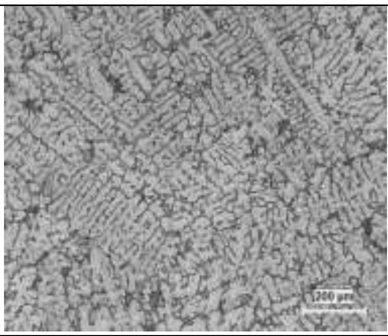
		
Al	2%Cu filled Al	4%Cu filled Al
		
6%Cu filled Al	8%Cu filled Al	

Fig -3: Microstructure images of Al and its alloys

3.3 Hardness and Density Results

The hardness and density values of Al and its alloys are given in Figure 4. As shown from Figure 4, hardness values of Al alloy increased when copper added. While the hardness of the aluminum alloy of commercial purity was 34 HB, by the addition of 2% Cu, this value was obtained as 46 HB with 35% increase. Depending on the amount of Cu the hardness value was increased. When compared with Al alloy, the hardness values of Al and its alloys were increased 61%, 117% and 179%, respectively. The increasing of hardness with Cu addition can be arise due to the hard AlCu compounds occurred in the structure, as seen in the microstructure images. A quick look to Fig. 4 shows that the intensity value rises with Cu addition. While the density value of commercial purity Al is 2.71 g/cm^3, it was obtained at 2.83g/cm3 with the addition of 8% Cu, because the Cu element has higher density than Al.

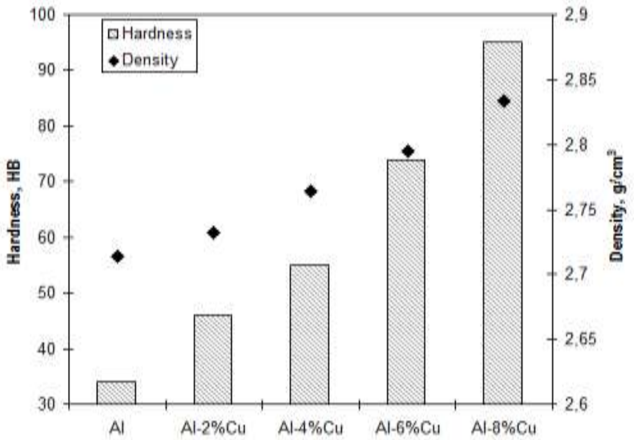


Fig -4: Hardness and density result of Al and its alloy

3.4 Wear Results

Table 3 presents coefficients of friction and wear rate values for Al and its alloys against X40CrMoV5-1 steel disc, at room temperature, dry sliding, 0.5-1.5m/s sliding speed and at 20-60N loads. Figure 5 and 6 shows the change of friction coefficient of Al and its alloys depending on the load at 0.5m/s and 1.5m/s sliding speeds, respectively. It is apparent from the figure that coefficients of friction of Al alloys increase linearly when the load increased from 20N to 60N. Similar results obtained by Herbert [16] and Prabhudev [18]. The coefficient of friction has increased average 18% when the load increased. Coefficient of friction for Al and its alloys are 6.97%, 17.1%, 37.4% and 84.5% lower values than that of the Al alloy.

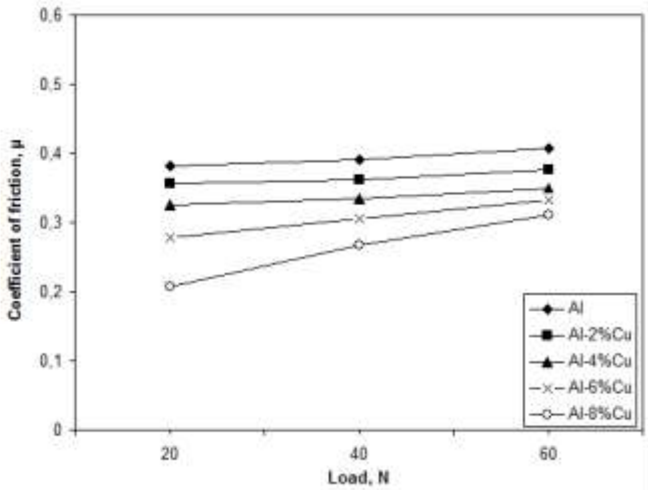


Fig -5: Change in friction coefficient by load for Al and Al alloys against steel (Sliding speed: 0.5m/s).

Table 3. Tribological properties for Al and its alloys against X40CrMoV5-1 steel disc at different sliding speed and load.

