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Tribological behavior of Al-Cu alloys and innovative Al-Cu metal matrix composite fabricated using stir-casting technique

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Abstract

Tribological behaviour of an Al–5-wt% Cu alloy, Al–10-wt% Cu alloy (hypoeutectic alloy), and an innovative composite combination of an Al–5-wt% Cu alloy as the matrix and a 5-wt% Cu powder as the reinforcement have been investigated. The metal matrix composite was prepared and fabricated by using a stir-casting process by dispersing the Cu powder (average particle size of 105 µm) in the molten base Al–5-wt% Cu alloy. The wear and frictional properties of the metal matrix composites was studied by performing dry sliding wear test using a pin-on-disc wear tester. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L9 Orthogonal array was selected for analysis of the data.The regression equation for each response were developed for both the alloys and composite using MiniTab-17. SEM and EDAX analysis of the wear samples were also studied for morphology changes.

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Keywords: aluminum; copper powder; innovative composite; stir casting; scanning electron microscopy;

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1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. In the last two decades, research has shifted from monolithic materials to composite materials to meet the global demand for light weight, high performance, environmental friendly, wear and corrosion resistant materials. Metal Matrix Composites (MMCs) are suitable for applications requiring combined strength, thermal conductivity, damping properties and low coefficient of thermal expansion with lower density. These properties of MMCs enhance their usage in automotive and tribological applications. In the field of automobile, MMCs are used for pistons, brake drum and cylinder block because of better corrosion resistance and wear resistance. The wear performance of the composites, reinforced with various reinforcements ranging from very soft materials like graphite, talc etc., to high hardened ceramic particles like SiCp, Al_2O_3 etc.[1-4] have been reported to be superior to their respective unreinforced alloys. Properties of AMMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route [Surappa(2003)[5]. Wear is the progressive loss of material due to relative motion between a surface and the contacting subsurface or substances. Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components, particularly due to abrasion. Baker et al.[6] investigated the wear behaviour of Al6061 alloy filled with short saffil and mention that saffil reinforcement is significant in improving wear resistance of the composites. The TiB2 particles significantly improved the wear performance of Al-Cu alloy. Chaudhary et al.[7]. Martin et al.[8] investigated tribological behaviour of Al6061 reinforced with Al_2O_3 particles and described that a characteristic physical mechanism exists during the wear process. When a significantly high load is applied on the contact surface, the matrix phase is plastically deformed, and the strain is partially transferred to the particulates, which are brittle with small failure strains.

Kumar and Balasubramanian [9] developed a mathematical model to evaluate wear rate of AA7075/SiCp through powder metallurgy route. The results showed that the volume fraction of reinforcement, applied load, sliding speed were directly proportional to wear rate, while particle size of reinforcement and hardness of counterpart material were inversely proportional to wear rate. Modi et al.[10] showed that the effect of applied load on the wear rate of both Zinc alloy and the 10wt% Al_2O_3 particle reinforcement composite using statistical analysis of the measured wear rate at different operating condition. The effect of applied load on the wear rate of composite was found to be more severe. Wear behaviour of various particle reinforced aluminium alloy matrix composite was investigated experimentally by many investigators[Basavarajappa and Chandramohan[11], Suresh and Sridara[12], Metin Kok[13]].

A Ravikiran and M.K.Surappa [14], studied the effect of sliding speed on the wear behaviour of Al-30 wt% SiC_p composites. They concluded that the wear rate of composite decreases with increasing speed, and increasing reinforcement content. V Constantin et al [15] investigated the sliding wear behaviour of SiC_p reinforced aluminium composites against a stainless steel slider. Liang YN et al [16] studied the effect of particle size on the wear behaviour of 2024 Al- SiC_p composites investigated sliding wear, impact abrasion, and erosion. Composites containing large particles have shown excellent wear resistance under steady applied load. T. Miyajima and Y. Iwai [17] reported that, sliding wear is strongly dependent on the type and volume of reinforcement. The suggestive applications include rotor (disc/ drum) material in automotive brake system. Tjong. SC et al [18] studied the wear behaviour of Al-Si-SiC_p prepared by compo casting process, using block-on-ring test under dry conditions. Results reveal that addition of low volume fractions of reinforcements (2-8%), improves the wear resistance of composite. KM Shorowordi et al [19] reported that high sliding velocity leads to low wear rate and low friction coefficient for Al-B_4C and Al-SiC MMCs. L.Cao et al [20] reported that Al-SiC_w composite exhibits a good wear resistance especially for high sliding velocities and / or high loads. Yoshiro Iwai et al [21] reported that SiC_w reinforcing Al2024 improve the wear resistance in both severe and mild conditions. Hutching IM [22] studied the tribological properties of metal matrix composites and stated that MMCs show high wear resistance and is dependent on the wear mechanism. Sannino and Rack [23] reported the effect of the shape of reinforcement on sliding velocity.

