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Fluidity of mica particle dispersed aluminium alloy

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Cast aluminium alloy–mica particle composites were made by dispersing mica particles in a vortex produced by stirring the liquid Al–4 wt% Cu–1.5 wt% Mg alloy and then casting the melt containing the suspended particles into permanent moulds. Spiral fluidity and casting fluidity of the alloy containing mica particles in suspension were determined. Both the spiral fluidity and the casting fluidity of the base alloy were found to decrease with an increase in volume or weight percent of mica particles (of a given size), and with a decrease in particle size (for a given amount of particles). The fluidities of Al–4 wt% Cu–1.5 wt% Mg alloys containing suspended mica particles were found to correlate very well with the surface area of suspended mica particles. The regression equation for spiral fluidity Y (cm) as a function of surface area of mica particles per gram of spiral X ($cm^2 g^{-1}$) at 700° C was found to be $Y = 42.62 - 0.42X$ with a correlation coefficient of 0.9634. The regression equations for casting fluidity Y' (cm) as a function of surface area of mica particles per gram of fluidity test piece X' ($cm^2 g^{-1}$) at 710 and 670° C were found to be $Y' = 19.71 - 0.17X'$ and $Y' = 13.52 - 0.105X'$ with correlation coefficients of 0.9194 and 0.9612 respectively. The percentage decrease in casting fluidity of composite melts containing up to 2.5 wt% mica with a drop in temperature is quite similar to the corresponding decrease in the casting fluidity of base alloy melts (without mica). The change in fluidity due to mica dispersions has been discussed in terms of changes in viscosity of the composite melts. However, the fluidities of these composite alloys containing up to 2.5 wt% mica are adequate for making a variety of simple castings including bearings for which these alloys have been developed.

1. Introduction

Metals and alloys containing dispersions of non-metallic particles are generally referred to as metal base particle composites. Such composites can be made in the cast form by dispersion of non-metallic particles in a vortex created by stirring the liquid melt, and subsequently casting the melt containing the suspended particles into suitable moulds. Suspensions of solid particles in liquids are known to increase viscosity [1–3] and decrease fluidity [4] and they could impair the castability of these composites. Surappa and Rohatgi [5] have shown that the fluidity of molten Al–Si alloys containing dispersed graphite particles decreases with increasing amounts of graphite particles in the melt.

Cast aluminium–mica particle composites have recently been developed and have been shown to possess adequate mechanical properties as well as very good antifriction properties [6, 7]. These alloys have been successfully used as bearings under dry and semi-dry conditions without seizing. However, there is very little information available regarding the fluidity of melts containing dispersions of flake shape particles. The present paper describes the fluidity of Al–4 wt% Cu–1.5 wt% Mg–mica particle composites. Characterization of fluidity of aluminium–mica particle composite

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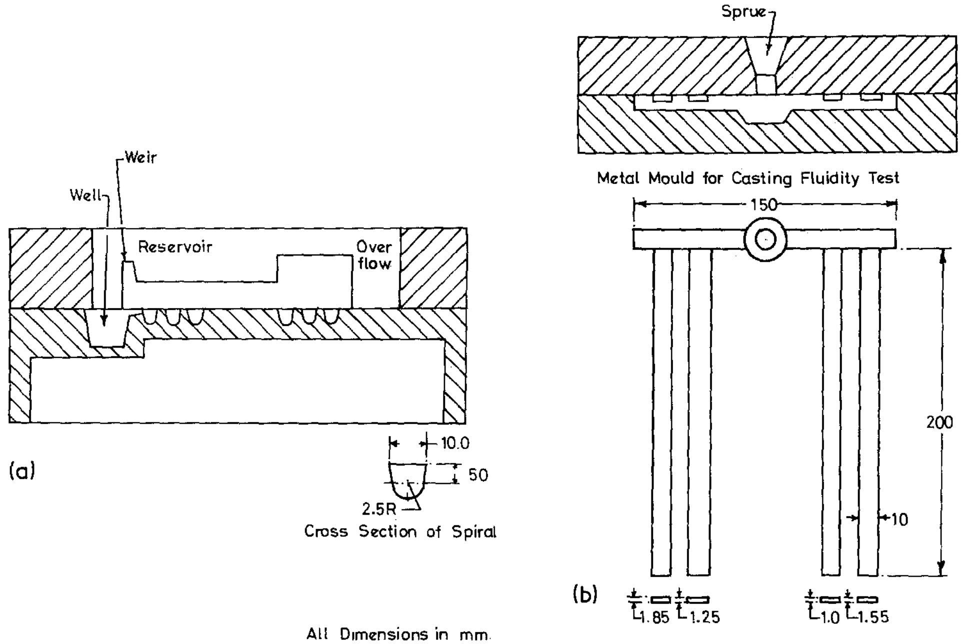


