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Aluminium alloy–solid lubricant talc particle composites

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This paper describes the method of synthesizing cast aluminium alloy talc particulate composites and their mechanical and wear properties. Talc particles were characterized using X-ray diffraction, infrared spectroscopy and differential thermal analysis techniques. Composites with two Al–Si alloys (LM 13 and LM 6) as matrices were prepared by heating the molten alloys to 750° C and adding the preheated talc powder (− 150 + 50 μm size) after creating a vortex by mechanically stirring the melt. Simultaneous addition of 2 wt% Mg was found to facilitate the introduction and dispersion of talc particles in molten Al–Si alloys. Composites containing 2.8 wt% talc in LM 13 and 2 wt% talc in LM 6 have been prepared. Optical micrographs of composites revealed uniform distribution of talc particles. Hardness and tensile strength of LM 13 + 2.8% talc were 85 BHN and 126 MPa, respectively. After suitable heat treatment hardness and strength were increased to 125 BHN and 211 MPa respectively. Wear rates of LM 13 + 2.8 wt% talc and LM 6 + 2 wt% talc composites were found to be 22 to 30% less than the wear rates of corresponding base alloys without any dispersions.

1. Introduction

In recent years there has been an increasing trend to use solid lubricants over a broad range of applications. Suitable techniques to disperse solid lubricant particles in metals and produce metal–ceramic particle composites are also developed. A variety of lightweight aluminium alloy composites containing dispersions of graphite and mica have been synthesized using these techniques [1–3]. However there is no single material which can be regarded as a universal solid lubricant that can perform the desired functions of separating two moving surfaces under boundary conditions and decrease the friction and wear under all operating conditions. For example, graphite which is commonly regarded as one of the three best solid lubricants fails to act as a lubricant in vacuum. Therefore, there are continued efforts towards finding new solid lubricants and extending the scope of the known ones.

The objective of the present paper is to explore the possibility of using talc particles as dispersoids in aluminium alloys to achieve desired improvements in tribological properties. Talc belongs to the layered silicate (phyllosilicate) group of minerals in which one brucite ($Mg(OH)_2$) layer is sandwiched between two sheets of Si–O tetrahedra [4]. It has also been mentioned in the literature that adjacent talc layers are held together by weak Van der Waal type of forces and can slide over each other with considerable ease when a shearing action is applied to the mineral [4]. In addition to its layered structure talc is the softest material in Mohs scale, and can be ground to finer size with ease. Talc is inert to most chemical environments and is considerably less expensive as compared to graphite. Talc in essence has potential to be an ideal solid lubricant. With the above objective in mind, attempts were made to disperse talc in aluminium silicon alloys (LM 13 and LM 6) by the liquid metallurgy technique. Talc appeared attractive as a dispersoid for the liquid metallurgy technique since its density is very close to that of aluminium alloy melts. Mechanical and wear properties of these composites are described in this paper.

2. Experimental details

2.1. Material preparation

Chemical compositions of raw materials used in the preparation of composites are shown in Tables I and II. Talc (in ~ 25 cm lumps) was obtained from the Department of Mining and Geology, Madhya Pradesh, India. These lumps were ground in the laboratory to a finer size using a mortar and pestle. Talc powder was sieved and a − 150 + 45 μm fraction was used in the preparation of composites. Scanning electron micrographs of talc powder are shown in Fig. 1. Aluminium–silicon alloys (LM 13 and LM 6) were obtained from the Bharat Aluminium Company. The method employed to prepare aluminium alloy–

TABLE I Chemical composition of aluminium alloy LM 6 and LM 13

Element	(wt %)	
	LM 13	LM 6
Silicon	13.47	13.00
Copper	1.07	0.1
Magnesium	1.00	0.1
Iron	0.69	0.6
Manganese	0.50	0.5
Nickel	0.49	0.1
Aluminium	Rest	Rest

TABLE II Chemical composition of talc powder

Compound	(wt %)
SiO_2	48.88
MgO	29.10
CaO	5.99
Al_2O_3	1.90
Fe_2O_3	0.47
LOI	5.23
Moisture	0.05
Alkali metals	Rest

Chemical formula: $3\,MgO \cdot 4SiO_2 \cdot H_2O$.

talc particulate composites was similar to the one employed to prepare aluminium alloy–graphite composites [1, 2, 5]. Aluminium alloy was melted in a coke fired pit furnace. Talc was first heated to remove absorbed water and other volatile materials. This preheated talc was added to the aluminium alloy melt after creating a vortex by mechanical stirring. Addition of 2 wt % Mg was found necessary to facilitate uniform distribution of talc particles in aluminium alloy matrix. Composite melts were cast into cylindrical shape using cast iron permanent moulds. Composite samples were chemically analysed for talc content. It was found that when 4 wt % talc was added to the melt, 2.8 wt % was retained in the samples. Samples were metallographically examined to determine the particle distribution.

