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Preparation and properties of cast aluminium alloy-granite particle composites

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With a view to develop light weight, low cost and abrasion resistant material cast aluminium alloy composites dispersed with granite particles were prepared and their properties were evaluated. Natural mineral, granite was crushed and treated prior to its incorporation in the aluminium alloy. Liquid metallurgy technique was used to prepare composites involving the following steps: melting of aluminium alloy in graphite crucible, stirring of the melt, addition of granite particles and reactive metal in the melt and pouring the composite melt into permanent moulds. Physical, mechanical, tribological and metallographic properties of composites were studied. It was observed that there was reasonably uniform dispersion of granite particles in the matrix. Hardness and tribological (abrasive wear) properties of the base alloy improved considerably due to addition of the granite particles into it. This clearly indicates that these cast aluminium alloy based composites can be used as wear resistant materials.

1. Introduction

Amongst the metal matrix composites a large fraction of research and development work has been dedicated to aluminium alloy based composites. Due to ease of preparation, low processing cost involved and adaptability of a wide range of properties, cast aluminium alloy based composites have been a subject of great interest to the researchers and technologists. Such composites are prepared using different aluminium alloys as base alloys and a variety of materials viz. graphite [1–3], silicon carbide [4–6], alumina [7–10], zircon [11–12], etc. in fibre, whisker and particulate form as second phase depending on their applications and property requirements. Some of the criteria for the selection of the second phase is its cost and availability. Generally fibres and whiskers are expensive as compared to the particulates and there has been a tendency to use even less expensive particulates as reinforcement in large fraction to develop composites provided property requirement aspect is satisfied.

Some of the natural minerals are referred as industrial minerals which can be used for the purpose other than the extraction of metal from them. A significant value addition to these minerals can be realised through their use in engineering applications [13]. Use of such minerals as dispersoid in metal, ceramic and polymer composites is one of the potential applications. Talc [14], mica [15], bauxite [16], corundum [17] and silica sand [18] are some of the minerals which have been used in aluminium alloy to develop materials for suitable applications. Prime requisite for the use of natural mineral as dispersoid is its thermal stability and chemical compatibility at processing temperature of the aluminium alloy melt in addition to physical and mechanical properties. Granite is a silica base mineral available in considerable quantity in many regions of India and has potential to be used as dispersoid in aluminium alloy. The mineral consists of a number of oxides in different fraction varying from source to source and hardness value lies between 6–7 in Mohs scale. In the present study granite particulates have been characterised and 10 wt% of granite particles were dispersed in the aluminium alloy adopting liquid metallurgy technique. The composites were characterised for their properties with an emphasis on abrasive wear behaviour.

2. Experimental

2.1. Materials

Aluminum silicon alloy (BS LM6: Al - 13% Si-0.6% Fe - 0.5% Mn - 0.1% Mg - 0.1% Cu) was selected as the base alloy. Large ingots weighing approx. 25 kg each were cut into small pieces for accommodating them into crucible. Granite was used as dispersoid. Large lumps weighting upto 3–4 kgs were collected from the mine situated in Central India (Chhatarpur, M.P.), ground manually in a ball mill and sieved to particles of the size range 50–150 μm.

Chemical composition of the granite particles was obtained by wet chemical method. Granite particles were analysed using X-ray diffraction and thermal analysis. In order to examine the thermal behaviour of the granite particles differential thermal analysis (DTA) & thermogravimetric analysis (TGA) upto temperature 1000 °C were carried out. In addition, the particles were heated up to 1000 °C and X-ray analysis was carried out to see any changes in the phases.

2.2. Preparation of composites

Composites were prepared using an oil fired furnace. Aluminium alloy (20 kg) ingot pieces were heated in a graphite crucible to its molten state. Degassing of the molten metal was carried out by nitrogen after covering the melt with a flux (Trade name: coveral-11 supplied by M/s Greaves Foseco Pune, India). Melt was cleaned by taking out the dross collected on melt surface by a perforated flat spoon. After maintaining the temperature of melt between 750–800 °C vortex was created in the melt by using a mechanical stirrer. While the stirring was in progress, preheated granite particles (900 °C for 1 hr.) in 10 wt.% quantity were added slowly to the melt. Simultaneous addition of magnesium pieces (1wt.% of melt and in 20–30 gm lumps) was done to the melt to facilitate dispersion of granite particles in the melt. Stirring was continued for 5 minutes after completion of addition of granite particles in the melt. Test specimen castings in the shape of discs (thickness: 6.0 mm, diameter: 120 mm) and in the shape of cylinders (diameter: 18 mm, length: 150 mm) were preparaed by pouring the melt into the cast iron permanent moulds.

