

Effect of transfer layer on dry sliding wear behaviour of cast Al-based composites synthesized by addition of TiO₂ and MoO₃

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ABSTRACT

Two types of composites have been developed by solidification processing by addition of 3, 4, and 5 wt% powders of oxide—TiO₂ and MoO₃, to molten Al-5 wt% Mg alloy. The oxide particles react with the molten alloy resulting in alumina and releasing alloying elements of Ti or Mo. Dry sliding wear behaviour of pins of cast composite, fabricated by solidification of melt-particle slurry in mold, has been determined by pin-on-disc wear tests carried out conventionally and while removing wear debris by camel brush. The accumulated volume loss in composites increases linearly with increasing sliding distance and the wear rate increases more or less linearly with increasing load. Increasing particle content decreases wear rate at a given load. The accumulated volume loss is considerably higher when wear debris is removed by camel brush during dry sliding wear. The nature of the wear debris has been confirmed to be oxidative. The relatively brighter compacted oxide transfer layer could be observed in the SEM micrograph of worn pin surfaces of the composites developed by addition of MoO₃ and TiO₂ respectively. Since the accumulated volume loss in wear is relatively more when the wear debris is removed during dry sliding wear test it may be inferred that wear debris is more beneficial for wear resistance through formation of transfer layer rather than its harmful role in enhancing volume loss through three body wear. At higher loads, the oxide debris are expected to get better compacted to form transfer layer, spread over a larger area of the sliding surface and thus, their removal causes a larger wear compared to that without removal of wear debris. However, a larger cover of transfer layer at higher load does not necessarily imply reduced accumulated volume loss because the wearing process is more aggravated at higher load. Apart from adhesion, micro-cutting and abrasion, the transfer layer also flakes off during dry sliding wear as indicated by the presence of chunky sheet of oxides in wear debris.

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1. Introduction

Composite materials have widened the horizon of engineering materials beyond natural combinations by introducing man-made combinations, even across different categories of materials—metals, ceramics and polymers. The topologically continuous major phase in the composite is called matrix, in which the other minor phase or phases may be discontinuously/continuously distributed to impart/reinforce certain properties. There are many metallic components where wear resistance is the primary consideration for application. Replacement of such components by those made of lightweight aluminium based composites may result in significant weight saving and thereby, fuel economy in automobile, aero-space and space industries [1]. Normally, aluminium alloys

have excellent mechanical properties coupled with good corrosion resistance but often possess poor resistance to wear and seizure. It is possible to reinforce aluminium alloys by various hard and soft particles such as SiC, Al₂O₃, flyash, glass, WC, graphite, mica, coconut shell char, TiO₂, etc. [2,3] to impart resistance to wear and seizure. The reinforcing particles may be either added from outside or generated within the matrix during processing. Synthesis of aluminium based lightweight composites by economic route of solidification processing [4] have received considerable attention due to significant improvements in the tribological properties of such composites including sliding and abrasive wear resistance, and also, seizure resistance [5–8]. High wear resistance of hard particle reinforced metal matrix composites (MMCs) is primarily attributed to decrease in real area of contact due to high hardness of composites reinforced with hard particles [9]. It has been observed that wear rate increases with increasing normal load but decreases with increasing volume fraction of particles if the bonding between the matrix and the particles is adequate. It has been observed that dry

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Table 1

Chemical compositions of as received commercial aluminium and magnesium ingots, in wt%.

Material	Si	Fe	Cu	Mg	Zn	Ti	Al
Al ingot	0.20	0.30	0.00	0.01	0.22	0.01	Bal.
Mg ingot	0.01	0.02	0.02	Bal.	0.00	0.00	0.00

sliding wear behaviour, although does not conform to the picture of simple adhesion considered by Archard, could be described broadly by Archard's law [9] given below:

$$W = \frac{KSN}{H} \quad (1)$$

where the wear rate, W , is volume of material worn during sliding, S is the sliding distance, N is the applied normal load and H is the bulk hardness of the material. K is the proportionality constant called the wear coefficient of a material. It is well known that during oxidative dry sliding wear, there is formation of transfer layer. Shorowordi et al. [3] in their study on wear, friction and tribo-chemistry of aluminium based composites sliding against counter face of phenolic brake, have also noted significant role of transfer layer formed on the sliding surface providing protective cover, which helps to reduce both wear rate and friction coefficient.

The present study aims to determine dry sliding wear behaviour in the context of formation of transfer layer on the sliding surface of cast Al-based composites synthesized by reaction of TiO_2 and MoO_3 in molten aluminium before solidification of the resulting slurry.

