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STUDIES ON CONTROL OF MICA PARTICLE DISTRIBUTION IN ALUMINIUM ALLOY-MICA PARTICULATE COMPOSITES.

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ABSTRACT

A mechanically stirred Al-4wt% Cu-1.5% Mg-mica particulate composite was solidified in a variety of moulds under different heat flow conditions and particles (41µm diameter and 3.8µm thick) in suspension were observed. There was floatation of mica particles before and during solidification resulting in a cast structure with non-uniform distribution of dispersed mica particles as well as mica-segregated and denuded zones.

The use of bottom chilling and/or low pouring temperatures were found to minimize mica segregations in relatively thick castings. A homogeneous distribution of mica particles was found to be possible in thin castings of about 12.5 to 3mm. The composite is a good candidate for tribological applications.

***Keywords**: Mica; Aluminium Alloy-Mica Particulate Composite*

1.0 INTRODUCTION

Particulate composites made from mica particles dispersed in metallic matrices have been found useful for antifriction applications (1-4). These composites have been conventionally fabricated through the costly powder metallurgy technique which can only produce simple shapes of smaller components (5, 6). It is much cheaper to fabricate particulate composites using casting techniques than the powder metallurgy process. It is also very possible to produce large, intricate and complicated components by casting.

The production process entails dispersing fine particles in the molten alloy and casting it into suitable moulds. Such cast composites are characterized by macro and micro segregation of the particles in the region that solidified last. This has been attributed to the particles' movement during solidification (6).

Several factors such as fluid convection due to momentum of pouring and thermal gradients, floatation of lighter particles, Flocculation of particles and particle rejection by the moving solid-liquid interface, are responsible for the segregation (7-9).

In this work, efforts were geared towards establishing how these factors determine the particle distribution in the metal matrix. Suitable controlling measures as well as solidification parameters (thickness of casting, pouring temperature, and application of chills etc) were employed to develop cast composites with uniform mica particles distribution.

2.0 EXPERIMENTAL TECHNIQUES

2.1 Materials used: A commercial pure aluminium of 99.7% purity (containing about 0.3wt % total of iron and silicon as main impurity) obtained from Tower Aluminium (Nigeria) Ltd. was used in this work. The copper is of electrolytic pure grade and the magnesium is of reagent grade. The mica particle is of fine grade (41 µm diameter and 3.8µm thick).