2.2. Material characterization

Talc powder was analysed using X-ray diffraction, infrared spectroscopy (i.r.) and differential thermal analysis (DTA) techniques. Talc was preheated to 1000° C and analysed in order to find out the thermal stability. Talc powder was also extracted from the final composite using standard chemical analysis procedures and X-ray diffraction was carried out on extracted talc in order to ascertain whether the talc particles had undergone any structural change during the preparation of composites.

Wear tests were performed using a standard pin on disc apparatus against EN 25 steel disc ground to a surface finish 1 μm central line average. Test samples were used in the form of 15 mm diameter cylindrical pins. The disc was rotated at a speed of 188 m min^{-1} and the tests were carried out with an applied load of 40 and 20 N.

LM 13 alloy–talc composites were heat treated by solutionizing at 510° C for 8 h followed by a 12 h ageing at 175° C. Ultimate tensile strength and hardness of the composites and base alloys were measured.

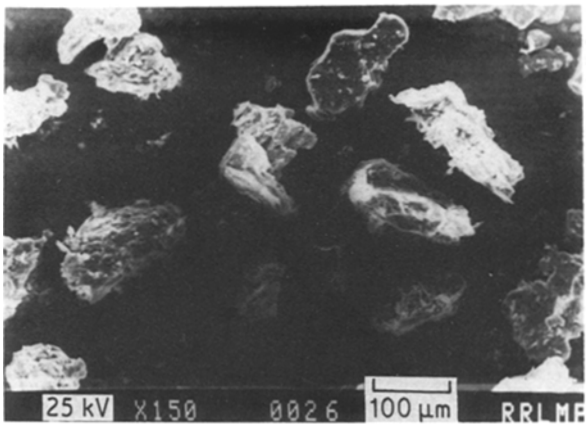

Figure 1 SEM micrograph of talc particles in as-received condition.

3. Results and discussions

3.1. Characterization of talc

Talc has a formula of $3\,MgO \cdot 4SiO_2 \cdot H_2O$ [4]. Composition and the type of impurities will vary according to the locality in which it was mined. It was therefore felt necessary to carry out complete characterization of the talc used in the present study.

X-ray diffraction data of talc powder in three different conditions (as received, extracted from composite and preheated at 1000° C for 2 h) is shown in Table III. Peaks were identified by matching with the standard peaks of talc and likely impurities from powder diffraction file. It can be seen from Table III that talc has the prominent X-ray diffraction peak corresponding to *d* values of 0.94, 0.469, 0.313 and 0.187 nm. The peaks corresponding to *d* values of 0.716 and 0.356 nm are most likely due to the presence of kaolinite. Kaolinite has a chemical formula of $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, and the chemical analysis of as-received talc has revealed 1.9 wt % of alumina, which indicates that kaolinite is the most likely impurity in the as-received talc. Kaolinite is most likely present in talc in free form; if it were associated with talc lattice two clearly identifiable peaks due to both talc and kaolinite would not have been possible. It is interesting to note that the X-ray diffraction data from the talc powder extracted from the aluminium alloy composite showed all the peaks due to talc. This indicates that talc did not undergo any transformation during the preparation of the composite material. The

TABLE III X-ray diffraction data of talc particles in three different conditions

2θ (deg)	*d* value (nm)	I/I_0			Identification*		
		As-received talc	Extracted talc from composite	Preheated at 1000° C for 2 h	Compound	*d* values (nm)	Plane
9.4	0.94	56	50	31	Talc	0.934	002
12.35	0.716	10	2	–	Kaolinite	0.718	001
18.9	0.469	16	14	7	Talc	0.466	004
25.00	0.356	12	1	–	Kaolinite	0.358	002
28.5	0.313	100	100	–	Talc	0.312	006
38.5	0.187	9	5	–	Talc	0.187	–

*From powder diffraction File No. 6–0221 and 13–558.