3. Property characterisation

Aluminium alloy and its composites were machined and cut to sizes for their property evaluation. Hardness measurement and metallographic study were carried out on small cylinderical specimens of 15 mm height and 15 mm diameter whereas wear test was carried out on disc specimens cut to a size of 40 mm × 35 mm × 4 mm. Tensile samples were machined from the ingots and tested in universal testing machine (Instron 1185 model) at a cross head speed of 2 mm per minute.

3.1. Metallographic study

Specimens were polished following standard metallographic techniques and etched with Keller's reagent for

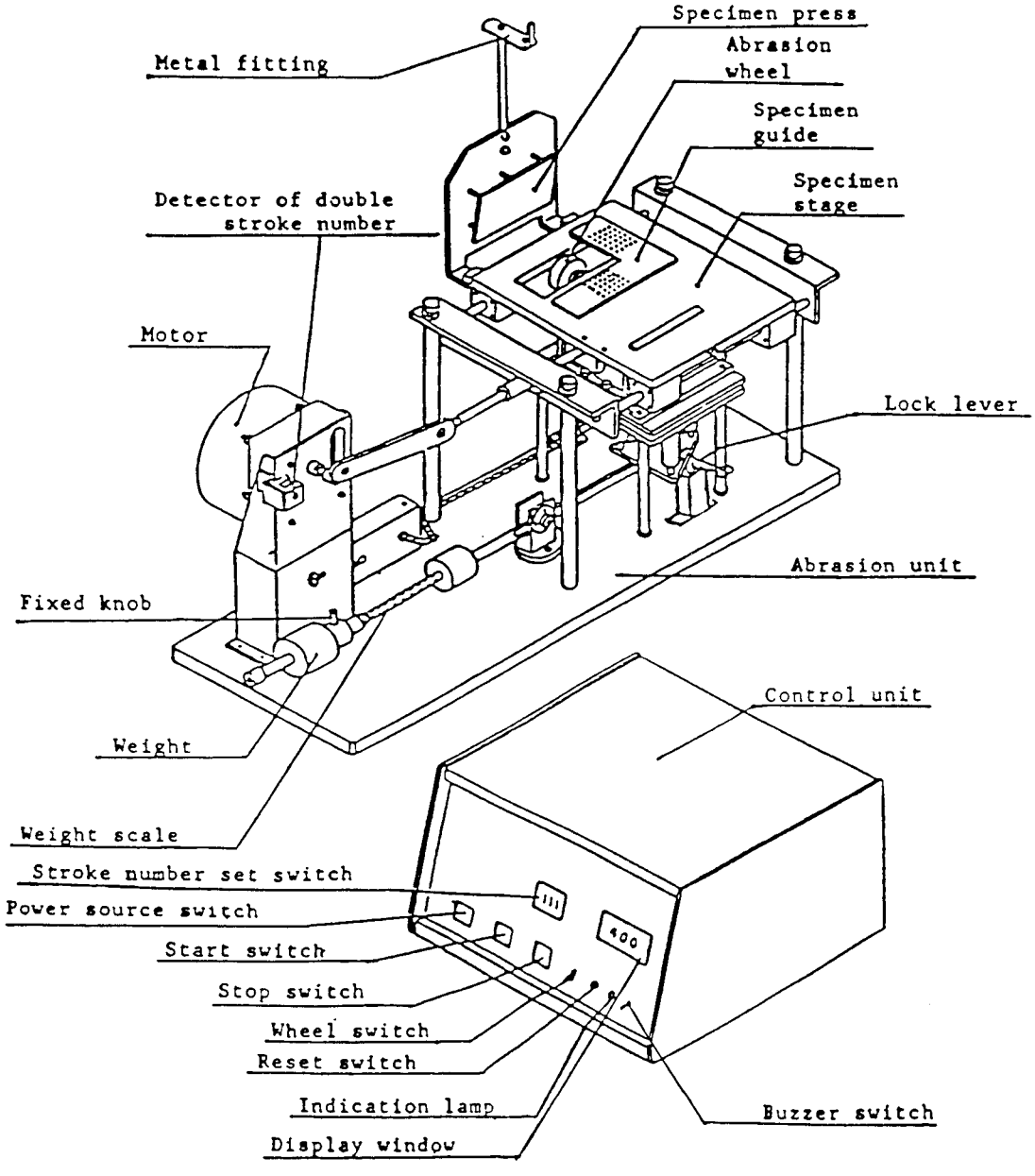


Figure 1 Schematic diagram of abrasion test machine.

microstructural examination. Worn surfaces were observed in SEM (35 CF Jeol make) after abrasion studies. Specimens were coated with a thin layer of gold before SEM study.

3.2. Abrasion wear test

High stress (two body) abrasion tests were conducted on $40 \times 35 \times 4$ mm rectangular specimens using a Suga make abrasion tester (model: NUS1, Japan). A schematic view of the abrasion test machine is shown in Fig. 1. Emery paper embedded with the desired size of SiC particles was cut to size and fixed on a wheel (diameter: 50 mm, thickness: 12 mm) to serve as the abrasive medium. The specimen was fixed with a loading arrangement against the abrasive medium. Load on the specimen was applied with the help of a cantilever mechanism. The specimens experienced to and fro motion while the abrasive changed its position by the time the specimen completed one cycle (corresponding sliding distance: 0.065 m); this enabled the exposure of fresh abrasive to the specimen surface in each cycle.