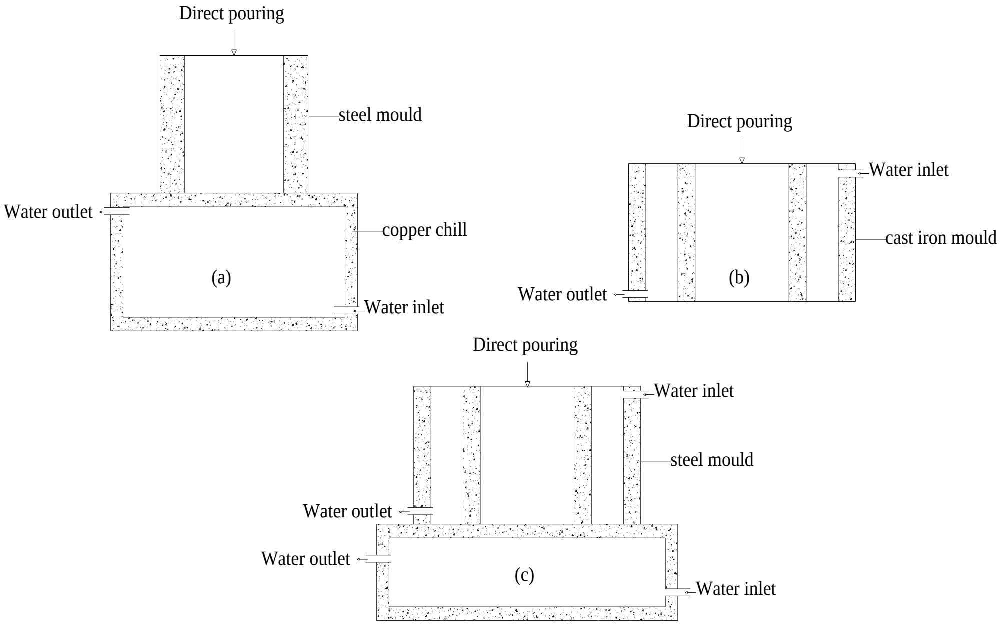


Figure 1: Permanent moulds with different chilling arrangements. (a) Steel mould with water- cooled copper chill at the bottom. (b)Cast iron mould water-cooled from the sides. (c) Steel mould water-cooled from the bottom as well as from the sides.

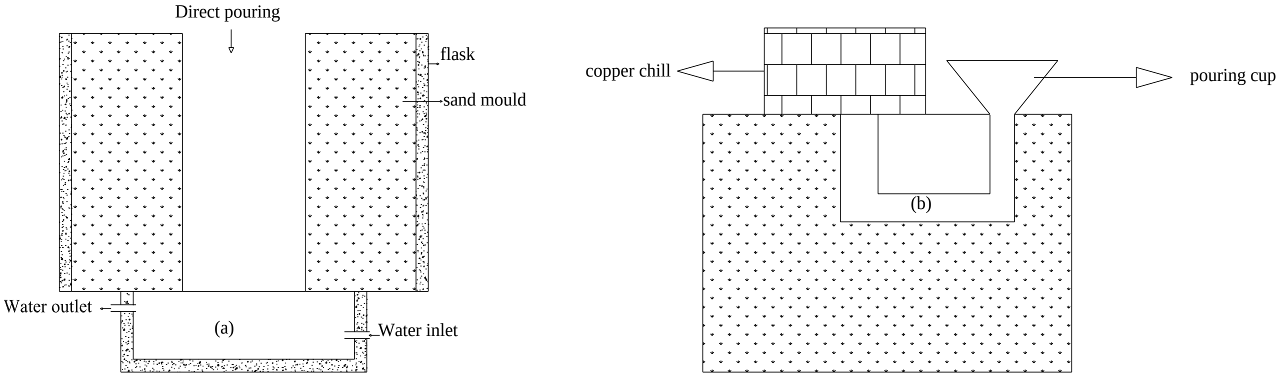


Figure 2 : Sand moulds with chilling arrangements as follows: (a) top poured mould with water- cooled copper chill at the bottom; (b) bottom-poured mould with water- cooled heavy copper chill at the top

2.2 Mould Preparation: Different mould media were employed to develop various moulds used in this study in order to achieve the following.

(i) *Moulds developed to obtain a uniform distribution of mica particles in the composite.*

(a) A steel mould as shown in Fig 1 (b)

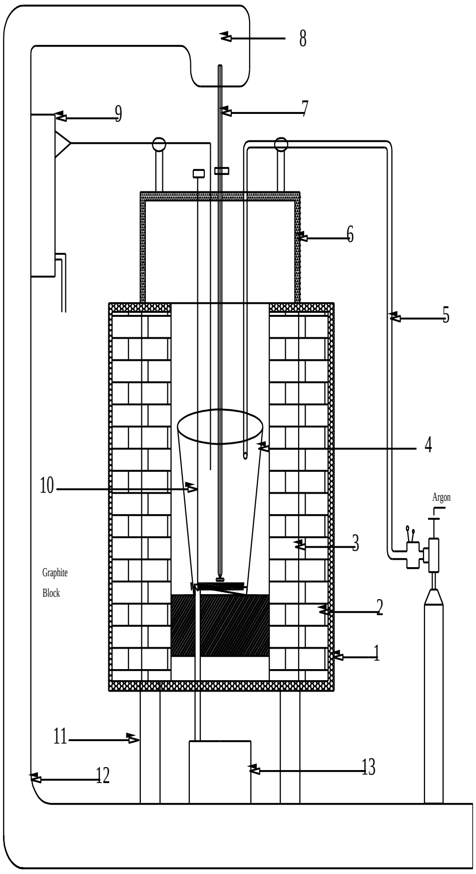
(b) A cast iron plate mould with a 13mm x 130mm x130mm cavity and 30mm wall thickness.

