Study of hardness and tensile behaviour of Fe_2O_3 reinforced Al-Cu alloy metal matrix composites by stir squeeze casting

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ABSTRACT

Keywords:
MMCs,
Hematite,
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The processing of metal matrix composites (MMCs) by casting process is a very promising way of manufacturing near net shape composites at relatively low cost. The liquid metallurgy stir, squeeze casting technique has the characteristics such as fine microstructure as a result of rapid cooling, low porosity and good bonding between the particles and base alloy. Hematite is a common iron oxide with a formula called Fe_2O_3 and has been widespread in rocks and soils. Hematite forms in the shape of crystals through the rhombohedral lattice system, and it has the same crystal structure as lmenite and corundum. The paper presents the results of experimental investigation on mechanical properties of Fe_2O_3 particle reinforced aluminium metal matrix composite. The influence of 3, 6, 9 and 12wt% Fe_2O_3-p reinforced on mechanical properties was examined and the outcome of the tests revealed that hematite particles can be successfully used as a reinforcement material and it does not deteriorate the properties. The increase in hematite particle percentage and high squeeze pressure resulted in high density of the compact, thereby increasing compression strength, tensile strength and hardness of the composite. The results also showed that for the same base alloy the squeeze cast shows higher hardness, tensile and compression strength compared to the gravity cast base alloy. Squeeze cast composites exhibit higher hardness tensile and compression properties by increasing weight percentage of reinforcements. The microphotographs of squeeze cast samples shows uniform dispersion of the reinforcements in MMCs with good bonding between the matrix and reinforcement.

1. Introduction

The physical and mechanical properties of Aluminium-based metal matrix composites (MMCs) have made them attractive materials for automotive and aerospace applications [1-3]. Cost is the key factor for their wider application in modern industry, although potential benefits in weight reduction, increased composites life and improved recyclability should be taken into account [4-5]. Even today MMCs are still significantly more expensive than their competitors. Cost reductions can be achieved only by simpler fabrication methods, higher production volumes and cheaper reinforcements [6-11]. Compared with permanent - mold casting, mechanical properties of the alloy prepared by squeeze casting are much higher [12-17]. Micro particulates are very economical because of their low prices and easy dispersion during fabrication. The micron particle reinforced Al matrix composites own the potential commercial use for its relatively low cost and good mechanical properties. Among various discontinues disperoids used, hematite (Fe_2O_3) is one of the several iron oxides with a rust-red streak, most inexpensive, harder than iron and very brittle reinforcement available in large quantities [18-20]. Addition of Fe_2O_3 particle as reinforcement in MMCs is advantages for obtaining higher structural homogeneity with minimum possible porosity levels, good interfacial bonding, higher mechanical strength and act as a load bearing constituents [21-22]. Many authors reported that Al-Cu alloy accelerates the

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age-hardening and also the stiffness, hardness, tensile strength, compression strength, flexural strength, fatigue strength and abrasive wear resistance are all substantially improved together with addition of hard reinforcements [23-26]. To meet the requirements of today's situation, advancements of materials has been the prime focus and more and more newer materials have been developed to satisfy the present day needs. In the present investigation an attempt has been made by considering Al-Cu alloy as base matrix, casted by both gravity and squeeze casting. Different weight percentage of Fe_2O_3 particulates is reinforced by squeeze casting route. The liquid casting mainly squeeze casting is preferred as it is the simplest, cheapest and persuadable to mass production. The samples obtained were tested for hardness tensile and compression strength. Microphotographs using scanning electron microscope (SEM) has been carried out to investigate the particle-matrix interface.

2. Experimental Work

In the present work, squeeze casting system was constructed to produce specimens. A die and plunger was designed and made of cast iron for die, and tool steel for plunger. Melting of base alloy, degassing and additions of particulates were performed in an electrically resistance heated furnace. Graphite crucible was used for melting of matrix alloy, and the addition and mixing of particulates were made into the melt in the crucible. For squeeze casting operations a constant 130MPa pressure was used for unreinforced matrix alloy and the composites. Al-Cu alloy was additionally produced by a gravity die casting method into a cast iron mould heated to around 350°C to compare the properties with squeeze cast unreinforced alloy. Al–Cu alloy was chosen as matrix alloy because of its widespread commercial applications. Four composites were produced by introducing Fe_2O_3 particulates with 3, 6, 9 and 12wt% to the Al–Cu matrix with the particle size varying between 24 and 36μm shown in Fig 1.