Materials	Load, (N)	Sliding speed (m/s)					
		0.5	1.0	1.5	0.5	1.0	1.5
		Coefficient of friction, (μ)			Specific wear rate, (m^2/N)		
Al	20N	0,382	0,450	0,482	8,02E-13	1,16E-12	5,08E-12
	40N	0,391	0,474	0,504	4,74E-13	8,26E-13	2,70E-12
	60N	0,408	0,517	0,547	3,47E-13	7,86E-13	1,94E-12
Al-2%Cu	20N	0,357	0,384	0,428	5,27E-13	8,82E-13	1,13E-12
	40N	0,361	0,408	0,477	3,90E-13	6,25E-13	7,90E-13
	60N	0,376	0,451	0,495	3,26E-13	5,89E-13	7,10E-13
Al-4%Cu	20N	0,326	0,353	0,391	4,14E-13	7,72E-13	1,01E-12
	40N	0,334	0,37	0,427	3,46E-13	5,39E-13	6,61E-13
	60N	0,349	0,397	0,443	2,92E-13	4,96E-13	6,03E-13
Al-6%Cu	20N	0,278	0,303	0,328	3,92E-13	5,58E-13	8,96E-13
	40N	0,305	0,343	0,392	3,20E-13	4,70E-13	6,08E-13
	60N	0,333	0,366	0,401	2,80E-13	4,33E-13	5,29E-13
Al-8%Cu	20N	0,207	0,216	0,237	3,18E-13	4,52E-13	6,71E-13
	40N	0,267	0,305	0,331	2,60E-13	3,77E-13	5,47E-13
	60N	0,311	0,35	0,377	2,35E-13	3,29E-13	4,54E-13

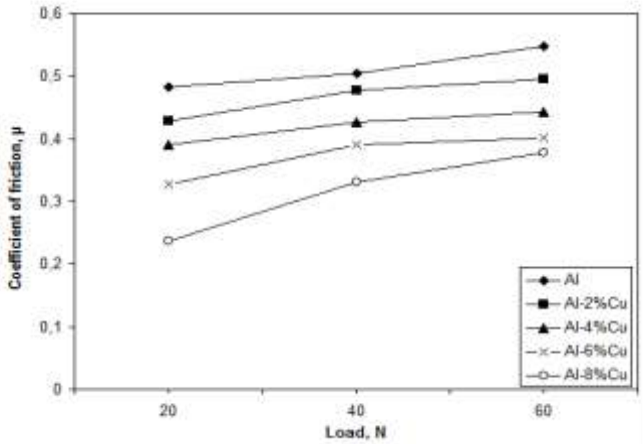


Fig -6: Change in friction coefficient by load for Al and Al alloys against steel (Sliding speed; 1.5m/s).

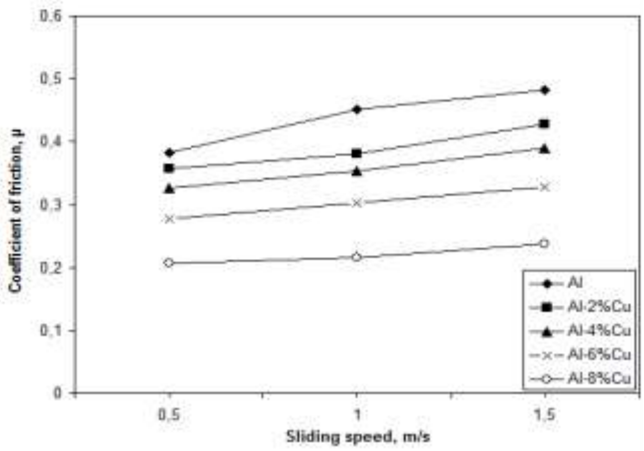


Fig -7: Change of friction coefficient by speed for Al and Al alloys against steel disc (Applied Load; 20N).

The change in the coefficient of friction for Al and its alloys are given in Figures 7 and 8 depending on the sliding speed under 20N and 60N load. The coefficient of friction for all samples increase linearly when the speed increase. In the case of Al, the average increased by 25% by the increase of speed. For Al alloys, the average friction coefficient increased by 20%, 19%, 18% and 14% when speed increase from 0.5m/s to 1.0m/s.