(c) A cast iron plate mould with 60mm x 160mm x 165mm cavity and 40mm wall thickness (pouring temperature 665^{0}C)

(ii) *Moulds developed to study the floatation and segregation of mica particles*

(a)A steel mould with 75mm internal diameter, water-cooled from the sides as shown in Fig 1 (a)

(b) Cast iron moulds with 5mm and 65mm internal diameter, 5mm wall thickness and 210mm height



1. Electric Resistance Furnace
2. Insulation Brick
3. Refractory Brick
4. Clay-Graphite Crucible
5. Gas pipe
6. Furnace cover
7. Stirrer
8. Electric motor
9. Temperature Controller
10. Stopper Mechanism
11. Stand
12. Carrier
13. Mould

Figure 3: The sketchmatic diagram of melting furnace with arrangement for gas purging and stirring mechanism for the melt.

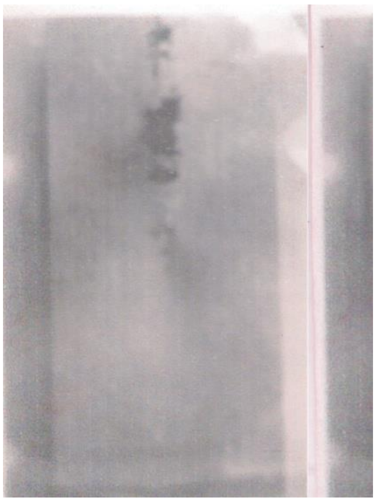


Figure 4: Macrograph of a longitudinal section of cast aluminium alloy-mica composite cast in 55mm diameter cast iron permanent mould (x0.95).

Figure 5: Micrograph showing voids resulting from the peeling off of mica particles in aluminium alloy-mica composite (x230).

Figure 6: SEM Micrograph of the tensile fracture surface of cast aluminium alloy-mica composite showing voids formation at the matrix-particle interface (x300).

Figure 7: Macrograph of longitudinal section of cast aluminium alloy-mica composite poured in a bottom water-cooled copper chill sand mould showing how mica particles floated to the top portion of the casting (x0.90)

Figure 8: Macrograph showing a longitudinal section of cast aluminiumalloy-mica composite poured in a top heavy copper chilled sand mould in which mica particles segregated to the top (x0.90).

Figure 9: Macrograph of a longitudinal section of cast aluminium alloy-mica composite poured in a side water-cooled permanent steel mould showing mica denuded zone at the central portion of the casitng (x0.80).

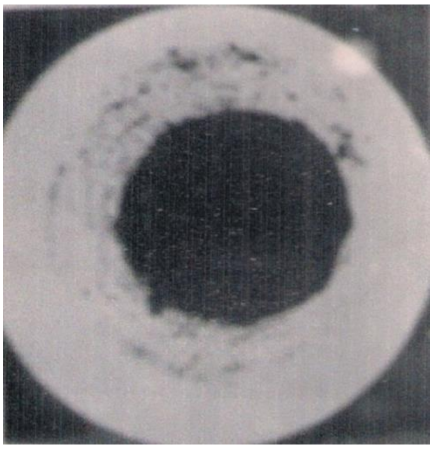


Figure 10: Macrograph of a radial section of cast aluminium alloy-mica composite cast on a centrifugal machine, showing mica particles at the periphery of the casting.