Weight loss of the specimen was measured after it completed 400 cycles (corresponding sliding distance: 26 m) under a given set of (abrasion) conditions. A Mettler microbalance was used for the purpose of weighing the specimens prior to and after the wear test. Wear rate was computed from weight loss data. The reported (wear rate) data in this investigation represent an average of three observations. Applied loads in this study were 1, 3, 5 and 7 N while selected abrasive particle sizes were 25 μm, 100 μm and 200 μm. The sliding speed was maintained at 0.04 m/s in each case. The specimens were cleaned prior and after the wear tests. The matrix alloy and the composite specimens were subjected to identical test conditions.

4. Results and discussion

4.1. Characteristics of granite particles

Chemical composition of granite is given in Table I.

Granite is a blend of minerals which includes quartz and feldspars (Microcline-max, Albite) as essential minerals. Fig. 2 shows the shape and size of the granite particles. It is evident from the Fig. 2 that the particles have sharp edges and angular shape. Histrogram of the particle size distribution (Fig. 3) shows that the maximum fraction of particles lies in the size range of 50 to 150 μm.

Fig. 4 shows the X-ray diffractogram of as received and treated (heated upto 1000 °C) granite sample. X-ray diffraction data of major peaks of as received and treated granite sample is listed in Table II. Peaks were identifed by matching them with standard peaks of quartz and feldspars (Microcline- max, Albite).

Differential thermal analysis (DTA) of granite sample carried out up to 1000 °C, showed an exothermic effect at around 593 °C (Fig. 5) It reveals that some internal changes have taken place while heating. The comparison of the DTA & X-Ray Diffraction results confirm more dissociation of aluminium silicates viz, microcline & albite leading to the liberation of more silica phase in the region 560 to 1000 °C (increase in X-ray intensity of quartz after heating, Table II). Thermogravimetric analysis (TGA) showed that there is no change in weight of the sample upto 1000 °C. Thus

TABLE I Chemical composition of granite sample

Constituents	Wt.%
SiO_2	65.74
Al_2O_3	22.97
Fe_2O_3	1.45
CaO	0.02
MgO	0.34
Na_2O	1.20
K_2O	8.28

