AN EVALUATION OF THE SLIDING WEAR BEHAVIOUR OF SiC PARTICLES REINFORCED COPPER ALLOY COMPOSITE MATERIALS

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Abstract

The present paper aims at evaluation of the sliding wear behaviour of SiC particles reinforced copper (phosphor-bronze) alloy composite materials studied as a function of sliding speed and applied loads under unlubricated conditions. The content of SiC particles in the composites was varied from 1-5% in steps of 2% by weight. A pin-on-disc wear testing machine was used to evaluate the wear rate, in which EN24 steel disc was used as the counterface. Loads of 20-160 N in steps of 20 N and speeds of 1.25, 1.56, 1.87 m/s were employed. The results indicated that the wear rate of both the composites and the matrix alloy increased with increase in load and sliding speed. However, the composites exhibited lower wear rate than the alloys. It was found that above a critical applied load, there exists a transition from mild to severe wear both in the unreinforced alloy and in the composites. But the transition loads for the composites were much higher than that of the unreinforced alloy. The transition loads increase with the increase in weight % of SiC particles, but decrease with the increase in sliding speeds. SEM analysis of the wear surfaces as well as the sub-surfaces are used to explain the observations made.

1.0 Introduction

Metal matrix composites (MMCs) in the recent years are being increasingly specified as new wear resistant materials. The tribological properties of MMCs is of interest in several applications like bearing sleeves, piston and cylinder liners, aircraft brakes, etc.

A wide variety of copper (Cu) based alloys are used directly as bearing materials and also as backing materials for babbit liners. Their use in the former category covers a range of physical properties in terms of hardness and strength, that is wider than that of any other group of bearing alloys. Cu alloys are traditionally used for sliding applications particularly for bearings and electrical contacts. These alloys which are also used for various wear resistant applications like bearings are also being considered for bearing cages in systems where extended life is necessary.

The phosphor-bronze alloys are highly potential Cu alloys which exhibit good wear resistance, good machinability, cold workability, fatigue resistance, corrosion resistance, etc. and can operate in more severe conditions and up to temperatures around 450°C. High strength and wear-resistance make them suitable for wear and abrasion resistance applications which involve impact or shock loading. They are widely used as engineering tools and dies, bushings, guide plates, etc. Incorporation of ceramic reinforcement will certainly enhance the wear and friction properties of these wear resistant alloys.

Though very less, some extent of research has been carried out on Cu alloys based composite materials. Chen et al., [1] who have worked on tribological behaviour of Cu based composites using a pin-on-disc wear tester, have evaluated the coefficient of friction, wear rate and bulk temperature of the composites in terms of effect of normal pressure and sliding speed. They have reported that the wear rate increased with increasing normal pressure and decreased with increasing sliding speed in the studied range of normal pressure and sliding speed. Liu et al., [2] also have worked on tribological behaviour of Cu-20% Nb in-situ composites. It was found that Nb filaments underwent re-orientation, shearing and refinement. The SEM analysis used to study the micro-mechanisms of wear showed that surface deformation, filament re-orientation and refinement, and oxidation seem to play important roles in the friction and wear processes.

Even though Saka and Karalekas [3] have reported that the Cu based MMCs exhibit wear behaviour which is similar to that of Al based MMCs, the tribological properties of Cu alloys based MMCs have not yet been studied extensively. In addition, there is still an incomplete understanding of the wear mechanism of Cu based MMCs, due to which there is a great need for research on these highly potential alloy based MMCs for wear and frictional resistance applications. Moreover, Cu matrix composites have the potential for use as wear-resistance and heat-resistant materials, electronic materials, brush and torch nozzle materials. Hence studies on Cu alloy based composites with regard to their wear behaviour under dry sliding condition are of significance.