It is difficult to deduce the effects of reinforcement from the literature because; the conditions such as contact load and sliding velocity spread over very wide range and these studies employ different kinds of test apparatus. These effects of sliding velocity on the frictional and wear behaviour of aluminium MMC sliding against ferrous counter body have been studied by a number of researchers [24-26]. These studies revealed that the frictional and wear characteristics of aluminium MMC depend on the sliding speed in a complicated way. Depending upon the sliding velocity range, both increase and decrease in wear rate with sliding velocity were reported. G Wang and IM

Hutching [27] reported that wear resistance of the composites was found to range from almost two to six times that of the unreinforced matrix alloy. Rohatgi PK et al [28] reported that abrasive wear resistance of fly- ash reinforced A356 aluminium is comparable to that of alumina fibre-reinforced alloy and is superior to that of base alloy. Wang and Rack [29] compared the wear rates of composites having different types of reinforcement, 20% SiC_p and SiC_w (perpendicular or parallel). Results show that the steady state wear rates of the composites were generally independent of the reinforcement geometry (particulate or whisker) and orientation (perpendicular or parallel). Zongy Ma Jing et al [30] reported that discontinuous SiC reinforced aluminium alloy composites exhibit excellent abrasive resistance compared with the unreinforced matrix alloy. Kirit J, Bhansali and Robert Mehrabain [31] reported that the abrasive wear resistance of aluminium matrix composites containing Al_2O_3 were found to be superior to those containing SiC, using a dry sand / rubber wheel abrasion tester. Manish Narayan et al [32] have shown that the Al2014-15 vol% Al_2O_3 composite shows better seizure resistance than the unreinforced alloy in the peak aged condition, using dry sliding wear conditions. Also, in the as-extruded condition, wear resistance of the alloy is better than that of the composite. AT Alphas and J Zhang [33] studied the effect of the microstructural parameters, particulate volume fraction of and size on dry sliding wear of aluminium matrix composites.

Fabrication of MMCs has several challenges like porosity formation, poor wettability and improper distribution of reinforcement. Aluminium based copper particulate metal matrix composites fabricated using stir casting technique by varying the percentage of copper showed an increasing trend in hardness values with increase in percentage of copper. The tribological properties are considered to be one of the major factors controlling the performance.

The objective of the present work is to investigate the dry sliding wear behaviour of fabricated aluminium copper alloys and copper powder particles as reinforcement in aluminium copper alloy matrix. The wear rate and coefficient of friction was determined by considering the applied loads 10N, 20N and 30N with a different sliding velocities and sliding distances. Mathematical model for wear volume loss (WVL) and coefficient of friction (COF) is developed in terms of control parameters by a linear regression for the tested materials.

2. Experimental setup and procedure

2.1 Fabrication of alloys and composite

Aluminium with 99.17% purity was used as the base metal in the experiments for the fabrication of alloys and composite. In this study Al–5-wt% Cu alloy, an Al–10-wt% Cu alloy (hypoeutectic alloy), and an innovative composite combination of an Al–5-wt% Cu alloy as the matrix and a 5-wt% Cu powder (average particle size is 50 µm) as reinforcement are considered. The chemical composition for above compositions is tabulated in the Table 1.

Table 1 Chemical composition of alloys and composite

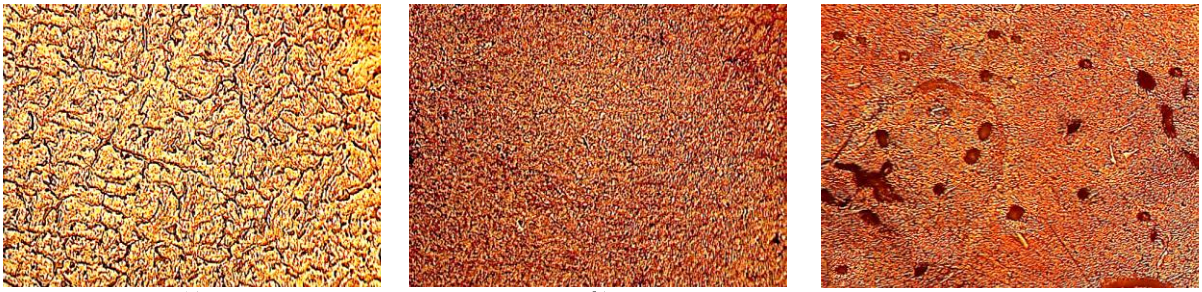
Element Concentration (wt%)	Material		
	Al-5-wt% of Cu alloy	Al-10-wt% of Cu alloy	Al-5-wt% of Cu alloy and 5- wt% Cu composite
Al	94.753	89.663	89.159
Cu	4.955	10.094	10.265
Mn	0.120	0.101	0.002
Mg	0.097	0.092	0.097
Fe	0.012	0.023	0.224
Si	0.021	0.011	0.129
Zn	0.008	-----	0.075
Pb	0.017	-----	0.031
Cr	0.003	0.003	0.002
Ti	0.004	0.003	0.006
V	0.010	0.010	0.010