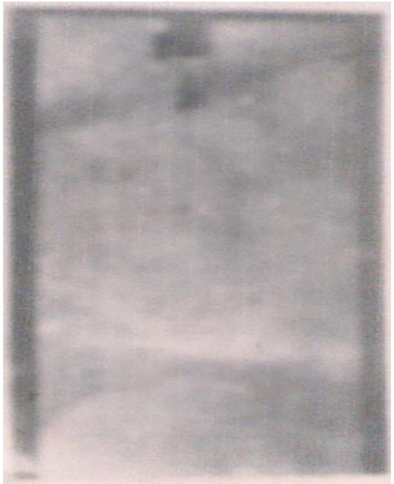


Fig. 11 Macrograph of a longitudinal section of aluminium alloy-mica composite poured at 705^{0}C in a bottom water-cooled as well as side water-cooled steel mould, showing even distributions of mica particles in the casting (x0.60).

Figure 12: Macrograph of vertical section of aluminium alloy-mica composite poured at 665^{0}C in a 60mm x 165mm x 250mm cavity and 40mm wall thickness cast iron mould, showing mica particles homogeneously distributed in the alloy matrix (0.85).

Figure 13: Macrograph of a longitudinal section of 13mm thick plate of cast aluminium alloy-mica composite showing homogeneity of mica particles in a thin casting.

(c) A cast iron rotating mould mounted on top of a rotating disc (centrifugal casting machine)

(d)Sand moulds with cooling arrangement as shown in Figs 2(a) and (b) were bottom poured and had a pouring cup, the upper level of which was 85mm above the top of the mould cavity.

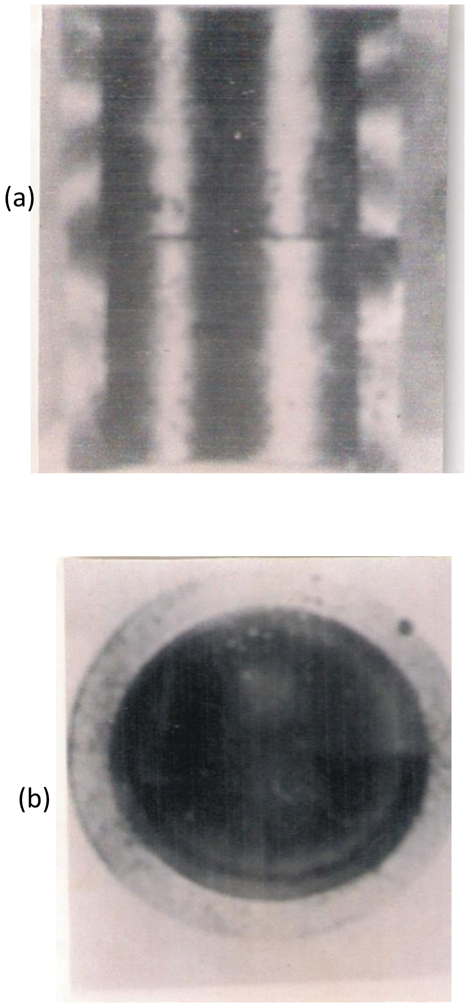


Figure 14: Macrographs of (a) longitudinal, and (b) transverse sections of a bearing made of cast aluminum alloy-mica composite solidified in a central steel core permanent mould (x1.50).

2.3 Melting and casting

A 25kg master alloy of Al-4wt% Cu was developed from the aluminium and copper procured. The master alloy was divided in batches of 3kg and properly cleansed of dirt and oil. An electrical resistance crucible furnace was preheated to about 350^{0}C and a 3kg Al- 4wt% copper alloy was carefully charged into graphite crucible. The furnace has provision for in- situ gas purging and mechanical stirring of the melt as shown in fig.3. The alloy was heated to about 700^{0}C and degassed by bubbling argon gas into it. The melt was mechanically stirred at about 950r.p.m. for 80 seconds during which pieces of magnesium and 2.0 wt% mica powder were added to the vortex created by the stirring. After the mica powder and magnesium addition, the stirring continued at a lower speed of 450 r.p.m. with the degassing for 60 seconds. The stirring mechanism was removed, and the melt stirred again by hand with a graphite rod and immediately poured into the moulds at about 710^{0}C. Eight different heats of the composite were made and 20 samples cast.

