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## **Influence of Cu Addition on Dry Sliding Wear Behaviour of A356 Alloy**

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### **Abstract**

Influence of addition of copper (Cu) on the dry sliding wear behavior of A356 alloy has been reported in the paper. Effect of load, composition and sliding distances on A356 alloy before and after addition of Cu has been studied. Wear test surfaces were examined by SEM/EDX. It was found that wear resistance of A356 alloy decreases with increase in applied normal pressures and sliding distances. However, wear resistance of A356 alloy increased with Cu addition. Increase in wear resistance is mainly because of increase in strength/hardness of the alloy after Cu addition. SEM studies have shown that the layer of oxide material links both the surfaces there by improves sliding wear performance.

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*Keywords:* A356, SEM/EDX analysis, Wear Resistance, Wear, Worn surfaces

### **1. Introduction**

Owing to superior property combinations like specific strength, specific stiffness, seizure resistance, inhibited coefficient of thermal expansion and enhanced damping characteristics, Aluminium (Al) alloys are becoming promising materials for industrial applications. Aluminium by itself has deprived tribological characteristics [1], as a

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result studying the behaviour of Al based materials w.r. tribology has become necessity. Amongst all Al-alloys, Al-Si alloys are considered to be the materials for tribological applications due to several reasons [2, 3]. Al-Si alloys can be classified as Hypoeutectic, Eutectic and Hyper eutectic alloys. A356 alloy being commercially available hypoeutectic Al-Si alloy find applications in the fields of automotive, marine, aerospace and general engineering, where it is for blocks & heads of cylinder, bulk castings due to better fluidity, reduced CTE, specific strength and good resistance against corrosion [4, 5]. Wear resistance of Al-Si alloys are influenced by many factors like hardness, strength, ductility, shape, size of microstructural constituents. Apart from these, wear resistance of Al-Si alloys also affected by practical conditions like pressure, speed, temperature, atmospheric conditions and rubbing surface [6-10]. Conditions like chemical composition, melt treatments, heat treatments and second phase elements influence greatly the physical and mechanical properties in these alloys [4-5, 12].

Several researchers have investigated the role of adding alloying elements like Fe, Mg, Mn, Ni, Zn, Pb and P on microstructural and mechanical performance in these Al-Si alloys [13-17]. However, very limited work is being carried out on addition of Cu and its role as alloying element. It is believed that presence of Cu/Mg/Ni in trace amount improves strength of Al-Si base matrix [18-20]. Mg/Ni as alloying element in Al-Si alloys is preferred when intended for automotive applications [21]. The alloying elements added also assist in modifying wear characteristics of Al-Si alloys [22-23]. Lingaard et al. [24] and Gibson et al. [25] in their work on Al-Si alloys found that addition of small amounts of Si, Cu and Mg lead to improvements in hardness and strength in turn the wear resistance. In another study, it was reported that use of Cu as alloying element in Al-Si alloy result in precipitation of  $\text{CuAl}_2$  phase which increases strength in cast products. Also addition of Cu is expected to enhance machinability and conductivities while ductility decreases [26]. Dasgupta and Bose [27] in their work on Al-Si alloys concluded that wear resistance is increased with Cu addition because of  $\text{CuAl}_2$  phase. In another work it was reported that 1.5% Cu addition to Al-Si alloy resulted in refinement of dendrites and mechanical behaviour of Al-Si alloys was improved [12]. In one of our recent work[28], it was observed that addition of Cu in amounts of 0.1-0.5% to A356 alloy has led to improved mechanical performance through refinement of  $\alpha$ -Al. Maximum Mechanical Performance was achieved when the amount of Cu added is 0.5%. Considering the above, this work aims at studying the outcome of Cu (0.5% Cu) incorporation on wear behaviour of A356 alloy and to study the dominant wear mechanisms under varying wear parameters.

## 2.0 Experimental details

### 2.1 Specimen preparation for wear

Melting of the charge was carried out at  $720^\circ\text{C}$  in an electric resistance furnace under a cover flux containing NaCl, KCl and NaF. To expel all the absorbed gases, degassing of the melt is done using  $\text{C}_2\text{Cl}_6$  in tablet form. To incorporate Cu into the melt Al-15Cu master alloy is used. Chips of Al-Cu master alloy were added to liquid Al. Manual Stirring of the melt is carried out with steel rod after Cu addition. Two castings at different times of 0 and 5 min. were produced by pouring liquid Al in to mould having dimensions of 12.5mm dia and 125 mm height. From these castings wear specimens of dimensions 10mm dia and 32mm length (ASTM G99) were machined [29]. Compositional analysis of the alloys used in the present study was done using spectrometer (model Varian AA-240, Netherlands) which is given in Table 1.