The MMC was prepared and fabricated by using stir casting method by dispersing copper powder(average particle size is 105µm) in the base molten Al-5-wt% Cu alloy. The Al-5-wt% Cu alloy and Al-10-wt% Cu alloy castings are prepared by adding copper in the form of chunks to the molten aluminium. Copper powders are produced by fixing the copper rod in the lathe and filing manually, by rotating copper rod at high speeds. Next the powder is placed in a ball mill and it is operated for 2 hours. Then the powder is placed in the top sieve of the sieve shaker and it is operated for 5 to 10 minutes. For reinforcement the Cu powder particles of average size 50 µm was taken. For producing castings of Al-5- wt% Cu alloy and Al-10-wt% Cu alloy, initially the weighed quantity of pure Al is kept in to an Inconel alloy crucible (bottom poured) of electric resistance furnace as shown in Figure 1.The furnace temperature was increased around 750^0C and is maintained at this temperature for two hours. Then for alloying a 5- wt% Cu is added to the molten Al at 750^0C. The melting process is continued for another 30 minutes, for complete solubility of solute metal in the base molten aluminium. After complete solubility the crucible bottom will be opened by operating the control switch on the control panel for pouring the molten metal in to the die, which is situated exactly below the crucible opening. During the melting process the argon gas was circulated in the crucible chamber and the die chamber for reducing the oxidation and for getting defect free castings. The same procedure was followed for Al-10-wt% Cu alloy castings.

Figure 1 Electric resistance furnace used for manufacturing of alloys and composite

The innovative Composite metal castings of Al-5-wt% Cu alloy and 5-wt% Cu composite are prepared by stir casting technique using mechanical stirrer. For getting the Al-5-wt% Cu alloy and 5-wt% Cu composite castings, the melting process is same as for Al-5-wt. % Cu alloy. The temperature is reduced from 750^0C to around 675^0C, mean while the copper powder is separately preheated to around 200^0C for 30 minutes. The preheated copper powder is slowly added to the molten aluminium and Cu alloy through the pipe situated above the crucible and start stirring the molten metal with motor operated stirrer for few seconds at 200 rpm for mixing and equal distribution of reinforced Cu particles in the Al- Cu alloy and immediately poured the molten metal in to the die cavity. During the melting period the argon gas was circulated in the crucible and die chamber. Both alloys and the composites are cast into fingers of size150mm×18mm dia. After removing the castings from the die, they are homogenised for 24 hours at 100^0C and quenched in water. Further the castings are solutionized at 500^0C for 2 hours and followed by water quenching. Finally the alloys and composite casting samples are age hardened at 190^oC for several hours and cooled to room temperature,for finding the (T6) peak time and hardness for alloys and composite.

Figure 2 shows optical photomicrographs of the Al–5-wt% Cu alloy, Al–10-wt% Cu alloy (hypoeutectic alloys), and composite Al–5-wt% Cu and 5 wt% Cu powder at 150X magnification. The specimens are cut from the samples having a diameter of 15 mm and a thickness of 10 mm. All samples were molded with an acrylic cold setting compound, then ground with different grades of emery papers, polished with diamond paste and finally etched with Keller's reagent. The optical photomicrographs show the homogeneous distribution of the Al–Cu alloys and the distribution of Cu particles (as reinforcement) in the Al–Cu alloy matrix. The microstructure of the composite shows that the Cu powder is distributed throughout the matrix of the Al–5-wt% Cu alloy.



(a) (b) (c)

Figure 2 Images of the microstructures of the (a) Al–5-wt% Cu alloy, (b) Al–10-wt% Cu alloy, and (c) Al–Cu composite.