Figure 1 Standard casting fluidity and spiral fluidity cast iron moulds. (a) Standard mould and runner system with cross-section of spiral channel. (b) Details of test piece for casting fluidity.

alloys is important since it will determine the kinds of castings that can be made out of these alloys. The viscosity of these alloys with suspended mica particles will effect the rheocasting behaviour and die casting behaviour of these alloys.

2. Experimental procedure

Batches of about 3 kg aluminium alloy were melted in super salamander crucibles. The suspension of mica particles in the alloy was obtained by dispersing mica powder in a vortex created by stirring the molten alloy with the help of a mechanical stirrer as described elsewhere [6, 7]. Mica dispersed aluminium alloy melts containing different amounts of particles of different sizes were poured into standard casting fluidity and spiral fluidity cast iron moulds (Fig. 1) at different temperatures. Both types of fluidities were measured. The method of pouring and measurement of fluidities were the same as described by Seshadri *et al.* [4]. The solidified spiral and casting fluidity test pieces were machined and polished to observe the distribution of mica particles, since it was not possible to see the distribution of mica particles while the composite was molten. Some change is expected in the distribution of mica particles during solidification, especially on a microscopic scale due to pushing of mica by solid–liquid interfaces. It is easier to see mica particles on machined surfaces and during scanning electron microscopy of fractured surfaces [6, 7].

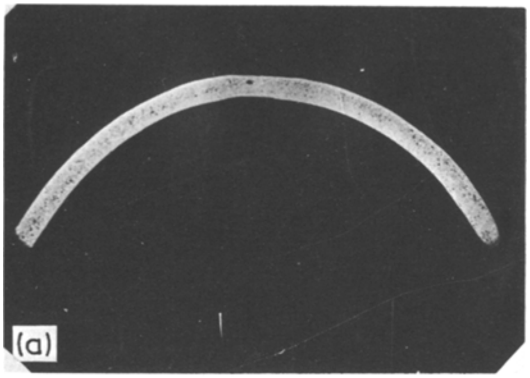
3. Results and discussions

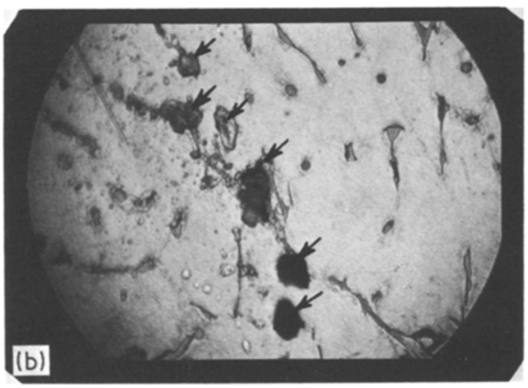
3.1. Spiral fluidity

A typical macrophotograph of a fluidity test spiral cast from an aluminium alloy–mica particle composite is shown in Fig. 2a; the distribution of mica is generally uniform except for agglomeration of a few particles and formation of some voids around some particles. Fig. 2b shows a microphotograph of the distribution of mica particles and Fig. 2c shows a scanning fractograph of the flake shaped mica particles. The length of fluidity spiral as a function of mica content is plotted in Fig. 3. The length of spiral test piece is also plotted as a function of surface area of mica particles present per gram of spiral in Fig. 4.

The measured values of surface area per gram of mica particles were used to calculated the surface area of mica particle per gram of fluidity spiral and casting fluidity test pieces. The equipment known as "permair", which works on the principle of permeability, was used to measure the surface area per gram of mica particles.