2.4 Metallography

After solidification, the composite castings were sectioned, machined, ground and polished to obtained smooth mirrow- like surfaces. The samples were etched in kellers solution and examined under a low magnification microscope.

3.0 RESULTS AND DISCUSSION

Most of the mica particles segregated towards the upper portion of the cast composite solidified in the permanent moulds as can be seen in the macrograph of fig.4. Mica denuded zone was observed at the central bottom portion of the casting up to the shrinkage cavity, after which a decrease in the particle- free zone was noticed towards the surface of the casting. The segregation was due to the floatation of mica particles in the aluminium alloy melt. There is partial wetting of mica particles by liquid aluminium leading to poor bonding between the mica particles and the aluminium alloy matrix. This poor bonding also resulted in low strength of the composite and peel- off of the mica particles during metallographic grinding and polishing, fig. 5. Under tensile loading of the composite, its strength drastically reduced because of the poor bonding between the aluminium alloy matrix and the mica particles giving rise to formation of voids at the matrix- particle interfaces as could be seen in fig. 6.

In the experiments conducted to investigate the segregation tendency of mica in the cast composite, it was noticed that heat dissipation during solidification of composite in sand mould having a heavy copper chill at the bottom occurred in a direction opposite to the buoyancy force on mica particles. The macrograph of the longitudinal section of this casting, fig 7, showed that the mica particles floated to the top portion. In another experiment where the heavy copper chill was at the top of the sand mould in a bottom poured casting, the maximum direction of the heat dissipation coincided with that of buoyancy forces. This implies that while the particles floated upwards, the solidification front moved downward. It was observed in the macrograph of this section, fig 8, that mica particles segregated near the top. In applications where only one surface is subjected to tribological conditions, castings with mica segregation near the top, fig 7 and 8 are good candidates. In the next casting where the composite solidified in a steel mould with water-cooling from the sides, maximum heat extraction occurred radially. This implied that the direction of mica floatation was perpendicular to that of maximum heat extraction. In the macrograph of the longitudinal section of this composite, fig 9, mica particles were present up to the bottom along its circumference, whereas there is mica denuded zone at the central portion of the composite casting at the bottom. When the mica-denuded zone was measured from the bottom of the casting, its maximum height was found to occur at the centre and eventually decreased progressively as one moved toward the periphery.

In the cast composite the last region to solidify is the centre where there was sufficient time for mica particles to float up at this portion. This casting can be transformed into a plain bearing if the pipe and the central mica denuded zone is machined out. It could be seen from the macrographs of figs. 7 to 9 that growing dendrites were not responsible for the pushing of mica particles. Heat diffusivity criteria for the entrapment of particles by a moving solid- liquid front was proposed by Surrapa et al (4). They observed that in systems in which the factor $[\lambda_p C_p \varrho_p / \lambda_L C_L \varrho_L]^{1/2} > 1$ (where p is particle, L is liquid, λ is thermal conductivity, C is specific heat, and ϱ is density), the particles were captured by the moving solid-liquid front whereas particles are rejected for systems in which this factor is less than unity.

The heat diffusivity criteria in this aluminium alloy-mica composite system may be valid under conditions where factors like body forces are not overriding the effects of heat flow as well as when there are very slow growth rates(4). Some extraneous factors such as flocculation as well as convection apparently seem to be of overriding importance.

It was also necessary in this work to investigate the influence of centrifugal force on the floatation of mica particles. The composite cast on a rotating disc served this purpose. Fig. 10 shows a macrograph of the radial section of composite cast on a rotating disc (centrifugal casting machine) in which mica particles were moved to the periphery where it is needed for tribological applications. The cast composite of fig 10 depicts segregation of mica towards the inner periphery thereby making it a suitable candidate for bearing applications. The outer mica-denuded zone has strength equal to that of the matrix alloy and as such offers a good backing materials to the matrix.