This shows that the Cu particles are not combined with the matrix; instead, they are precipitates in the outer fringes of the $CuAl_2$ dendrite structure. The metal matrix shows interdendritic pattern of the $CuAl_2$ phases in an Al solid solution. The grain boundaries are clear with $CuAl_2$ phases. The microstructure is homogenous without any segregation throughout the cross section. The matrix exhibited more undissolved $CuAl_2$ phases, leading to the dominant presence of the phase. It is clear that the prior solutionizing could not dissolve the eutectic, and it most likely remained owing to the solubility of the $CuAl_2$ phase in the primary Al phase. The dendritic pattern of the grains persists in the matrix. However, it is observed that more of the $CuAl_2$ phase appears in the Al matrix.

2.2 Wear Test

Standard wear specimens of 30mm length and 8mm ø were retrieved from thoroughly homogenized fingers of the Al–5-wt% Cu alloy, an Al–10-wt% Cu alloy (hypoeutectic alloy), and an innovative composite combination of an Al–5-wt% Cu alloy as the matrix and a 5-wt% Cu powder as the reinforcement through EDM process. The Copper die which is used for machining the samples, semi finished and finished samples are shown in the Figures 3, 4 and 5. All the samples of investigating alloys and composite material are age hardened (T6) at 190^0C for different time intervals depends on the peak hardness of the alloys and composite. ie Al–5-wt% Cu alloy for 24 hours, Al-10-wt.% Cu alloy for 28 hours, and Al-5-wt% Cu alloy as matrix and 5-wt.% of copper powder as reinforcement(composite)for 4 hours than followed by quenching in water. The initial weight of the samples were taken by using electron weighing machine of accuracy 0.0001gms. Volume of each sample must be calculated. Sliding Wear tests were carried out in air at ambient temperature using Ducom pin-on-disc wear testing machine as shown in the figure 6. The machine monitor wear, tangential frictional force and coefficient of friction. These three parameters were measured as a function of load, sliding velocity, sliding distance. For each type of alloy and composite, wear tests were conducted at three different applied loads (10, 20 and 30N) by varying the sliding velocity at 1.5,3.0 and4.5 m/s. and sliding distance 500m.,1000m. and1500m. The surface of the disc was polished to a roughness value of 0.1 ± 0.02 Ra. Specimen Pin is pressed against the rotating steel disc (hardness of 65HRC) by applying the load. Wear loss and frictional traction experienced by the pin during sliding are measured continuously by a PC based data logging system after running through a fixed sliding distance with varying sliding velocities. After completing the test final volume of samples were calculated. The wear rate (K) was defined as the volume loss (V), divided by the sliding distance (L). Hence the volumetric wear rate (K) was calculated from weight loss measurement and expressed in terms of mm^3/km. The frictional force (F) was continuously monitored during the wear test for determining the coefficient of friction (μ). The wear surface and cross-sections of the wear surface on the sample generated during wear tests were examined by SEM and EDAX. Table 2 shows designed experimental factors and their levels used for conducting wear test. Whereas, Table 3 shows the experimental plan for conducting wear test on Al–5-wt% Cu alloy, an Al–10-wt% Cu alloy (hypoeutectic alloy), and an innovative composite combination of an Al–5-wt% Cu alloy as the matrix and a 5-wt% Cu powder as reinforcement.

Figure 3 copper die

Figure 4 semi finished samples

Figure 5 Finished wear samples

Figure 6 pin-on-disc equipment used for wear testing

The track diameter was varied for each batch of experiments in the range of 50 mm to 100 mm and the parameters such as the load, sliding velocity and sliding distance were varied in the range given in Table 2. A load cell on the lever arm helps determine the wear at any point of time by monitoring the movement of the arm. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disc. This movement of the arm generates a signal which is used to determine the maximum wear and the coefficient of friction is monitored continuously as wear occurs and time was monitored for all the specimens i.e., for both the alloys and composite.

Table 2 Designed experimental factors and their levels

S. No.	Parameter	Units	Symbol	Level -1	Level-2	Level-3
1	Applied Load	N	AL	10	20	30
2	Sliding velocity	m/sec	SV	1.5	3.0	4.5
3	Sliding Distance	m	SD	500	1000	1500

Table 3 Experimental plan (L9 orthogonal array) used to conduct wear test

Expt. No.	Applied Load (N)	Sliding velocity (m/sec)	Sliding Distance (m)
1	10	1.5	500
2	10	3.0	1000
3	10	4.5	1500
4	20	1.5	1000
5	20	3.0	1500
6	20	4.5	500
7	30	1.5	1500
8	30	3.0	500
9	30	4.5	1000