It is clear from Fig. 3 that additions of mica particles to Al–4 wt% Cu–1.5 wt% Mg alloys result in a decrease in the fluidity of molten





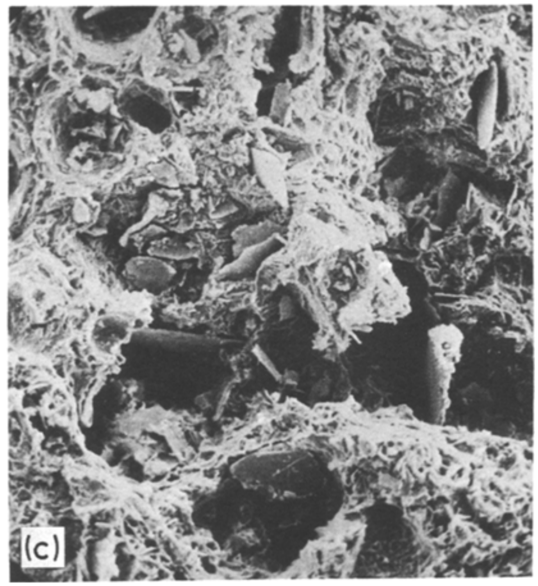


Figure 2 (a) Macrophotograph of a typical spiral fluidity test piece (machined) showing dispersion of mica particles (40 μm) in Al–4 wt% Cu–1.5 wt% Mg–2.2 wt% mica alloy at 700° C (the large hole in the centre was made for holding the piece during machining); (b) Typical distribution of mica particles on a microscopic scale; (c) Scanning picture of a fracture surface showing typical distribution of mica particles.

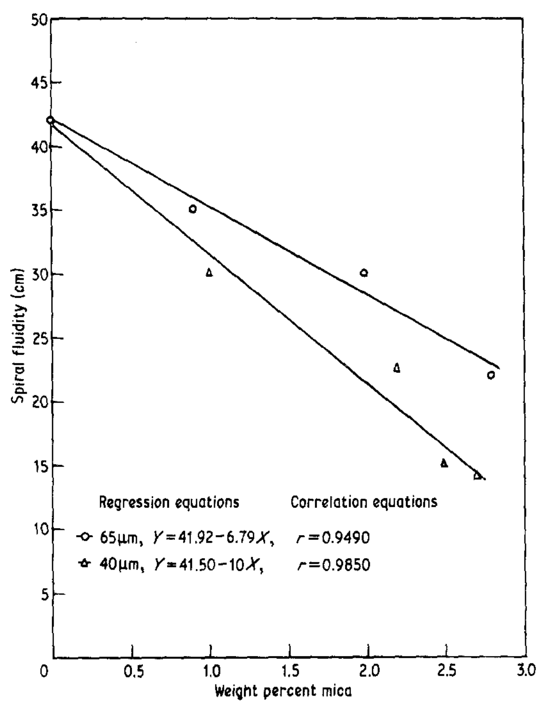


Figure 3 Spiral fluidity of Al–4 wt% Cu–1.5 wt% Mg–mica alloy as a function of weight percent mica for different particle sizes at 700° C.

aluminium alloys. Decrease in fluidity increases with increasing weight percentage of mica, for a given size of mica particles. The decrease in fluidity is more for a given volume percentage of finer particles, than for the same volume percentage of coarser mica particles. The decrease in fluidity of Al–4 wt% Cu–1.5 wt% Mg alloys due to addition of 0.9 wt% mica particles of average size 65 μm is 16%, whereas the decrease in fluidity of Al–11.8 wt% Si–1.25 wt% Cu by addition of 0.85 wt% graphite [5] is about 7.5%. Even though the base alloy compositions are different, this shows that there is a greater decrease in fluidity when a given weight percentage of mica particles is added compared to the case when the same weight percentage of graphite articles are added. This may be due to the fact that mica particles are plate shaped and have a greater surface area than granular graphite. The surface characteristics of mica and graphite particles are also different and these could also lead to different effects on fluidity.