2. Experimental Procedure

SiC particles of size 50-100 μm were used as the reinforcement. Phosphor-bronze alloy with the chemical composition in weight % : Sn-18 to 20%, Pb-0.25%, Fe-0.25% and P-1.0%, Cu-remainder, was used as the base matrix alloy. Liquid metallurgy technique was used to fabricate the composites, in which the preheated SiC particles were introduced into the vortex created in the molten alloy through an alumina coated steel impeller rotated at around 500 rpm. The coating of alumina is necessary in order to prevent contamination of the melt. The melt was thoroughly stirred, degassed subsequently by passing nitrogen at the rate of 2-3 litres/minute and poured into preheated split-type permanent moulds.

2.1 Wear test equipment

The dry tests of the wear specimens were conducted in accordance with ASTM G99 standards using a pin-on-disc sliding wear testing machine. EN24 steel disc of hardness HRc 57 and diameter of 200 mm was used as the counterface on which the test specimens slide. Arrangements were made to hold a specimen and also for application of the load on the specimen. The test specimen was clamped in a vertical sample holder and held against the rotating steel disc. More detailed description of the apparatus is available elsewhere [4]. In the present investigation, loads of 20-160 N in steps of 20 N were used. The rotational speeds employed were 200, 250 and 300 rpm, which at an average distance of 80 mm from the centre gave corresponding linear speeds of 1.25, 1.56, 1.87 m/s respectively.

2.2 Testing of Specimens

The specimens of the material under investigation were 6mm in diameter and 15mm in length. The disc was cleaned with acetone to remove any possible traces of grease and other surface contaminants. The specimens which were cleaned with ethanol were weighed before and after the tests using a balance accurate to ± 0.001g. The wear results were computed from weight loss measurements. The duration of each test was exactly 60 minutes. The wear volume was calculated from the ratio of weight loss to density and wear rate was calculated using sliding distance and wear volume. Usage of such relations to calculate the wear parameters is not uncommon and has been used by Rohatgi et al [5]. The data for the wear tests was taken from the average of three measurements. The standard deviation was about 5%. The surfaces of the worn specimens were cleaned thoroughly to remove the loose wear debris and then observed using a scanning electron microscope.

3. RESULTS

3.1 Effect of load and speed on the wear rate

The results were averaged to obtain the final wear rate which are presented graphically in Figures 1-3. The wear rate of the unreinforced alloy is also plotted in order to enable comparison with the composites. It is found from the graphs that the wear rate of both the unreinforced alloy and the composite specimens increased with the applied load. The wear rate of each phosphor-bronze alloy/SiC reinforced composite specimens reduced with the increase in SiC content.

It follows from the graphs shown in Fig 1-3 that the wear rate of the composites is lower than that of the alloy. The wear rate also decreases with the increase in SiC content. It is evident from the graphs that there exists a certain applied load, i.e. a transition phenomena at which there is a sudden increase in the wear rate of both reinforced as well as unreinforced materials. However, the transition loads for the composites were much higher than that observed for the unreinforced alloy and also the transition load increased with the increase in SiC particle content.

The unreinforced matrix alloy showed a transition from mild to severe wear at a load of 60 N, while the 1 and 3% fibre reinforced composites showed a transition at 140 N, and the same was observed at a load of 160 N in case of 5% reinforced composite. This observation indicates that the presence of SiC reinforcement delays the transition from mild to severe wear, and increases the transition load of the 5% reinforced composite by almost 2.5 times with respect to the unreinforced alloy.

The results show that at lower loads, comparatively low wear rates exist, indicating the regime of mild wear. In this regime of mild wear, the composites demonstrate more significant wear resistance than the alloy counterpart. At higher loads, the materials exhibit rapid increase in wear rate. At loads greater than the transition load, severe wear occurs leading to seizure of the materials. The severe wear manifested itself by a rapid rate of material removal in the form of generation of coarse metallic debris, and also by massive surface deformation and material transfer to the counterface.