3. Results and Discussions

3.1 Variation of WVL and COF

The results for various combinations of parameters were obtained by conducting the experiments as per the orthogonal array were shown in the Tables 4 and 5 respectively. The measured results were analysed using the commercial software MINITAB 17 specifically used for design of experiment applications. The experimental results are average of two repetitions for wear rate and coefficient of friction. The mathematical models were developed for prediction of WVL and COF for 5-wt% Cu alloy in terms of L, SV, SD were given by Equations (1) and (2) with an R square value of 84.4% and 92.7% respectively.

$$WVL = 0.218 + 0.0473\ L - 0.129\ SV + 0.00102\ SD \quad (1)$$

COF = 0.519 - 0.0140 L - 0.00611 SV + 0.000119 SD (2)

Table 4 Experimental results for WVL of alloys and composite

S. No.	Applied Load, L in N	Sliding velocity, SV in m/sec	Sliding Distance, SD in m	Wear Volume Loss in mm^3		
				Al-5-wt%Cu alloy	Al-10-wt%Cu alloy	Al-5-wt%Cu alloy & 5-wt%Cu composite
1	10	1.5	500	1.26	0.81	0.77
2	10	3	1000	1.12	0.97	0.82
3	10	4.5	1500	1.75	1.41	1.36
4	20	1.5	1000	1.86	1.48	1.32
5	20	3	1500	2.07	1.72	1.55
6	20	4.5	500	1.18	1.02	0.91
7	30	1.5	1500	3.21	2.89	2.21
8	30	3	500	1.52	1.22	1.06
9	30	4.5	1000	2.24	1.83	1.6

Table 5 Experimental results for COF of alloys and composite

S. No,	Applied Load, L in N	Sliding velocity, SV in m/sec	Sliding Distance, SD in m	Coefficient of Friction		
				Al-5-wt% Cu alloy	Al-10-wt%Cu alloy	Al-5-wt%Cu alloy & 5-wt%Cu composite
1	10	1.5	500	0.437	0.432	0.358
2	10	3	1000	0.447	0.449	0.362
3	10	4.5	1500	0.556	0.617	0.368
4	20	1.5	1000	0.382	0.389	0.335
5	20	3	1500	0.399	0.398	0.348
6	20	4.5	500	0.231	0.377	0.325
7	30	1.5	1500	0.231	0.347	0.316
8	30	3	500	0.162	0.331	0.281
9	30	4.5	1000	0.208	0.342	0.295

The mathematical models were developed for prediction of WVL and COF for 10-wt% Cu alloy in terms of L, SV, SD were given by Equations (3) and (4) with an R square value of 85.3% and 73.0% respectively.

WVL = - 0.117 + 0.0458 L - 0.102 SV + 0.000990 SD (3)

COF = 0.438 - 0.00797 L + 0.0187 SV + 0.000074 SD (4)

The mathematical models were developed for prediction of WVL and COF for Al-Cu composite in terms of L, SV, SD were given by Equations (5) and (6) with an R square value of 89.2% and 96.4% respectively.

WVL = - 0.001 + 0.0320 L - 0.0478 SV + 0.000793 SD (5)

COF = 0.382 - 0.00327 L - 0.00233 SV + 0.000023 SD (6)

Figure 7 depicts the variation of WVL of Al-Cu alloys and Cu composite at different load conditions. It is observed that the wear rate of the composite is lower when compared to both the alloys. Similar trend were reported by many investigators for the Al-SiC and Al_2O_3 composite (4-6). From the graph it was observed that as the normal load increases the WVL is also increases for Al-5Wt%Cu alloy and Al-10Wt%Cu alloy due to metal to metal contact. As a result of large scale plastic deformation occurs during dry sliding, large sized debris is formed. For the composite when normal load is increases the wear rate has changed mildly up to 30N load. The hard Cu particles reduce the plastic deformation of composite by impeding the dislocation. The WVL is high in Al-5Wt%Cu alloy as compared to Al-10Wt%Cu alloy and MMC for all load conditions. Figure 8 depicts the effect of sliding velocity on WVL. From the graph it was observed that the sliding velocity from 1.5m/s reduced to 3m/s and then begins to increases to 4.5m/s for both alloys and composite. Increase in sliding velocity increases the steady formation of tribo layer at the contact surface. It was also observed that the WVL for different sliding velocities is less for composite as compared to both the alloys.