The above results suggest that the decrease in fluidity of Al–4 wt% Cu–1.5 wt% Mg could be related to the total surface area of mica particles

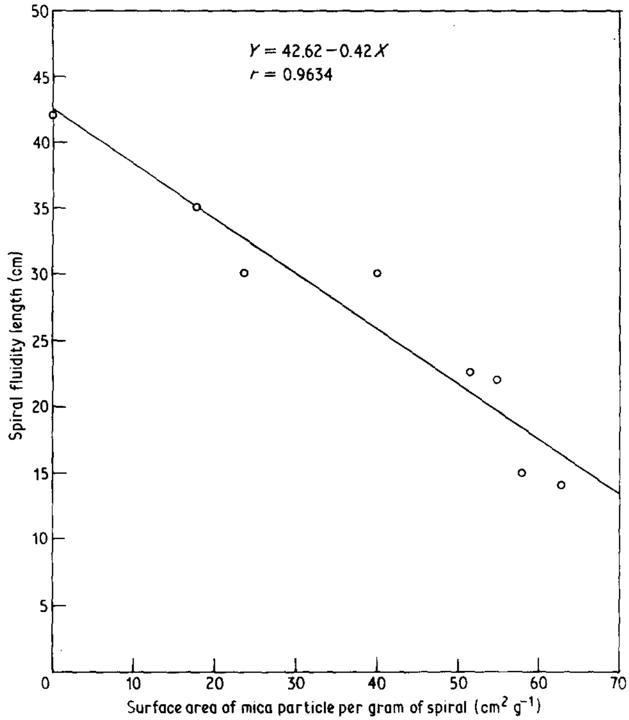


Figure 4 Spiral fluidity versus surface area of mica particle per gram of spiral at 700° C.

per gram of composite. The spiral fluidity as a function of surface area of mica particles per gram of composite shown in Fig. 4 indicates that the decrease in fluidity correlates well with the surface area of particles present in the spiral within the range of sizes and amounts investigated.

The increase in viscosity of fluids due to suspended particles has been reported for several non-metallic fluids [1, 2]. The presence of suspended insoluble particles in polymers has been reported to increase their viscosity. It has been shown that the viscosity of both metallic and non-metallic systems depends on the shape and size of the particles at a particular volume fraction of dispersoid [1]. Weltman *et al.* [2] found that for a fixed volume percentage of suspended particles, the viscosity rises with decreasing particle size. Nabularokayama *et al.* [3] have shown that the viscosity of solidifying aluminium–silicon alloy increases with decreasing size of primary crystals for the same volume fraction of solid. On the basis of their measurements of viscosity of glycerene methyl alcohol, containing polymer beads in suspension, they have shown that the viscosity increases with a decrease in particle size for the same volume fraction of particles [3]. Seshadri *et al.* [4] have also reported that modification of Al–12 wt% Si alloy results in decreased spiral fluidity which may be attributed to the increased viscosity, as reported by Jones and Bartlet [8]. Thus the literature suggests that the viscosity of a liquid containing particles in suspension, is also a function of size and shape, of the particles, in addition to the volume of particles present.

Viscosity of liquids containing ellipsoidal particles with plate like characteristics is given by Kuhn and Kuhn and shown by Lawrence [1] as

$$\eta = \eta_1\,(1 + 2.5\phi_2) + \frac{33}{15\pi}\left(\frac{1}{p} - 1\right)\phi_2$$

where η is the viscosity of fluids containing suspended materials, η_1 is the viscosity of the fluid without any particles, ϕ_2 is the volume fraction of suspended particles and p is the axial ratio of ellipsoidal particles.

For plate shaped particles we can take p as thickness to diameter ratio as a first approximation. Assuming* p is 1:15 for cut mica and

*The assumption of thickness to diameter ratio of particle as 1:15 is based on the measured surface area of 65 μm particle being nearly equal to the calculated area of the particle of the same size, when the calculation was made assuming thickness to diameter ratio as 1:15. It has also been reported [9] that wet ground mica has a thickness to diameter ratio of 1:25 and dry ground mica has a relatively lower ratio. During the present investigation, the powder was produced by cutting mica in air with a milling cutter and it is expected to have a thickness to diameter ratio considerably lower than 1:25.