Reduction of the solidification time of the casting helps in minimizing the mica segregation giving rise to casting with uniform distribution of mica particles in the matrix. This is realizable through pouring medium thickness castings at low temperatures; using bottom and side chilling for large castings, using cores in cylindrical castings to reduce the thickness to be solidified; and generally developing relatively smaller thickness castings. Fig. 11 depicts a macrograph of longitudinal section of 75mm diameter aluminium alloy-mica particulate composite cast in a bottom water-cooled and side water – cooled steel mould. Mica particles distribution was substantially improved as it could be seen throughout the section up to the bottom of the casting which otherwise could have been mica-denuded region up to the shrinkage cavity.

A macrograph of a vertical section of aluminium alloy –mica particle composite poured at 665^{0}C in 60mm x 150mm x165mm diameter cavity cast iron plate mould with 40mm wall thickness is shown in Fig 12. The mica particles were homogeneously distributed in the alloy matrix due to increased viscosity of the melt resulting from the low pouring temperature and reduced solidification time. The macrograph of the longitudinal section of 13mm thick plate of aluminium alloy – mica particulate composite shown in Fig 13 suggests how homogeneity of dispersed mica particles in the alloy matrix can be achieved through thin casting. A 30mm wall thickness cast iron mould was used to pour the casting at 705^{0}C and its solidification time was about 12 seconds. Reduction in solidification time as well as homogeneous distribution of particulate matter can also be achieved by use of a central core. A bearing of aluminium alloy – mica particulate composites produced in this way is shown transversely and longitudinally in fig 14 (a) and (b). A permanent mould with 50mm internal diameter and 30mm wall thickness and a central steel core of 30mm diameter coated with a clay-graphite mixture was used to pour the casting. Fig.4 showed a reverse of this i.e a non-cored produced casting obtained in a steel mould, and having non – uniform distribution of mica particles.

CONCLUSIONS

Mica particles segregated toward the top in alumimium alloy – mica particulate composite castings due to their floatation. Segregation of mica particles in thick castings can be minimized by the use of chills as well as pouring the castings at low temperature. In smaller section castings uniform distribution of mica-particles is also achievable. Castings where mica particles segregated near the top can find applications where only one surface is subjected to tribological conditions. Generally this composite can be developed as a good candidate for bearing applications.

REFERENCES

1. Metals Handbook – 9th Edition Vol. 7 Powder Metallurgy, American Society for metals (1984) Pg. 356.
2. M. E. Belitskii, Sov. Powder Metallurgical Ceramic 6 (1969) Pg. 472
3. V. F. Afanas et al, Fiz. KhimMekahn Materials 5 (1969) Pg 680
4. M. K. Surappa and P. K. Rohatgi, Journal of Materials Science 16 (1981) 562
5. Lenel, F. V. Powder Metallurgy – Principles and Application MPIF 1980 Pg 157
6. Hausner, H. H. Handbook of Powder Metallurgy, Chemical Publishing Corp. 1973 Pg 403
7. Tsunekawa, Y.;Okumiya M. Yoneyama, K. Niimi, M.; Yoneyama, K; Niimi, I. Centrifugally Cast Aluminium Matrix Composite Containing Segregated Alumina Fibres. Journal of Materials Science Letters Vol. 7 n 8 1988 Pg. 830.
8. Delannay, F.; Froyen, L.; Derugttere, A. Wetting of solid by Molten Metals and its Relation to the Preparation of metal – matrix Composites. Journal of Materials Science Vol.22 n1 Jan 1987 Pg. 1-16
9. Gungor, M. N.; Gornie, J. A.; Flemings, M. C. Response of Microstructures of Metal Matrix Composites to Solidification Time. Interfaces in Metal- MATRIX Composites Proceedings of a symposium of the Metallurgical Society 1986 New or leans LA USA Pg 124