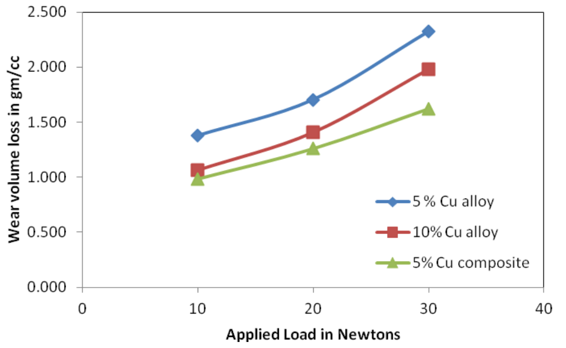


Figure 7 wear volume loss versus load of alloys and composite

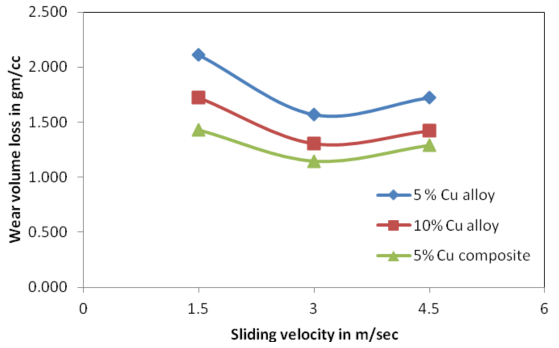


Figure 8 wear volume loss versus sliding velocity of alloys and composite

Figure 9 depicts the variation of WVL for different sliding distances. From the graph it was observed that as the sliding distance increases the WVL is increases for Al-5-Wt%Cu alloy, Al-10-Wt%Cu alloy and for composite. It was also observed that at different sliding distances the WVL is less in composite as compared to both the alloys. From Figures 7, 8 and 9, it was observed that the WVL is less for composite for different applied loads, sliding velocities and sliding distances as compared to both the alloys. The WVL is high in Al-5Wt%Cu alloy. In order to justify the above statement hardness test on the fabricated alloys and composite was performed. Figure 10 shows the Vickers micro hardness of the alloys and composite in homogenized, solutionized and age hardened (T6) conditions. The figure depicts that the hardness values increases from homogenized condition to T6 condition for both the alloys and composite. The high hardness values are observed for composite as compared to both the alloys in above conditions. Homogenized structures contain interdendritic regions (IDRs) rich with solute contents in alloys and exhibit copper powder particles as composite structure embedded between the dendrites. Homogenizing treatment yields, fine and uniform dispersion of Al_2Cu precipitates throughout the structure resulting increased hardness of the alloy. Solutionizing treatment enhances the hardness due to supersaturation of copper in the solid solution of alloys and copper reinforced particles distribution in aluminium-copper alloy matrix.T6 condition enhances the hardness to higher values due to coherent fine precipitates of θ^1 (Al_2Cu) throughout the matrix.

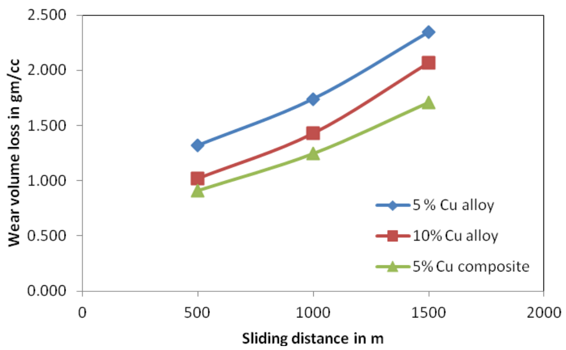


Figure 9 wear volume loss versus sliding distance of alloys and composite

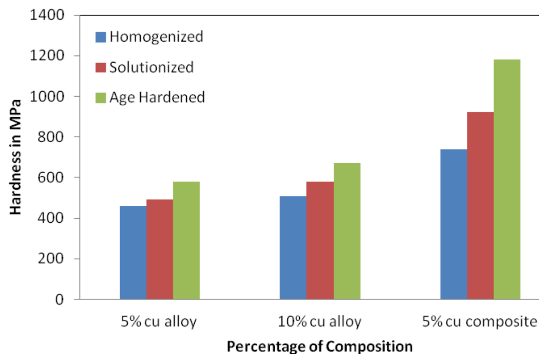


Figure 10 Hardness values of the alloys and composite under various heat-treatment conditions