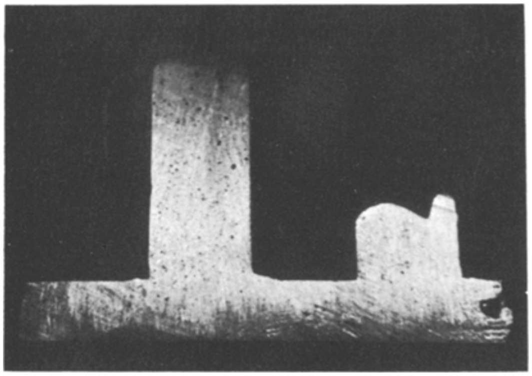


Figure 5 Macrophotograph of a typical casting fluidity test piece showing macroscopic distribution of mica particles in Al–4 wt% Cu–1.5 wt% Mg–1.4 wt% mica (120 μm) alloy at 700° C (× 0.25).

ϕ_2 is 0.02, the ratio $\eta:\eta_1$ according to the above equation is 1.227, suggesting an increase in the viscosity of the order of 22.7%. The measured decrease in fluidity due to the presence of 2 wt% mica particles (65 μm size, $p = 1{:}15$) comes to about 30% indicating that much of this decrease could be due to an increase in the effective viscosity of the alloys. These numbers are reasonably close to each other and part of the difference between them could be due to three reasons: (a) the equation by Kuhn and Kuhn is valid for ellipsoidal particles with plate like characteristics whereas in the present experiment thin mica flakes have been used, (b) the percentage increase in viscosity need not be exactly equal to the percentage decrease in fluidity and (c) in actual castings there is agglomeration of some particles and there may be formation of voids around some particles, whereas the calculation is valid for a perfectly homogeneous dispersion of particles.

3.2. Casting fluidity

The macrophotograph of a typical casting fluidity test piece is shown in Fig. 5. The distribution of mica particles is generally uniform, except for agglomeration of a few particles and formation of voids around some particles specially in the top part of the castings. However, the volume of such particles is of the order of 5% of the total number of particles. The remaining particles are apparently well distributed.

Fig. 6 shows the plot of length of casting fluidity test piece as a function of weight percent of mica particles at 670 and 710° C. Fig. 7 shows the casting fluidity as a function of surface area of mica particles present per gram of fluidity test pieces.

The dispersion of mica particles shown in the macrophotograph of casting fluidity test piece (Fig. 5) indicates that mica particles can travel along with the liquid metal, even in sections with a thickness as low as 1.0 mm. The observed effects of additions of mica particles on casting fluidity aluminium alloys (Figs. 6 and 7) lead to conclusions similar to those observed for spiral fluidity. The decrease in casting fluidity of Al–4 wt% Cu–1.5 wt% Mg alloys by addition of 1.7% of 65 μm average sized mica particles is 28% whereas the decrease of casting fluidity of Al–11.8 wt% Si–2.1 wt% Cu alloy by addition of 1.66% granular graphite particle is 15% [5]. This greater decrease in casting fluidity caused by additions of mica compared with the decrease caused by graphite may be due to the plate shaped morphology of mica with a higher surface area.

Figs. 4 to 7 also show that, as in the case of liquid alloys with no suspensions, the casting fluidity of composite alloys with suspended solid

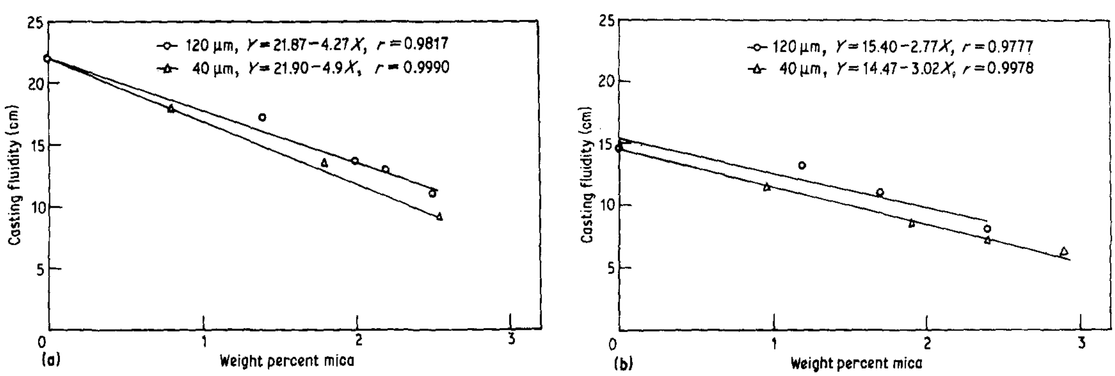


Figure 6 Casting fluidity as a function of weight percent of mica for different particle sizes (a) pouring temperature 710° C (b) pouring temperature 670° C.