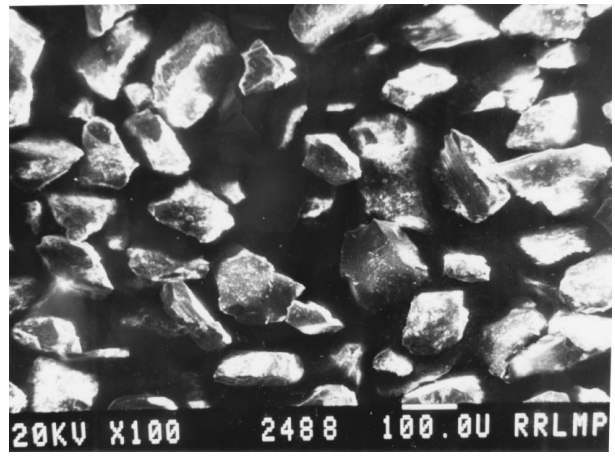


Figure 2 SEM micrograph of granite particles.

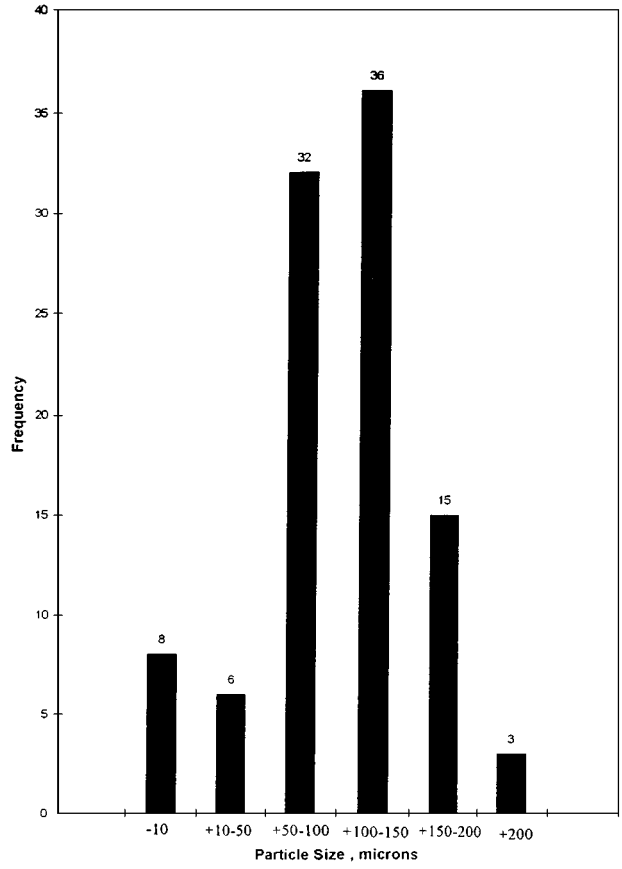
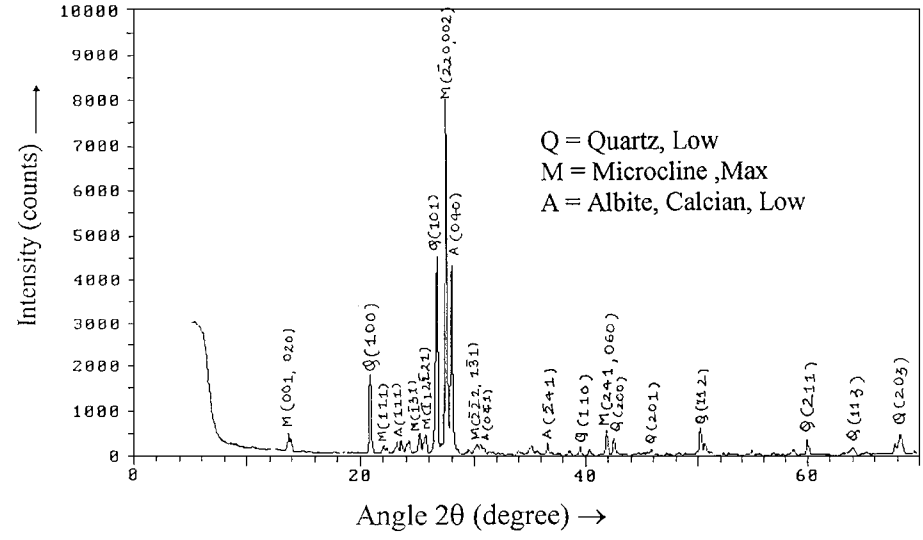
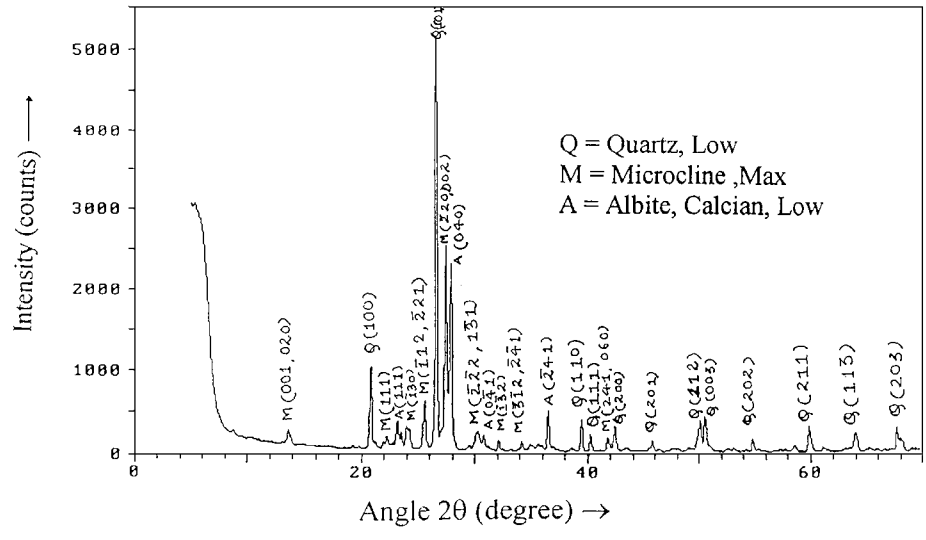