2. Experimental procedure

Pieces of commercially pure aluminium of composition given in Table 1, have been heated in a graphite crucible kept in a vertical electric resistance muffle furnace to attain molten state. When the temperature of the melt reaches 800°C , it is stirred by a graphite stirrer to create a vortex in the melt. MoO_3 or TiO_2 particles with

Table 2

Details of MoO_3 , TiO_2 and graphite powders used in processing of cast in-situ composite.

No.	Powder	Purity (%)	$\rho(\text{g}/\text{cm}^3)$	Supplier
1.	MoO_3	99.0	3.79	S.D. Fine-Chem Ltd., Mumbai, India
2.	TiO_2	98.0	3.29	S.D. Fine-Chem Ltd., Mumbai, India

characteristics described in Table 2, are added into the vortex for their transfer into the melt and magnesium pieces are also added to the melt to help wetting of in-situ generated particles by molten aluminium and retain them inside the melt. Melt-particle reaction is allowed to continue for 20 min.

The resulting slurry of melt containing oxide particles is then cast into a steel mould by bottom pouring [4]. The cast in-situ composite ingots is made to cool very fast by immersing (quenching) them in water immediately after casting.

The Brinell hardness tests of the composites have been carried out with a 2.5 mm diameter hardened steel ball at a load of 31.25 kg to avoid excessive indentation. The tensile properties of the composite specimens at room-temperature have been determined by a computer-controlled tensile testing machine, Hounsfield, Monsanto, H25KS/05, Surrey, England, at a strain rate $1.67 \times 10^{-4}/\text{s}$, following ASTM E8 for mechanical testing.

Dry sliding wear tests of the different cast in-situ composites and un-reinforced alloys have been performed under the ambient condition of relative humidity in the range between 40 and 60% and temperature between 17 and 25°C , using a pin-on-disc machine, manufactured by M/S. DUCOM, Bangalore, India. The experiments are conducted following ASTM G99-90 standard, using counter face of steel disk 316L/EN-32 hardened to 62–65 HRC. The contact surface of the pin is flat and polished using 1/0, 2/0, 3/0, and 4/0 grade emery papers before conducting the sliding wear test of the pin under five different loads of 9.8 N, 19.6 N, 29.4 N, 39.2 N and 49 N and a fixed sliding speed of 1 m/s.

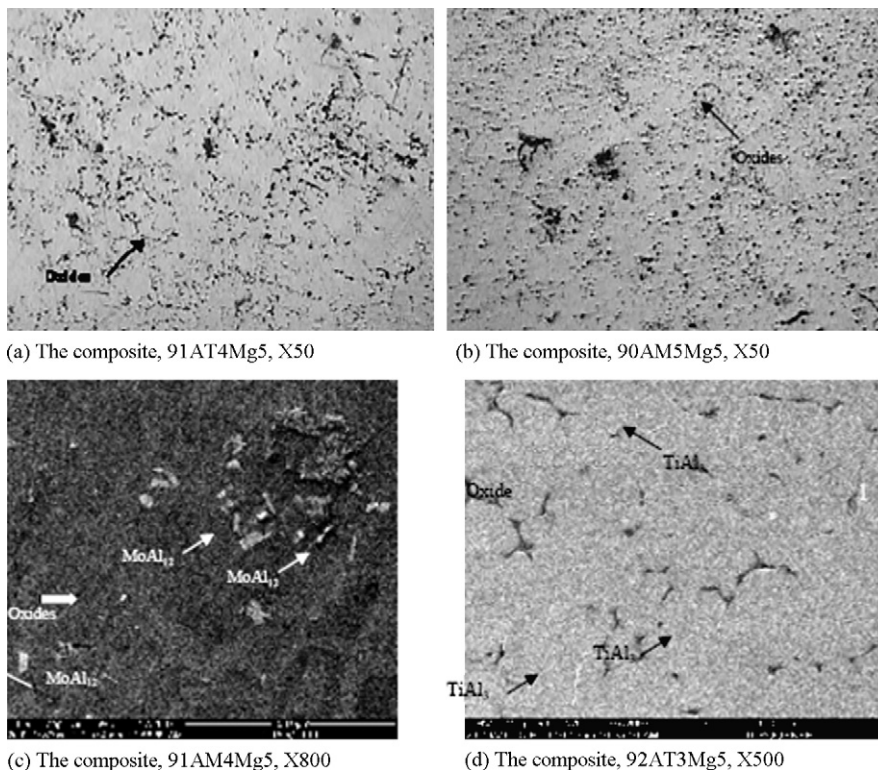


Fig. 1. Unetched optical microstructures of (a) 92AT4Mg5, (b) 91AM4Mg5 and the microstructures observed under FESEM of (c) 91AM4Mg5 and (d) 92AT3Mg5.

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