Figure 11 depicts the variation of COF of composite and unreinforced Al-Cu alloys with 10N, 20N and 30N normal loads. From the graph it was observed that for both the alloys and composite that as the load increases the COF decreases The COF is less for MMC at 10N load as compare to both the alloys. At 20N and 30N load the COF is less in Al-5Wt%Cu alloy and more for MMC and Al-10Wt%Cu alloy. It was also observed from the graph the COF is high for Al-10Wt%Cu alloy because of Al_2Cu layer is formed at the grain boundaries of (ALFA) phase different applied loads. Though in both the Al-10Wt%Cu alloy and composite is having approximately same copper percentage, the composite shows less WVL and COF as compared to Al-10Wt%Cu alloy. This indicates the reinforcement Cu particles are distributed throughout the alloy matrix. Figure 12 depicts the variation of COF for different sliding velocities. From the graph it was observed that the COF is less for composite as compare with both the alloys at different sliding velocities. The COF is very slightly decreased from 1.5m/s sliding velocity to 4.5m/s sliding velocity for composite and Al-5Wt%Cu alloy, but for Al-10Wt%Cu alloy the COF is very high at 4.5m/s sliding velocity.

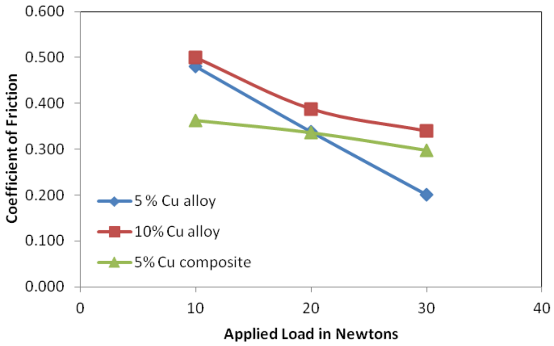


Figure 11 Coefficient of friction versus load of alloys and composite

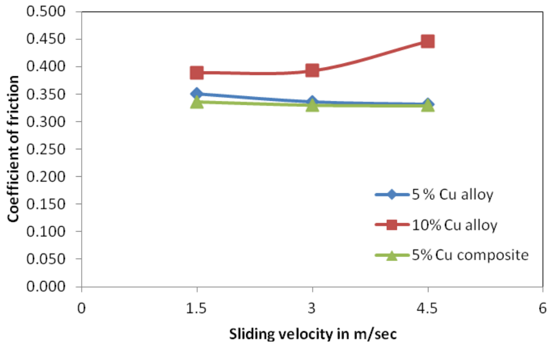


Figure 12 coefficient of friction versus sliding velocity of alloys and composite

Figure 13 depicts the variation of COF for different sliding distances. From the graph it was observed that as the sliding distance increases the COF is also increases for both the alloys and composite. At 500m sliding distance the COF is less for Al-5Wt%Cu alloy as compared to composite and Al-10Wt%Cu alloy. It was also observed that the sliding distance increases there is very slight increase in COF for composite. The COF is less for composite at 1000m sliding distance and at 1500m sliding distance as compare to both the alloys. From Figures 11, 12 and 13 it was observed that the COF is high in 10Wt%- Cu alloy as compared to MMC and 5Wt%-Cu alloy for different applied loads, sliding velocities and sliding distances, even though the percentage of copper is same in the above alloy and composite. It is evident from the MMC microstructure, that the reinforced copper powder is not alloyed, rather it is distributed in the Al-Cu alloy matrix.

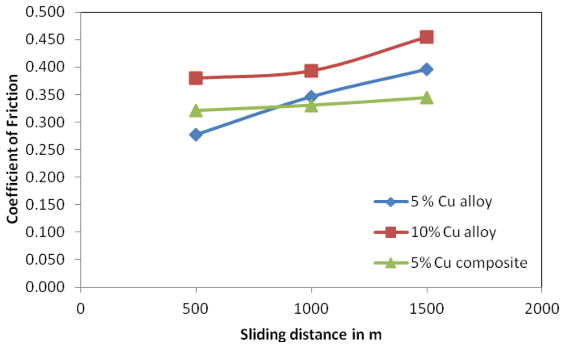
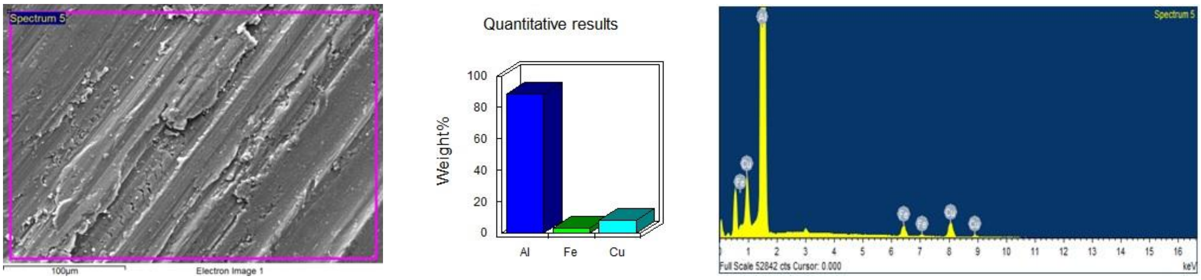