Figure 3 Histogram of granite particle size distribution.



(a)



(b)

Figure 4 X-ray diffractogram of (a) as received and (b) heat treated granite sample.

TABLE II X-ray diffraction data of granite sample

	I/I_o			Identification*	
d (Å)	As Received	Heat-treated	Compound	*d*-values	Plane
4.26	17.2	14.8	Quartz	4.26	100
3.48	4.8	10.6	Microcline- max	3.478	$\bar{1}12$, $\bar{2}21$
3.34	54.4	100	Quartz	3.343	101
3.24	100	49.5	Microcline- max	3.246	$\bar{2}20$, 002
3.19	54.4	45.2	Albite- calcian, low	3.18	040
2.28	3.4	10.3	Quartz	2.282	102
2.16	10.3	4.8	Microcline- max	2.16	241, 060

*From powder diffraction File Nos. 5-0490, 9-457, 22-687.

indicates that the granite sample was thermally stable upto 1000 °C (Fig. 5).

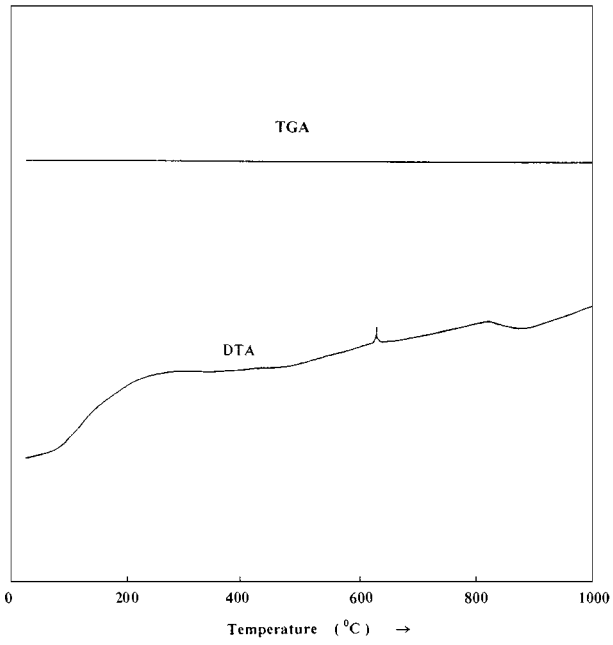


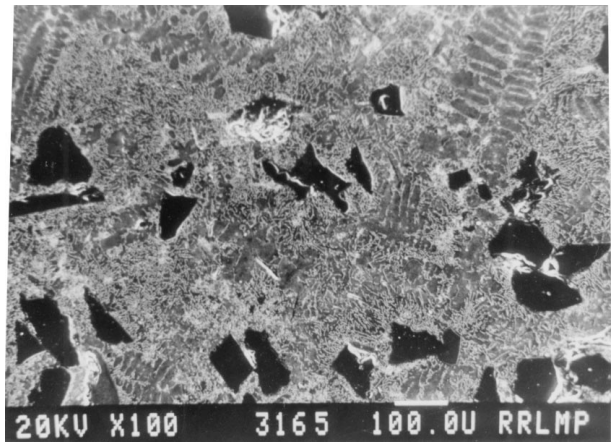
Figure 5 DTA & TGA curve for granite sample.

4.2. Properties of composites

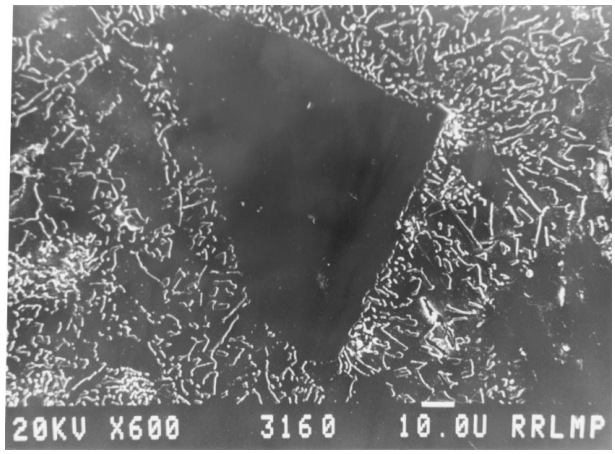
Metallographic examination of composite specimen shown in Fig. 6a revealed a reasonably uniform

TABLE III Mechanical properties of Al-alloy granite particle composite

Material	LM6 alloy	Composite
Hardness (HV)	57	71
Ultimate Tensile Strength (MPa)	132	105.3
% Elongation	2.25	1.75



(a)



(b)

Figure 6 (a): SEM micrograph of composite microstructure; (b): SEM micrograph of composite at higher mangification.

distribution of granite particles in the matrix. Higher magnification micrograph (Fig. 6b) of composite revealed the interface between the matrix and particle to be free from porosity. The mechanical properties of the matrix alloy and the 10 wt.% granite composite are shown in Table III. It can be seen from the table that the hardness of the matrix alloy has increased from 57 to 71 HV due to dispersion of granite particles in the matrix. However, the ultimate tensile strength has decreased from 132 to 105 MPa and percentage elongation has decreased from 2.25 to 1.75. The results are similar to Al alloy composites dispersed with other second phase particles [19].

Fig. 7 indicates the variation in wear rate with abrasive size at different applied loads of the base alloy and the composite. Wear rate of the aluminium alloy was more than the composite at all loads except at 7 N for coarser (200 μm) abrasives. At higher load (7 N) and for coarser (200 μm) abrasives the trend of wear