It follows from the graphs shown in the Fig. 1-3, that the unreinforced alloy shows a transition at 60 N when tested at 200 and 250 rpm, while the same is observed at 40N in case of 300 rpm test. Similarly, the composite with 1 and 3% SiC shows a transition at 140N when tested at 200 and 250 rpm, while the same is observed at 120N in case of 300 rpm test. The composite with 5% SiC shows a transition at 160N when tested at 200 and 250 rpm, while the same is observed at 140N in case of 300 rpm test. The above observation clearly indicated that the sliding speeds employed have a significant effect on the wear rate transition of the materials. The transition in wear rate decreases with the increase in speed in all the materials. The results obtained are on par with the one obtained by Lee et al., [6] who have reported that the wear mechanisms are strongly dependent upon the sliding speeds.

The mild wear of the alloy is oxidation dominated wear at low sliding speeds and loads. In the case of composites, due to the existence of SiC particles, the oxide film of the metal is not continuous and tenacious, it is removed by sliding friction forces resulting in oxidation assisted mild abrasion wear. Hence, it can be considered that the dominating wear mechanism is the removal and reproduction of the oxide film.

This kind of wear is maintained until higher loads are employed, at which the wear mechanism transforms from mild wear to severe wear. The morphologies of wear surfaces of 5% SiC reinforced composites are shown in Fig.4. The wear tracks in Fig.4 (a) show typical abrasive wear for the composites tested at low loads of 40N. Hence it can be concluded that the dominating wear mechanism is abrasive wear at low loads.

At higher loads at which transition occurs from mild to severe wear, the wear rate quickly increases sharply. Due to the high loads employed, the friction and wear increased obviously. In this condition, the removal and formation of oxide films are faster than that of mild oxidation, thereby resulting in relatively higher wear rates. Severe plastic deformation in the subsurface layers may be caused at high loads leading to subsurface cracking. In view of the subsurface crack seen in Fig.5, it can be concluded that it is the adhesion and delamination wear that is dominant at high loads. Seizure may occur with the further increase in the applied load.

3.2 Effect of SiC particles on wear rate

SiC which is a ceramic, due to its directional covalent bonds and relatively lower concentrations and mobility of crystalline defects, is not prone to seizure under rubbing conditions. This property along with high strength, wear resistance, corrosion resistance, etc., have shown that this material is a possible candidate for use in wear resistant applications.

It is also to be observed that the transition load increases with the increase in SiC content and also the wear rate of the composite was lower than that of the base alloy without SiC reinforcement. This is obviously due to the release of SiC by the composite specimens on to the mating surface during sliding which provide resistance to wear. Alpas and Zhang [7] who have studied the sliding wear behaviour of Al-Si alloys reinforced with SiC particles have indicated that under the conditions where particles support the load, SiC reinforcement leads to significant improvement in the wear resistance. Ames and Alpas [8] have reported that the addition of SiC particles delay the transition to the severe wear and increase the transition load over 2.5 times with respect to the unreinforced A356 alloy.

During the sliding wear, the SiC particles get sheared and then the sheared layers adhere to the metal surface with the major axis parallel to the sliding direction forming a thin film between the mating surfaces. Moreover, the hard SiC has very limited ductility and has the ability to withstand stress without plastic deformation or fracture under low load conditions. It is well established by investigators [9] that the wear rate and surface damage can be minimised if the plastic deformation of the material at the contact interface is prevented. The hard SiC withstands high stresses without plastic deformation or fracture and is very effective in reducing the wear rate in the case of composites. Hence, it can be concluded that the ability of the sheared reinforcement layers to adhere to the sliding surface decides the effectiveness of the SiC particles in reducing the wear rate of the composite materials.

3.3 SEM analysis

For brevity and convenience, the SEM micrographs of only 5% SiC composites wear tested at speed of 300 rpm (1.87 m/s) have been presented. However, the explanation holds good even for the composites with 1 and 3% reinforcement. The SEM micrographs of typical worn surfaces of the 5% SiC reinforced composites are presented in Fig.4 which show the wear track morphology of the specimens tested at various loads.