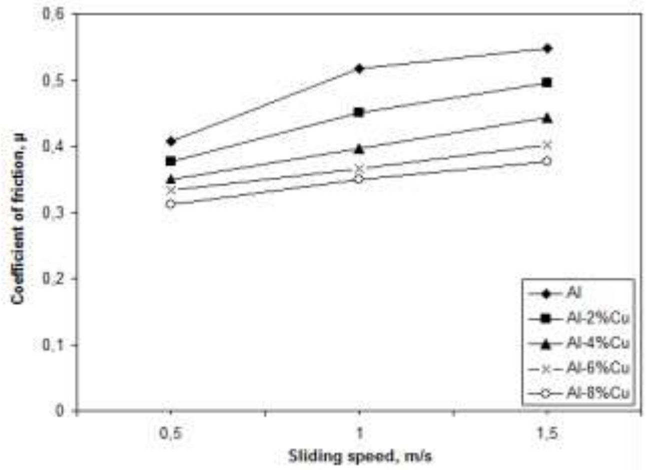


Fig -8: Change of friction coefficient by speed for Al and Al alloys against steel disc (Applied Load; 60N).

Figures 9 and 10 show the change of wear ratio for Al and its alloys depending on load. It is apparent from the figure, when load increased from 20N to 60N, the wear ratio decreased for Al and its alloys. In general, the wear ratio of Al is about 10^{-12} while its alloys are in the order 10^{-13} m^2/N. The lowest wear ratio is for Al-8%Cu alloys with a value of $2.35x10^{-13}$ m^2/N followed by Al-6%Cu with $2.80x10^{-13}$

m^2/N, Al-4%Cu with $2.92x10^{-13}$ m^2/N and Al-2%Cu with $3.26x10^{-13}$ m^2/N, the highest value is $5.08x10^{-12}$ m^2/N for Al. It means located Cu in the Al alloys was reduces by 85% the wear rate of Al material. Similar results are also obtained by Herbert [16].

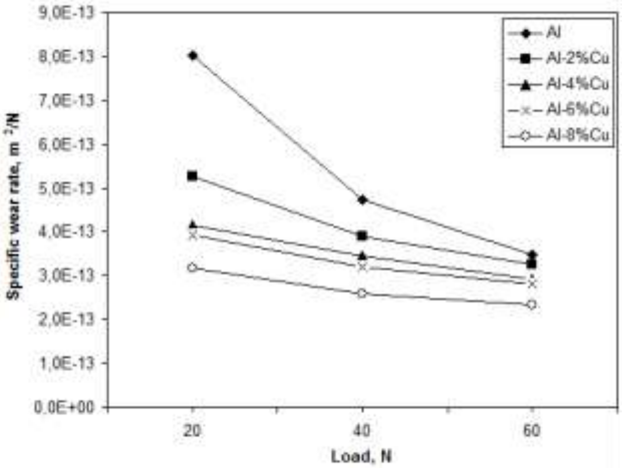


Fig -9: Change of wear ratio by load of Al and Al alloys against steel disc (Speed; $0.5ms^{-1}$).

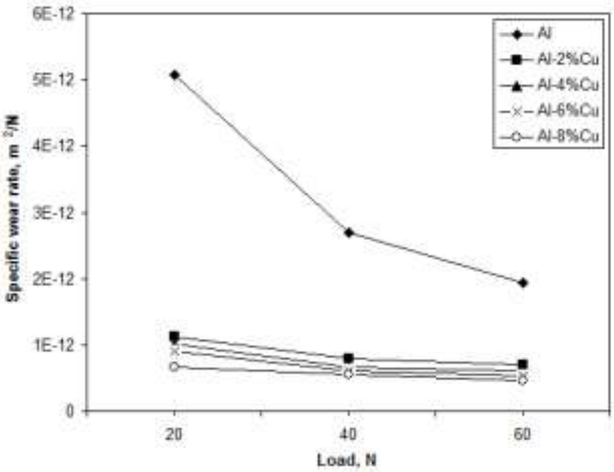


Fig -10: Change of wear ratio by load of Al and Al alloys versus steel disc (Speed; 1.5m/s).

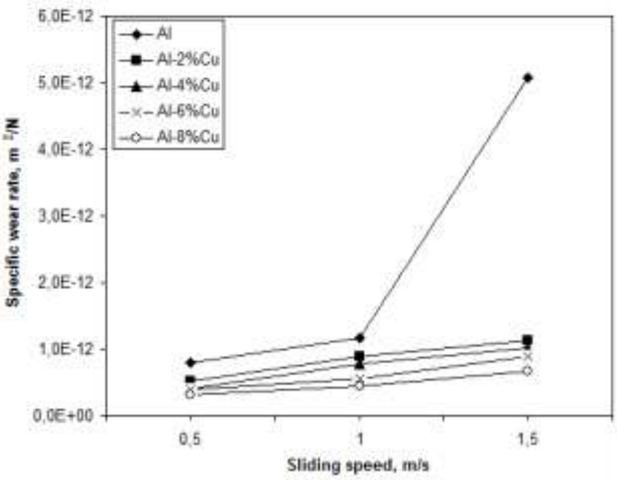


Fig -11: Change of specific wear ratio by sliding speed of Al and Al alloys against steel disc (Load; 20N).