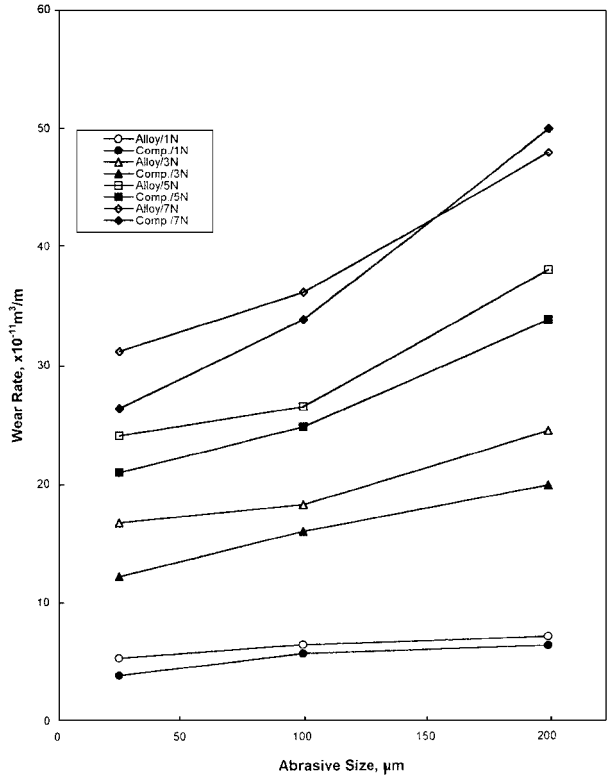
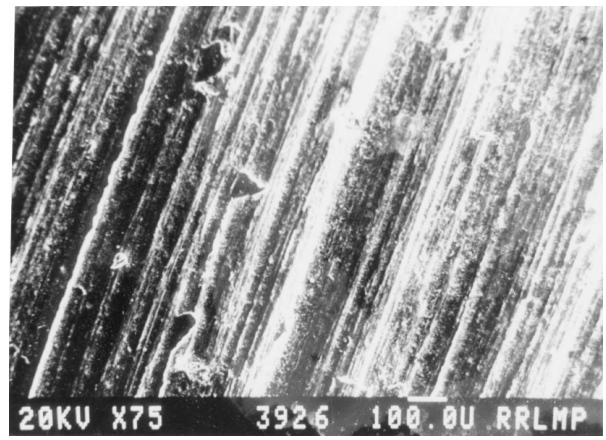
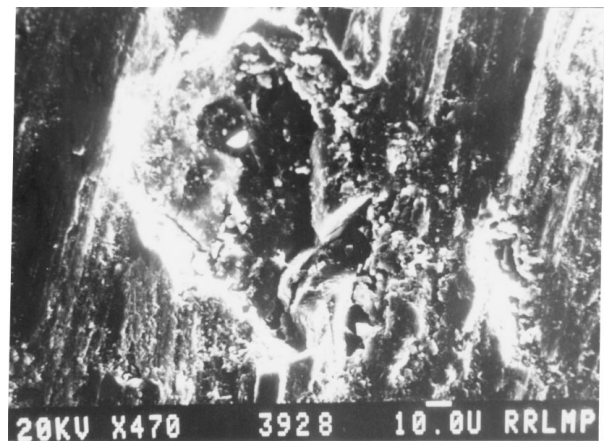


Figure 7 Variation of wear rate as a function of abrasive size at different applied loads for the alloy and the composite.



(a)



(b)

Figure 8 (a): SEM micrograph of the wear surface of composite showing presence of dispersoid particles on the wear track formed by coarser abrasives (at 1 N load); (b): SEM micrograph of the wear surface of composite showing particle fracturing due to coarser size abrasives (at 7 N load).

rate got reversed i.e. the composite was found to suffer more wear loss than the matrix alloy. Reduced wear rate of the composite over the matrix alloy with finer abrasive (25 μm) particles agree well with the considerably smaller size of the abrading particles than that of the dispersoid particles (50–150 μm). This could be attributed due to the smaller depth of cut made by finer abrasive particles than the size of dispersoids ultimately enabling dispersoids to protect the matrix [20, 21]. At higher loads the increase in wear rate of the composite was less than the base alloy due to an increased protection offered by dispersoid particles to the matrix. SEM micrographs of wear surfaces showed (Fig. 8a and b) the presence of dispersoid particles on the wear track. Contrary to the wear pattern at smaller abrasive size, the wear rates of the composite were higher than that of the matrix alloy at higher load when the coarser size abrasive used (Fig. 7). In such cases the depth of cut made by coarser abrasive particles exceeds the size of dispersoid particles. This leads to scooping of latter causing more severe material loss than the matrix alloy [20, 21]. Though the wear of the material takes place by cutting, wedging or ploughing action depending on the nature of the material and abrasion test conditions. The present study showed wear grooves formed in the ploughing and cutting action of abrasives (Fig. 8a and b).

5. Conclusions

The following conclusions may be drawn from the present study-

a. Cast composites consisting of aluminium alloy and 10 wt% of granite particles can be synthesised by liquid metallurgy technique.

b. Granite has got thermal stability and compositional properties to be used as dispersoid in aluminium alloy.

c. Hardness and abrasive wear properties of the aluminium alloy improved significantly by addition of the granite particles in it.

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