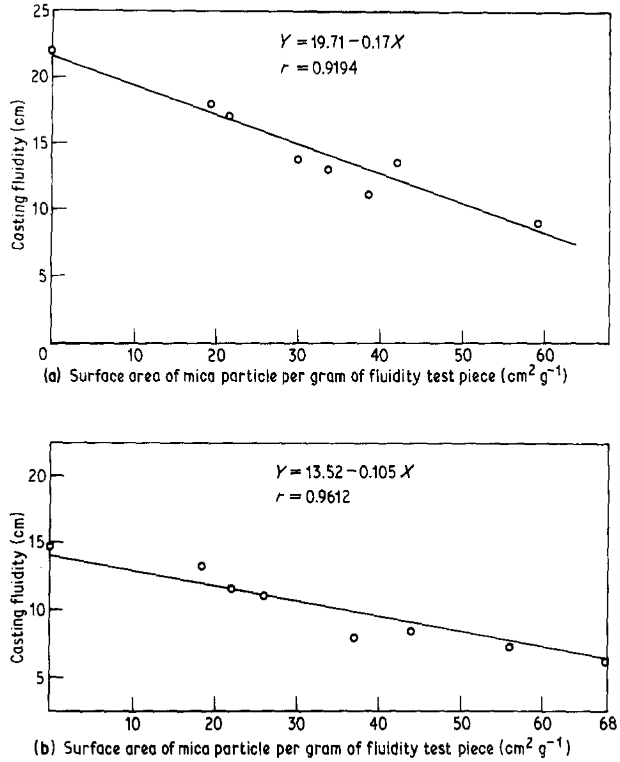


Figure 7 Casting fluidity as a function of surface area of mica particles per gram of fluidity test piece.

particles also decreases with a decrease in temperature. The decrease in casting fluidity of mica dispersed alloys with a 40° C decrease in pouring temperature is of the order of 28%. The order of decrease is similar to that observed in alloys with no suspended particles, as shown in Table 1. This implies that the mechanism of change in casting fluidity of the melts with temperature is not significantly altered by the suspended particles.

From the above discussions it is clear that both the casting fluidity and the spiral fluidity of Al–4 wt % Cu–1.5 wt % Mg alloy decreases as a result of increase in the amount of suspended mica particles. However, up to the level of 3 wt % mica particles, investigated in this study, the fluidity values (casting fluidity 10 cm at 710° C for 120 μm particle, spiral fluidity 22 cm at 700° C for 65 μm particle) are adequate for making a variety of castings. This was borne out by actual experiments in which it was possible to make acceptably sound castings of different sizes using mica dispersed aluminium alloy melts containing different amounts of mica particles. Fig. 8 shows a macrophotograph of a typical bearing casting made from this alloy which has been successfully tested for antifriction applications.

It also shows mica in the form of dots on the machined surfaces [6, 7]. Some of these dots are quite large as a result of agglomeration and segregation of some particles (the staining around the particles also increases the size of dots). However, the volume of such particles is quite small compared to the particles which are uniformly distributed. This is borne out by the fact that the typical densities of cast composites are of the order of 2.594 g cm^{-3} and they possess adequate mechanical and tribological properties. The density of the mica particles is quite close to the density of liquid alloys, therefore the volume percent of mica particles would be almost the same as the weight percent of mica generally used in this paper.

TABLE I Percentage decrease in casting fluidity of Al–4 wt % Cu–1.5 wt % Mg alloy mica particle composite as a result of decrease in "pouring temperature" from 710 to 670° C

mica (wt %)	Percentage decrease in casting fluidity	
	40 μm size particle	120 μm size particle
0.00	28.00	28.00
0.80	–	29.00
0.95	32.00	–
1.50	28.50	26.00
2.00	–	27.00
2.50	26.00	31.00