Table 1 showing chemical composition of base alloy and Al-15cu master alloy

Composition	Composition (in wt.%)									
	Si	Cu	Mg	Fe	Ti	Mn	Zn	Sn	Pb	Al
A356	6.95	0.11	0.29	0.51	0.24	0.32	0.11	0.03	0.2	Rest
Al-15 Cu	-	14.7	-	-	-	-	-	-	-	Rest

### 2.2 Dry sliding wear experiments

Wear studies were performed using pin-on-disc wear testing machine attached with information acquirement

system. During wear tests specimens were positioned in collet which is clamped to the holder. Wear specimen is mounted on to the disc with weight. Measurement of roughness of the surface is done using SJ-201 tester (Make: Mitutoyo, Japan) and was lying between 0.30-0.72  $\mu\text{m}$ . En-32 steel disc of dimensions 165mm and 8mm thick, with roughness value of 0.47 – 0.87  $\mu\text{m}$  and with hardness of  $\text{HR}_{\text{C}}61$  was used in the present work. In order to maintain dry sliding conditions both wear specimens and steel disc were treated with emery papers, acetone before every test. Further, the Pin-On Disc machine used for wear studies has a loading capacity of 200N and tests were conducted with a track diameter of 90mm. Weight loss method is adopted to study the wear behaviour and weight of the wear specimen before and after each test was measured using balance with an accuracy of 0.0001g. A sensor is used for measuring frictional force. Wear behaviour of A356 alloy before and after addition of Cu was studied at various applied normal pressures and sliding distances. For every specimen three tests were conducted and average value is reported. SEM/EDX was used for characterization of the wear specimens before and after the test and with and without addition of Cu.

### 3.0. Results and Discussions

#### 3.1. Influence of varying applied normal pressures

Fig. 1a-b shows the effect of Cu addition on wear behaviour of A356 alloy under different applied normal pressures and on frictional force respectively. Fig.1a clearly reveals that wear resistance of A356 alloy decreases with increase in applied normal pressure in both cases i.e with and without addition of Cu. From graph Fig. 1a.it can be seen that wear in A356 alloy without Cu occurs in three modes. Initially, lower wear region, then mild region upto 0.572  $\text{N}/\text{mm}^2$  thereafter increases drastically with applied normal pressure. Drastic increase in wear rate observed at pressures of 0.715  $\text{N}/\text{mm}^2$  and 0.859  $\text{N}/\text{mm}^2$  is mainly due to bulk shift of material from wear specimen to steel disc. While mild region observed could be due to the formation of oxide layer on wear specimen surface which inhibits bulk shifting of material. At very high pressures, increase in temperature at the interface is resulting in softening of the matrix thereby higher wear rate. However, the addition of 0.5% Cu to A356 alloy has resulted in decreased wear rate compared to only A356 alloy. Decreased wear rate can be attributed to factors like higher hardness, strength, microstructural changes and reduced micro cracks due to the addition of Cu.

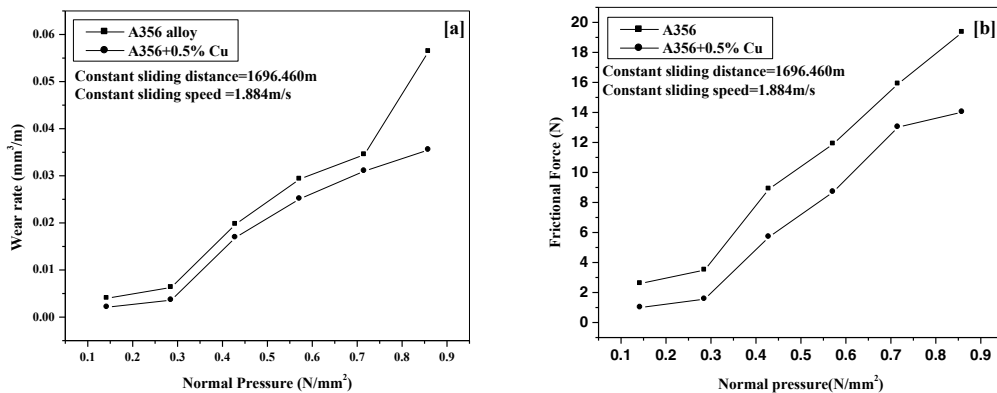


Figure1 Showing the influence of varying normal pressures on (a) Wear rate & (b) Frictional force of A356 alloy before and after addition of 0.5%Cu