A stir casting setup which consisted of a resistance furnace and a stirrer assembly is used to synthesis the composite. Al-4.5wt.%Cu alloy commercially prepared was melted in a resistance heated muffle furnace and casted in a clay graphite crucible. The temperature of the melting is increased to 750°C and it is degassed by cleansed with hexachloroethane tablets. Then the molten metal was stirred to create a vortex and the reinforcements were added. The stirrer is maintained approximately 450rpm. The preheated Fe_2O_3 were slowly added into the melt with Mg (0.4wt.%) were also added to ensure good wettability of particles. Graphite lubricated die and plunger were preheated to 450°C to avoid premature chilling. Solidification was carried out under the pressure of 130MPa for a period of 60 to 120 seconds immediately after stirring. Composites produced were subjected to T6 heat treatment as the base metal is age hardening. The castings were heated to 450°C for 12 hours, quenched in 100°C water and reheated to 150°C for 16 hours. Specimens of the unreinforced matrix alloy were also squeeze cast under identical conditions. Furthermore, a sample of the unreinforced matrix alloy was produced by gravity die casting in order to determine pressure effects of composites. Squeeze casting specimens and unreinforced matrix alloys produced by both gravity and squeeze were cut to prepare samples for mechanical tests and metallographic examinations. The chemical

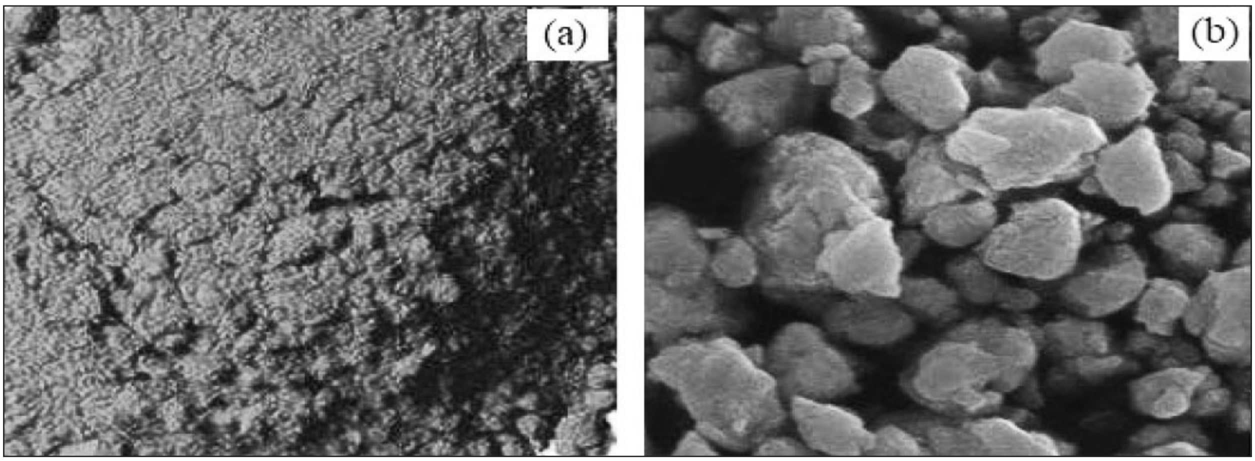

Fig.1. Hematite (a) Photograph of Fe_2O_3, (b) SEM of Fe_2O_3 (24-36 microns).

composition of samples casted is shown in Table 1.

The hardness measurement was carried out using a Brinell hardness tester. Tensile test samples having 6mm diameter with a gauge length of 25mm, were prepared for testing in Tensometer. The Compression strengths were determined using a computerized UTM with an electronic extensometer as per ASTM E-8 standards. Online plotting of load versus extension was done continuously through a data acquisition system. Scanning Electron Microscopy (SEM) of the composite after casting was examined to study the effect of Fe_2O_3 percentage on polished section of each sample.

3. Results and Discussions

3.1 Hardness

Comparing the hardness of both gravity and squeeze casting of base alloy and composites, it was found from Fig. 2 that by increasing the wt% of Fe_2O_3, the hardness of composite gradually increased. The squeeze casting of base alloy exhibit higher hardness when compare to gravity casting. The gravity casting exhibit a hardness of 82BHN and the same alloy when squeezed to a pressure of 130MPa has a hardness of 96BHN which is almost 14% increase in hardness of squeezed specimen. Application of pressure during solidification in squeeze casting minimizes porosity and makes the matrix to resist plastic deformation rendering higher hardness [8]. The hardness of composites increases with increasing percentage of Fe_2O_3 with a peak value of 143BHN for 12wt% reinforcements. This may be due to combined effect of denser matrix and hard ceramic particle during squeeze which gives homogeneous crystal structure. The dendrite arms were broken down and fine-grained equiaxed microstructure will obtained by squeeze casting.