It can be seen that a lot of parallel, continuous and deep ploughing grooves exist on the wear surface of the composite and abrasion phenomenon is observed at low loads. The parallel grooves suggest abrasive wear as characterised by the penetration of the hard SiC particles into a softer surface, which is an important contributor to the wear behaviour of ZA-27/SiC composites. The worn surfaces in some places reveal patches from where the material was removed from the surface of the material during the course of wear and smeared on to the sliding surface.

This abrasive wear is quite possible at low loads where the reinforcing SiC particles remain intact without fracture during wear and thus act as load-bearing elements. Also the macroscopic observation reveal the presence of the microgrooves on the surface of the steel disc which provides sufficient evidence for the abrasive effect of the carbide particles. Hence, it can be stated that a prerequisite for this type of wear is that the SiC particles should remain unfractured during wear so that they can support the applied load and act as effective abrasive elements [10]. This observation was made at low loads where the SiC particles could resist the fracture. But at higher loads, the induced stresses exceed the fracture strength of the carbide particles causing particle fracture. When the particles fracture, they lose their effectiveness as load-bearing components and the damage-accumulation processes including subsurface void nucleation and crack propagation may become operative. Further, the shear strains induced in the process get transmitted to the matrix alloy and the wear mechanism proceeds by a subsurface crack propagation induced delamination wear.

Clear evidence of subsurface cracks in the composite material, the rate of propagation of which controls the wear rate, can be seen from the SEM micrograph shown in Fig.5. Das et al., [11] are of the opinion that in delamination wear, the subsurface cracks which may either exist earlier or get nucleated due to the stresses, propagate during the course of wear and when such subsurface cracks join the wear surface, delamination is the dominant wear mechanism. The surface material gets removed and the cracks get nearer to the surface and the shear strain is increased thus causing the removal of the surface layers by delamination.

4. Conclusion

Under unlubricated sliding wear, with the increase in applied load and speed, the wear behaviour of the Cu/SiC composites transforms from mild wear to severe wear and then to seizure. The mild wear is characterised by oxidation assisted abrasion, while the severe wear is dominated by subsurface cracks assisted delamination. The transition in the wear rate which occurs above the critical load, where a sudden increase in the wear rate occurs, restricts the application of the alloys in some important tribocomponents such as cylinder liners, high-speed bearings or high-load bearings. It follows from the results obtained in the present study, that the presence of hard SiC particles hinder the mild-to-severe wear transition. The wear behaviour further improves with the increase in SiC content, thereby improving the wear resistance of the alloys even at higher loads.

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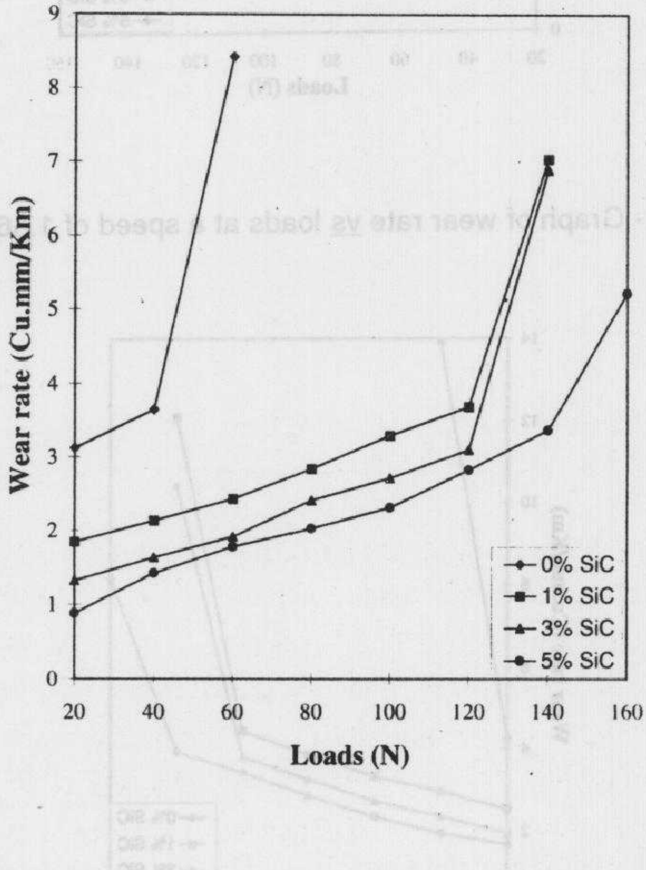