From Fig.1b it is clear that addition of Cu to A356 alloys has resulted in decrease of frictional force when compared to A356 alloy without Cu at all applied normal pressures. As applied normal pressure is increased, A356 alloy undergoes softening and becomes plastic due to increased asperity contact thereby increased frictional force. Further, the softening of the matrix could also be due to increase in frictional temperature at the point of contact. However, addition of Cu to A356 alloy is making the alloy strong enough and also reduces the temperature at the

interface there by decreases wear rate.

### 3.2. Influence of varying sliding distances

The influences of sliding distance on wear rate of A356 alloy with and without Cu addition, at constant pressure of  $0.715 \text{ N/mm}^2$  and at constant sliding speed of  $1.884 \text{ m/s}$  are shown in Fig.2a. Figure clearly reveals that as sliding distance increases, wear resistance decreases in both alloys i.e A356 alloy with and without Cu addition and at all conditions. The decrease in wear rate can be attributed to prolonged intimate contact between the two mating surfaces. However, A356 alloy with Cu addition has shown relatively better wear resistance when compared to A356 alone. Probably, addition of Cu has resulted in microstructural modifications which contribute to increase in hardness and strength of the base alloy thereby reducing the surface damage and thereby increases wear resistance. Further, during wear tests generation of an oxide intermediate layer between mating surfaces is also one of the probable reason for increased wear resistance. Influences on frictional force at different sliding distances for A356 alloy with and without Cu are represented in Fig. 2b. Figure clearly reflects the fact that for both A356 alloy with and without Cu frictional force increases as sliding distance increases at constant pressure of  $0.715 \text{ N/mm}^2$  and at constant sliding speed of  $1.884 \text{ m/s}$ . However, increase in frictional force is relatively lower with Cu addition when A 356 alloy without Cu. Decrease in frictional force of A356 with Cu addition can be attributed to better hardness and strength and also due to creation of an intermediate oxide rich layer between mating surfaces.

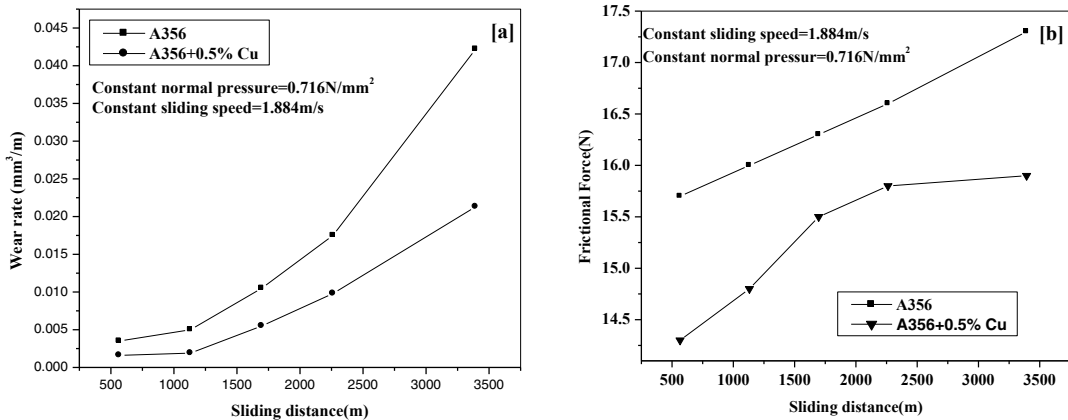


Figure 2 showing the influence of varying sliding distances on the (a) Wear rate & (b) Frictional force of A356 alloy before and after addition of 0.5% Cu

### 3.3. Worn surface studies

SEM microphotographs of A356 alloy with and without Cu addition after wear test are presented in Fig.3a-d. Fig.3a. clearly suggests abrasive wear in A356 alloy revealing grooves due to abrading action by the hard particles which got entrapped. For the same A356 alloy, when the pressure is increased from  $0.143 \text{ N/mm}^2$  to  $0.859 \text{ N/mm}^2$ , SEM microphotographs revealed small cracks with grooves and dislodging of material clearly indicating combination of abrasive and delaminative wear. However, addition of Cu to A356 alloy has resulted in improved wear resistance at both pressures of  $0.143 \text{ N/mm}^2$  and  $0.859 \text{ N/mm}^2$ , which can be seen through mild abrasive grooves (Fig. 3c) and smooth abrasive grooves filled with oxides (Fig.3d).