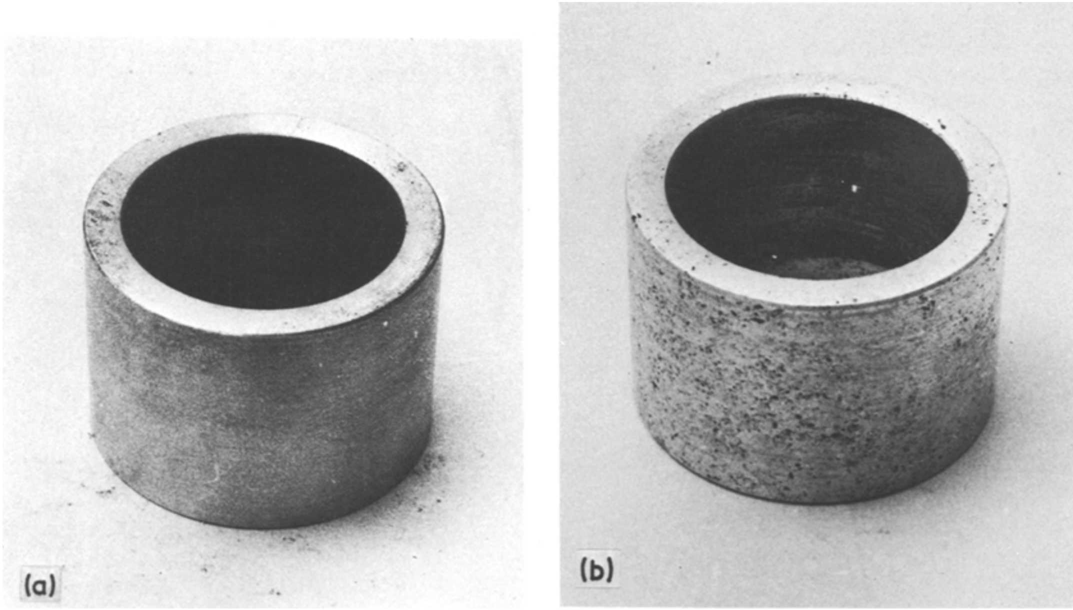


Figure 8 (a) Macrophotograph of a typical bearing casting of the base alloy Al–4 wt % Cu–1.5 wt % Mg. (b) Macrophotograph of a typical bearing casting of Al–4 wt % Cu–5 wt % Mg–1.5 wt % mica composite after a successful bearing test.

It was also possible to make a 6 kg casting of dimensions 250 mm x 160 mm x 55 mm from Al–4 wt % Cu–1.5 wt % Mg–2 wt % mica alloy and a 150 mm x 125 mm x 12.5 mm thick casting from Al–4 wt % Cu–1.5 wt % Mg–3 wt % mica alloy. Likewise, Fig. 5 also suggests that even 1 to 2 mm thick castings can be produced from these alloys. It has already been demonstrated in an earlier paper [6, 7] that these castings have adequate mechanical and tribological properties for a variety of bearing and other antifriction applications.

4. Conclusions

(1) Both the casting fluidity and the spiral fluidity of mica dispersed aluminium alloys decrease with increasing amounts of mica particle (of a given size) and decreasing size of the particle (for a given amount of particles) within the range investigated.

(2) Both the spiral fluidity and the casting fluidity were found to correlate well with the surface area of mica particles suspended in the melt. The regression equation for spiral fluidity Y (cm) as a function of surface area of mica particles per gram of spiral (cm^2 gm^{-1}) at 700° C was found to be $Y = 42.62 - 0.42\,X$ with a correlation coefficient of 0.9634. The regression equation for casting fluidity Y' (cm) as a function of surface area of mica particles per gram of fluidity test piece X' (cm^2 g^{-1}) at 710 and 670° C were found to be $Y' = 19.71 - 0.17\,X'$ and $Y' = 13.52 - 0.105\,X'$ with correlation coefficients of 0.9194 and 0.9612 respectively.

(3) Casting fluidity of aluminium alloys containing suspended particles decreases with a decrease in temperature in a manner similar to fluidity of molten alloys without any suspended particles.

(4) Though the fluidity of aluminium alloy mica particle composites decreases with the amount of mica, the values of casting fluidity and spiral fluidity of alloys containing 2 wt % mica appeared adequate to make a variety of castings. This has also been borne out by experiments where a variety of sound castings of aluminium alloy–mica particle composites have been made.

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