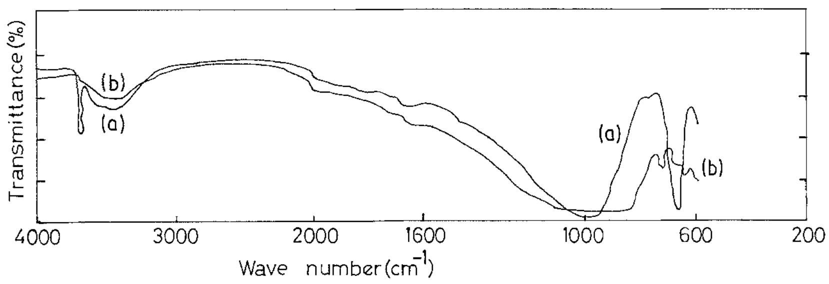

Figure 2 i.r. spectra of talc (a) in as-received condition and (b) heated to 1000° C.

diffraction data on extracted talc also showed much reduced intensity of peaks corresponding to kaolinite as compared to the diffraction data on as-received talc. It has been reported in the literature [6] that kaolinite dissociates at 600° C. This indicates that the kaolinite must have undergone decomposition during preparation of composite. Diffraction data on talc powder preheated to 1000° C indicate the absence of all the peaks due to kaolinite and some peaks due to talc. A few additional peaks corresponding to d values of 0.335, 0.318 and 0.289 nm were also observed and were identified to be due to enstatite. It has been reported in the literature [4] that talc undergoes decomposition beyond 850° C losing its combined water. This study indicates the need to control the temperature during the preparation of composites. I.r. spectrum of as-received talc (Fig. 2a) indicates the sharp absorption peaks at 3680 cm^{-1} corresponding to the hydroxyl OH group. Preheating of talc to 750° C did not produce any change in the i.r. spectrum. However, preheating of talc to 1000° C has resulted in the absence of the 3680 cm^{-1} (Fig. 2b) peak, indicating the loss of hydroxyl group. In all the cases the presence of absorbed water can be seen at 3440 and 1650 cm^{-1} in the i.r. spectrum. It can also be seen from Fig. 2 that radial changes were brought out by heating the talc at 1000° C as there are new peaks at 720, 670 and 640 cm^{-1}. Comparing the X-ray and i.r. data, it can be confirmed that talc undergoes a structural change by losing the hydroxyl groups upon heating to 1000° C. DTA curves of talc in as-received condition is shown in Fig. 3. The curve shows two endothermic peaks at 630 and 870° C. Since the presence of kaolinite in talc is detected from X-ray diffraction data the endothermic peak at 630° C (Fig. 3) can be attributed to the dissociation of kaolinite [6]. The second endothermic peak at 870° C can be attributed to dissociation of talc [4].

3.2. Properties of composites

Optical micrographs of a cast sample of the LM 13–talc composite are shown in Fig. 4a. It can be seen that the distribution of the talc particles in the matrix is fairly uniform. An SEM micrograph of the polished surface of the composite (Fig. 4b) showed good particle matrix interfacial bond without any interfacial porosity. It is also evident from Fig. 4b that talc particles can fragment during polishing. This would be beneficial in tribological applications where talc particles can fragment during sliding contact and reduce the metal to metal contact by spreading over a large area of the sliding surface. An SEM micrograph of a typical talc particle in as-received condition is shown in Fig. 5a. Layered structure of talc can be clearly seen from the micrograph. As mentioned earlier talc belongs to the layered silicate group of minerals [4] and adjacent talc layers are held with weak Van der Waal forces. Thus the layers seen in Fig. 5a can slide over each other when shearing action is applied during sliding contact. SEM micrograph of typical talc particle extracted from the composite (Fig. 5b) also shows similar layered structure after it was dispersed in aluminium alloys.