Figure 13 coefficient of friction versus sliding distance of alloys and composite

3.2 SEM analysis

The Figure 14 shows the SEM and EDAX of Al-5 wt%-Cu alloy wear sample. It was observed that the wear surface with deep grooves, because of the plastic deformation. The WVL is high in this alloy. It is evident from EDAX the Fe peaks are also observed along with Al and copper peaks, because that the debris of the Fe particles removed from the disc material is embedded to the test specimen surface.



(a) (b) (c)

Figure 14 (a) SEM micrograph of worn surface of Al-5-wt% Cu alloy, (b) its quantitative results and (c) its corresponding EDAX analysis

In order to study the wear behaviour of Al-5-Wt% Cu alloy the sample having major wear loss was selected and the SEM photograph for the sample Al-5Wt%Cu alloy is shown in the Figure 15. It was depicted that major WVL was observed, because of the delamination of Al_2Cu grains from the grain boundaries. When load increases the temperature at the contact surface is also increases and plastic deformation occurs. Due to this the surface layer of alloy formed more scratches and it was observed in the SEM photograph. The Figure 16 shows the SEM image of Al-10-wt% Cu alloy wear sample at a load of 20N, Sliding velocity 3.0 m/sec and Sliding distance of 1500m. It is observed that the wear track with scratches and debonding of Al_2Cu from the specimen surface. The Figure 17 shows the wear track of composite at a load of 30N, Sliding velocity 1.5 m/sec and sliding distance of 1500m. The micro structure shows the very thin scratches on the surface, because the copper particles are having strong bonding with aluminium copper matrix alloy. The composite is having high hardness when compared to both the alloys which resulted in minimized the scratches. The composite shows high wear resistance as compared to both the alloys.

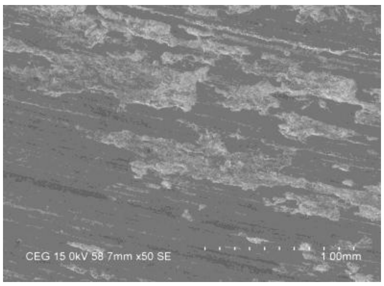


Figure 15 SEM image of worn out pin of Al-5-wt% Cu alloy at 10 N load, 4.5 m/sec sliding velocity and 1500 m sliding distance

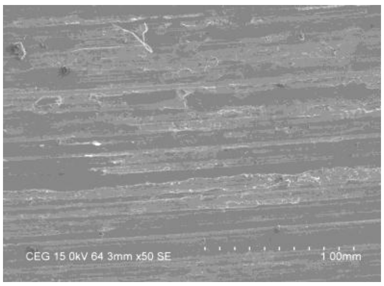


Figure 16 SEM image of worn out pin of Al-10-wt% Cu alloy at 20 N load, 3 m/sec sliding velocity and 1500 m sliding distance

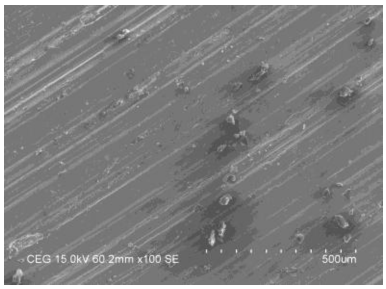


Figure 17 SEM image of worn out pin of Al-Cu composite at 30 N load, 1.5 m/sec sliding velocity and 1500 m sliding distance

4. Conclusions

An innovative MMC is fabricated using liquid-stir casting, which is economical. The following conclusions are drawn on the basis of an experimental investigation of tribological behavior of Al-Cu alloys and composite:

- The WVL is less for composite for different applied loads, sliding velocities and sliding distances as compared to both the alloys. The WVL is high in Al-5Wt%Cu alloy.

- The hardness of the composite is high as compared to both alloys.
- The COF is high in 10-Wt%-Cu alloy as compared to MMC and 5Wt%-Cu alloy for different applied loads, sliding velocities and sliding distances, even though the percentage of copper is same in the above alloy and composite.
- It is evident from the MMC microstructure, that the reinforced copper powder is not alloyed, rather it is distributed in the Al-Cu alloy matrix.
- From the above conclusions we predict that sliding distance and applied load have the highest influence on wear rate for both the alloys and composite. Similarly, applied load is only parameter which is largely influence the coefficient of friction for both the alloys and composite.

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