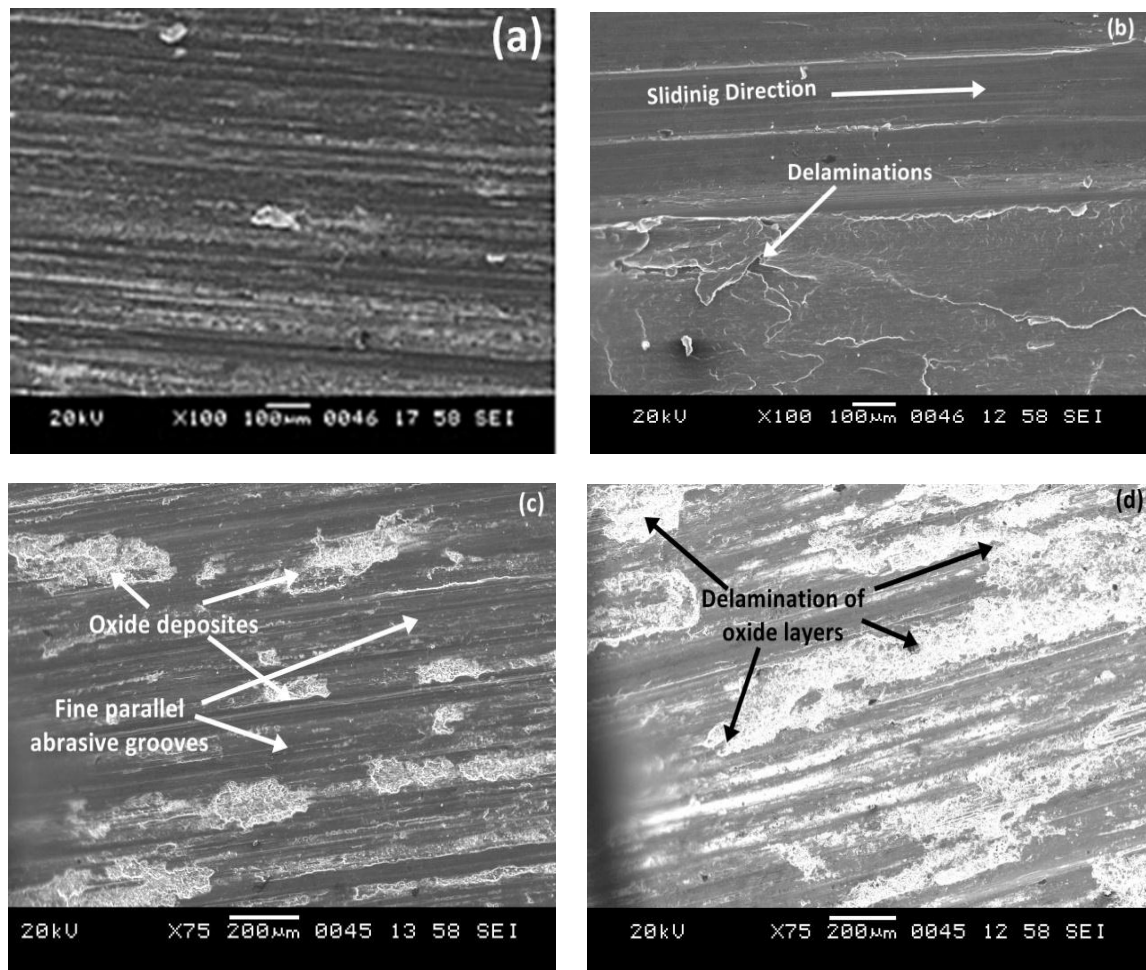


Figure. 3 shows SEM of worn surfaces at varying normal pressure of (a) A356 alloy at 0.143 N/mm<sup>2</sup> (b) A356 alloy at 0.859 N/mm<sup>2</sup> (c) A356 alloy with 0.5%Cu at 0.143 N/mm<sup>2</sup> & (d) A356 alloy with 0.5%Cu at 0.859 N/mm<sup>2</sup>; under constant sliding distance of 1696.460 m, at constant sliding speed of 1.884 m/s

Effect of Cu addition and varying sliding distances on the worn surfaces of A356 alloy are shown in SEM microphotographs (Fig. 4a-d). A356 alloy without Cu addition and at distance of 565.486 m has revealed constant analogous abrasive grooves filled with oxide as shown in Fig. 4a indicating abrasive and oxidative wear. However, increasing sliding distance to 3392.92 m has resulted in severe wear in terms of deep grooves filled with oxides and material detachment from the surface as evident in Fig.4b. Further, SEM Microphotographs of A356 alloy with Cu addition i.e Fig. 4c-d have revealed decreased wear rate at both distances when compared to A356 without Cu addition. Addition of Cu has reduced the depth of abrasive grooves due to higher hardness (Fig.4c) and increased intermediate layer of oxide (Fig.4d.).