Hardness and tensile strength of LM 13 + 2.8 wt %

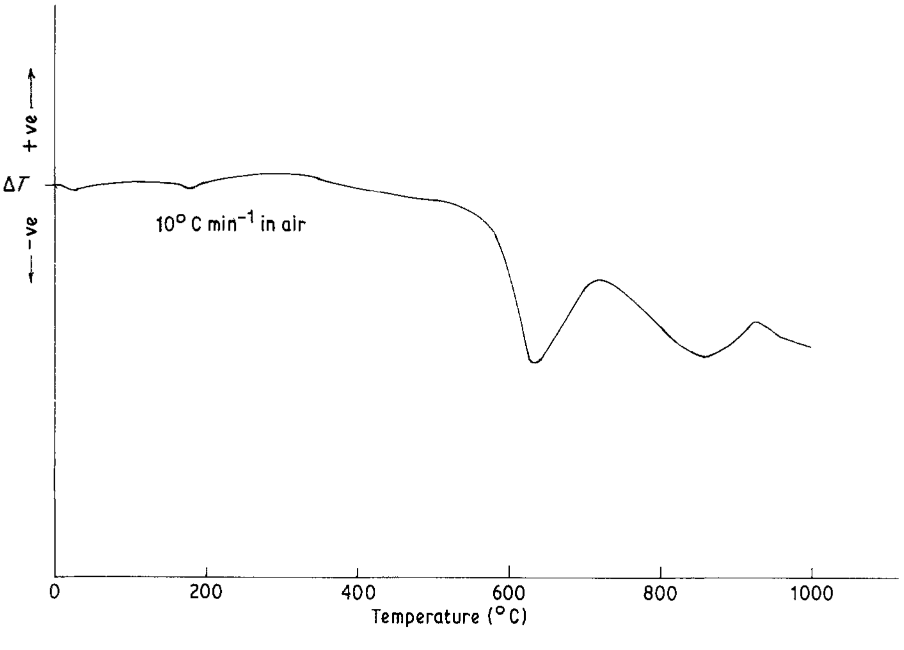

Figure 3 DTA curve of talc particles.

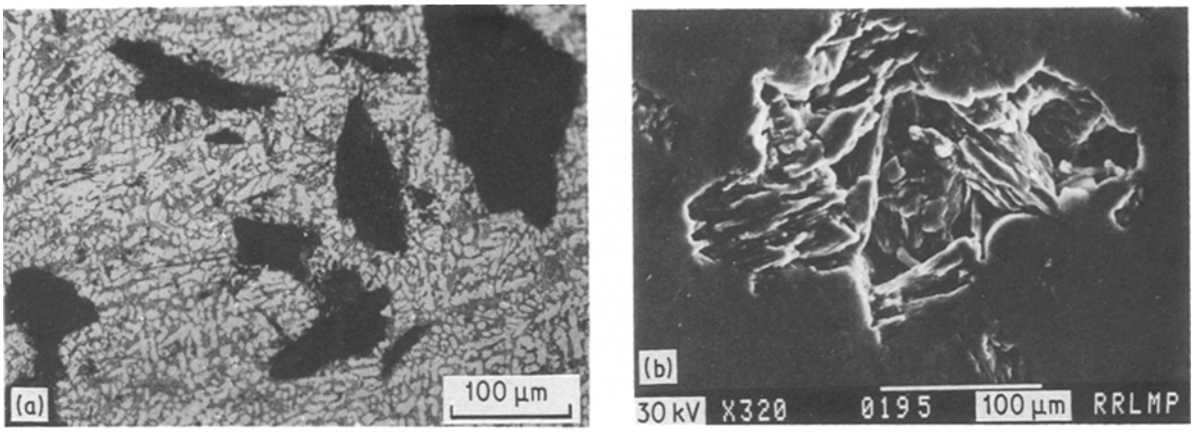

Figure 4 (a) Microstructure of LM 13–talc composite showing distribution of talc in the matrix. (b) A higher magnification micrograph of Fig. 4a showing the interface between talc and matrix.

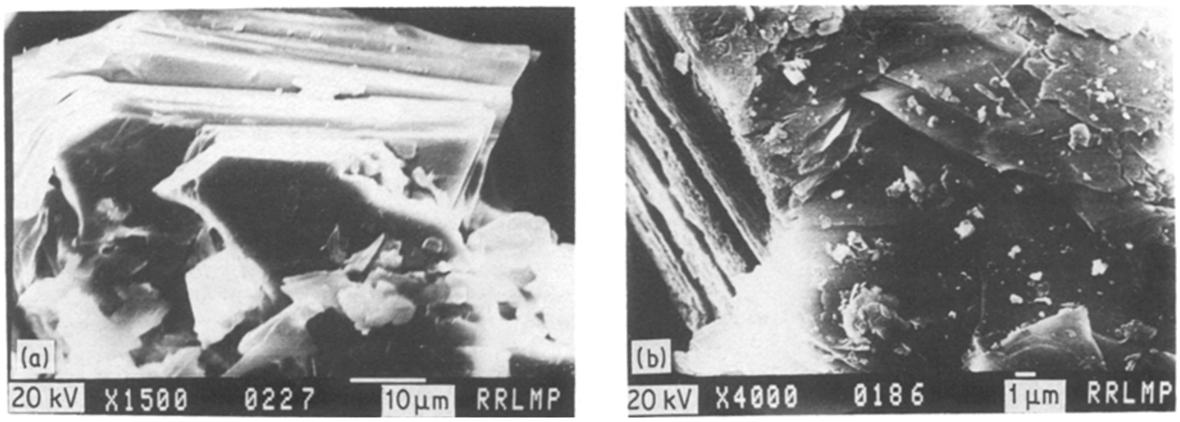

Figure 5 Higher magnification micrographs of talc powder showing layered structure of (a) as-received talc and (b) talc extracted from composite.