Figure 11 and 12 present the change of wear ratio depending on speed under 20 and 60 N load, respectively. The wear ratio increased when the speed increased from 0.5m/s to 1.5m/s. The coefficient of friction was decreased and wear ratio was developed by addition of Cu to Al alloys. Pure Al showed the highest specific wear rate value. Wear rate was reduced because of higher hardness, strength, change of microstructural and reduced micro cracks by the addition of the Cu [18].

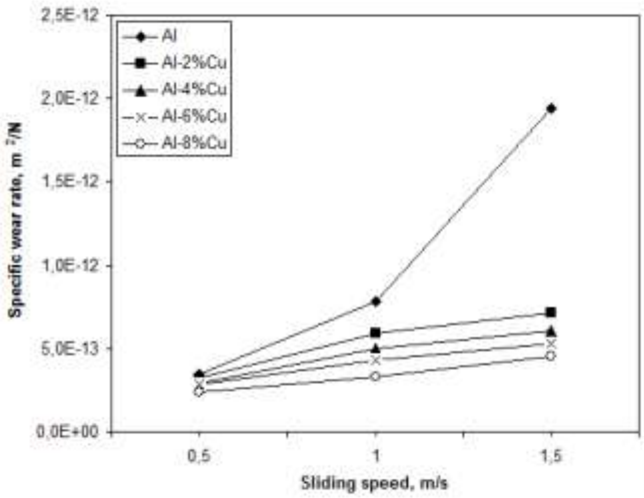


Fig -12: Change of specific wear ratio by sliding speed of Al and Al alloys against steel disc (Load; 60N).

4. CONCLUSION

In this study, the microstructural and mechanical features of Al alloys with addition of different amount of Cu were examined. The results obtained from experimental studies can be summarized as follows:

1- The internal structures of alloys contain varying amount of AlCu compounds depending on α master matrix and Cu content.
2- While the density value of commercial purity Al is 2.71 g/cm^3, it was obtained at 2.83 g/cm^3 with the addition of 8% Cu.
3- The hardness value of commercial purity Al alloy was obtained at 34 HB.
4- When compared with Al alloy, the hardness values of Al alloys were increased 61%, 117% and 179%, respectively.
5- The coefficient of friction of Al and Al alloys increase linearly with increase of load and sliding speed.
6- In general, the wear ratio for Al is about 10^{-12} while Al alloys are in the order 10^{-13} m^2/N.
7- The wear ratio values decreased with increase load while increase with sliding speed.
8- The addition of Cu into Al decreases the friction coefficient and wear ratio of Al alloys.

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BIOGRAPHIES

Assist. Prof. Murat ÇOLAK, He is an academic member of the Materials Sci. and Nanotechnology Engineering Department at Bayburt University in TURKEY. His major areas of interests are: Material science, Manufacturing process, Casting, Modeling, Casting simulation and image analysis.
E-mail : **mcolak@bayburt.edu.tr**

Lecturer Gürhan DENIZ, He is an academic member of the Tecnical Education Department at Sakarya University in TURKEY. His major areas of interests are: Welding properties of materials, Material science, Manufacturing process, Casting, Modeling, Casting simulation and image analysis.
E-mail : **gdeniz@sakarya.edu.tr**

Prof. Dr. Fehim FINDIK, He is an academic member of the Metallurgy and Materials Engineering Department at Sakarya University in TURKEY. He published 60 SCI journal and 50 conference papers. His major areas of interests are: Tribological properties of industrial materials, Biomedical materials, Production and characterization of powdered alloys.
E-mail : **findik@sakarya.edu.tr**

Assist. Prof. Salih Hakan YETGİN, He is an academic member of the Manufacturing Engineering Department at Dumlupınar University in TURKEY. His major areas of interests are: Material Science, Polymer materials, Wear behavior of polymer materials, Production and characterization of polymer foam materials.
E-mail : **hakan.yetgin@dpu.edu.tr**