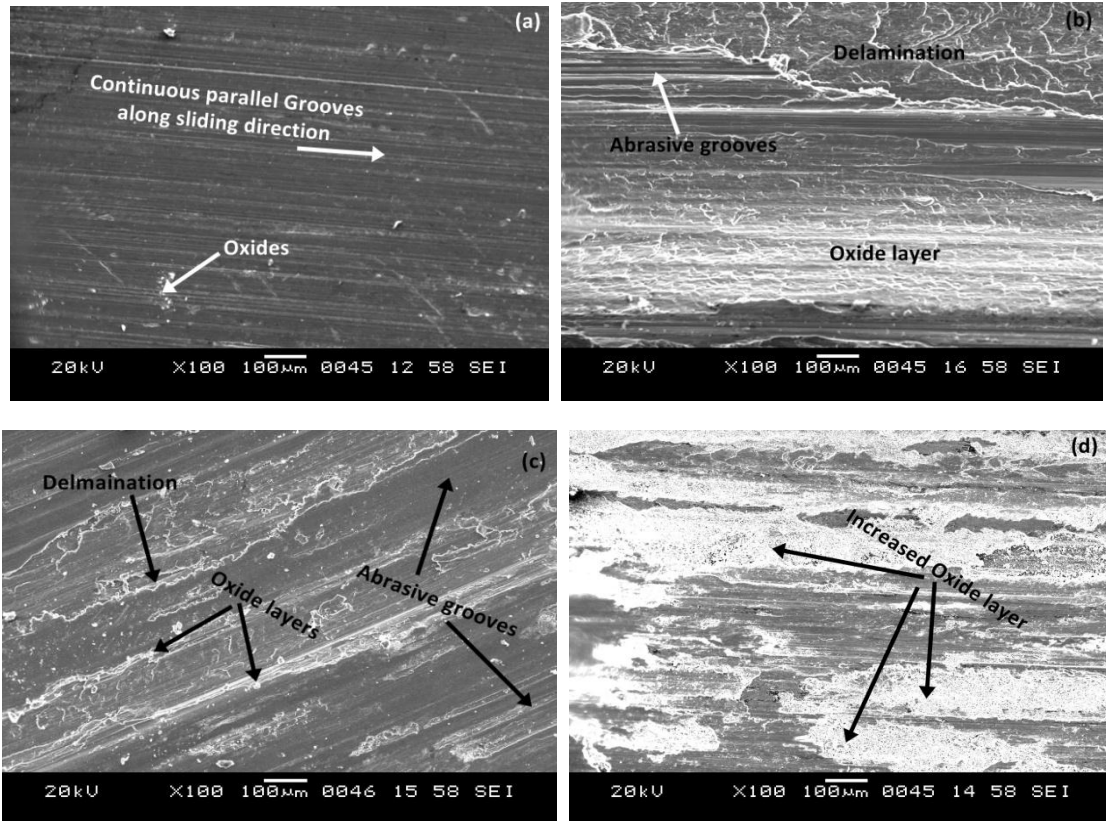


Figure 4 shows SEM of worn surfaces at varying sliding distances (a) A356 alloy at 565.486 m (b) A356 alloy at 3392.92 m (c) A356 alloy with 0.5% Cu at 565.486 m & (d) A356 alloy with 0.5% Cu at 3392.92 m; under constant normal pressure of  $0.716 \text{ N/mm}^2$  & constant sliding speed  $1.884 \text{ m/s}$

#### 4.0 Conclusions

1. Addition of small amount of Cu (0.5%) has resulted in improvements in wear resistance of A356 alloy when compared to A356 without Cu.
2. In both alloys frictional force increases with increasing normal pressures and sliding distances at all conditions. However, lower Frictional force was observed in A356 alloy when added with Cu.
3. Addition of Cu to A356 alloy has resulted in microstructural changes, increases in hardness and strength and promotes formation of oxide layer between the mating surfaces which is responsible for control of wear and friction.

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