Fig. 1 - Graph of wear rate v/s loads at a speed of 1.25 m/s.

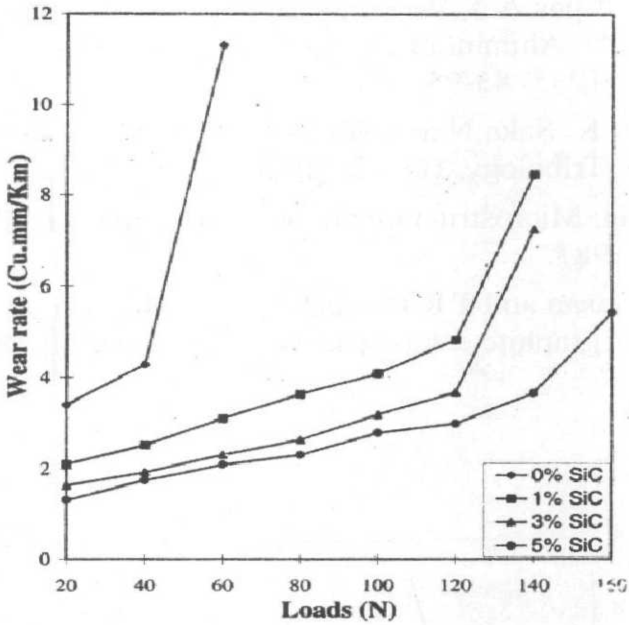

Fig. 2 - Graph of wear rate vs loads at a speed of 1.56 m/s.

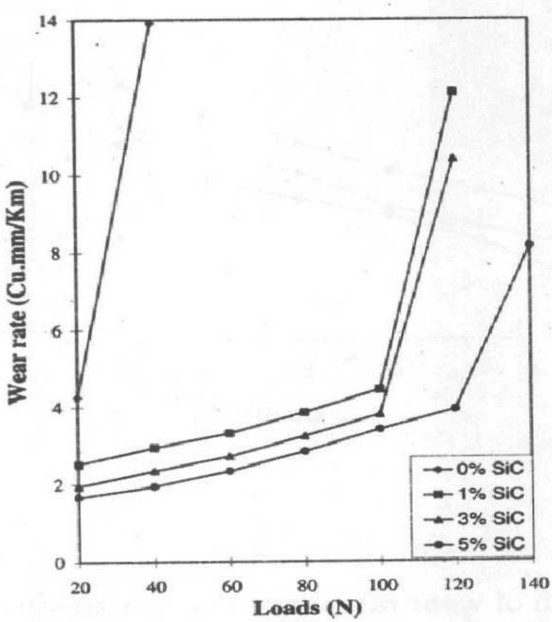

Fig. 3 - Graph of wear rate vs loads at a speed of 1.87 m/s.

Fig.-4. SEM showing wear track morphology of 5% SiC composite at 1.87 m/s and loads of (a) 40 N and (b) 100 N.

Fig.-4. SEM showing wear track morphology of 5% SiC composite at 1.87 m/s and loads of (a) 40 N, and (b) 100 N.

Fig.-5. SEM showing the subsurface crack in 5% SiC composite.