talc and LM 6 + 2 wt % talc are shown in Table IV. It can be seen that tensile strength of the LM 13 was reduced from 195 to 126 MPa with the incorporation of 2.8 wt % talc and the hardness was reduced from 90 to 85 HB. Similarly, the tensile strength of LM 6 was reduced from 190 to 130 MPa due to the addition of 2 wt % talc. LM 13 alloy composites were heat treated by solutionizing at 510° C for 8 h followed by a 12 h ageing at 175° C. It can be seen from Table IV that LM 13–talc composite responded to heat treatment like the base alloys, and the tensile strength of heat treated composites is comparable to the tensile strength of LM 13 in the as-cast condition.

Wear rates of composites and base alloys are shown in Fig. 6. It can be seen from the bar chart in Fig. 6 that the wear rate of LM 13 alloy was reduced from 1.853×10^{-3} to $1.437 \times 10^{-3}\,\mathrm{mm^3\,m^{-1}}$ with the addition of 2.8 wt % talc. This represents a decrease of about 22%. When the applied load was 40 N both LM 6 and LM 6 + 2 wt % talc composites siezed within a span of 5 min. Wear rates of LM 6 alloy and composites were measured at a reduced load of 20 N. It can be seen from Fig. 6 that 2 wt % addition of talc to LM 6 alloy resulted in a 30% reduction in wear rate.

TABLE IV Mechanical properties of Al-alloy–talc particle composites

Material	As-cast		Heat treated	
	Hardness (HB)	UTS (MPa)	Hardness (HB)	UTS (MPa)
LM 13 alloy	90	195	135	195
LM 13 + 2.8 wt % talc	85	126	125	211
LM 6 alloy	60	190	Not heat treatable	
LM 6 + 2 wt % talc	60	130		

4. Conclusions

1. Cast composites of aluminium alloy (LM 13 and LM 6) containing dispersions of 2.8 and 2 wt % talc particles (− 150 + 50 µm) have been synthesized by liquid metallurgy technique.

2. DTA of talc powder showed that the talc particles undergo structural changes at 870° C.

3. X-ray diffraction and SEM studies revealed that the talc particle retained its original structure (chemical and layered) when incorporated in the composite.

4. Tensile strength of LM 13 alloy was reduced from 195 to 126 MPa due to the addition of 2.8 wt % of talc particles. Tensile strength of heat treated LM 13 + talc composite was comparable to that of LM 13 alloy in as-cast condition.

5. Wear rates of LM 13 and LM 6 aluminium alloy talc composites were found to be 22 to 30% lower than the wear rates of corresponding base alloys when tested using pin-on disc apparatus against ground EN 25 steel disc.

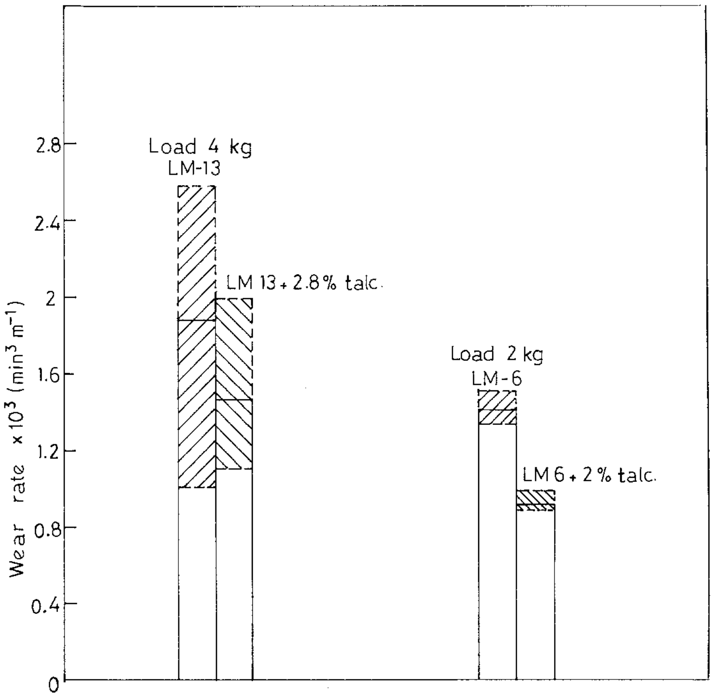

Figure 6 Wear rates of LM 13–2.8 wt % talc and LM 6–2 wt % talc particle composites and corresponding matrix alloys. Speed 188.52 m min^{-1}; distance 2.827 km.

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