3.2 Tensile strength

The influence of Fe_2O_3 particulate content on the Ultimate tensile strength (UTS) of the MMC is shown in Fig.3. It was noted that the UTS increases

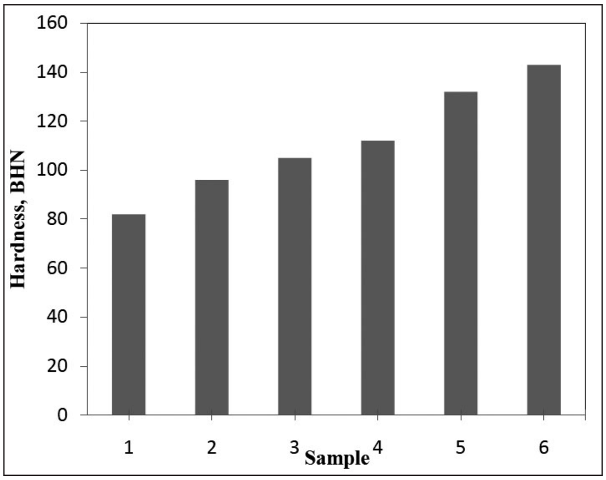

Fig.2. Hardness of gravity, squeeze cast of base alloy and composite.

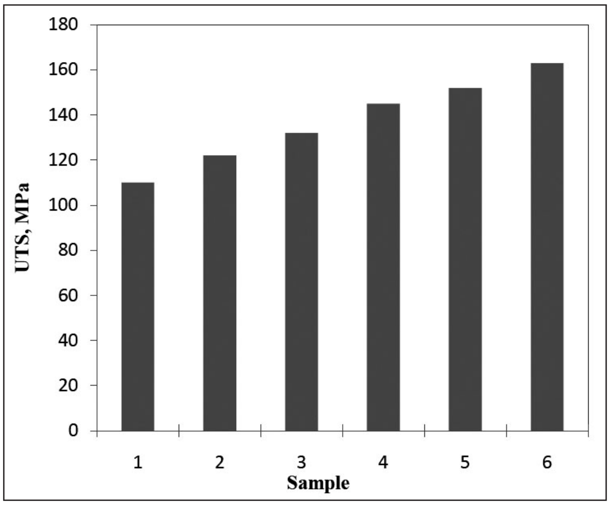

Fig.3. Variation of gravity cast, squeeze cast and Fe_2O_3 composite on ultimate tensile strength.

Table 1
Measured chemical composition of samples (wt.%).

Sample		Composition
Gravity cast matrix alloy	Sample 1	Al-Cu alloy
Squeeze cast matrix alloy	Sample 2	Al-Cu alloy
Squeeze cast Composite 1	Sample 3	Al-Cu alloy+3wt% Fe_2O_3
Squeeze cast Composite 2	Sample 4	Al-Cu alloy+6wt% Fe_2O_3
Squeeze cast Composite 3	Sample 5	Al-Cu alloy+9wt% Fe_2O_3
Squeeze cast Composite 4	Sample 6	Al-Cu alloy+12wt% Fe_2O_3

with the addition of reinforcements. The UTS shows the peak value of 163MPa for 12wt. %. Fe_2O_3 reinforced and shows an increase of strength to around 25% when compared to squeeze cast of base alloy. This is due to the hard and heavier microsphere of Fe_2O_3 which act as barriers to the movement of dislocation and refines the structure of matrix. Increase in UTS is possible due to the thermal mismatch between the metallic matrix and the Fe_2O_3 which is a major mechanism for increasing the dislocation density. Similarly the UTS of squeeze cast base alloy are 122MPa and that of gravity cast is 110MPa. which is around 10% increase in strength. This could be due to the applied pressure while squeezing. The applied pressure attributed to eliminating of micro-pores in the alloy and microstructure refining enhancement of solubility of solute [27].

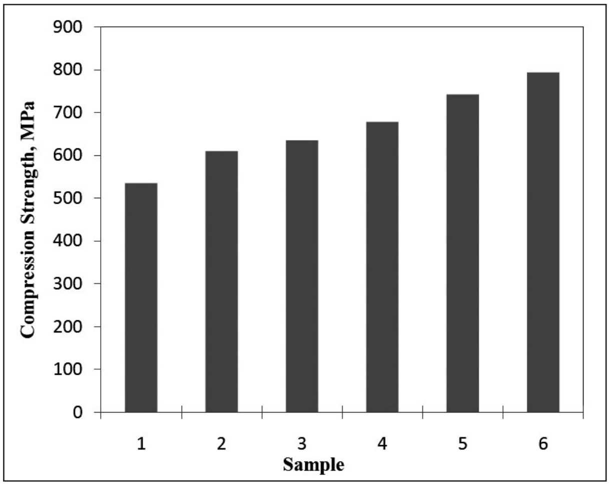

Fig.4. Variation of gravity cast, squeeze cast and Fe_2O_3 composite on compression strength.

3.3 Compression strength

Fig.4 shows the results obtained from uniaxial compression as a function of Fe_2O_3 particulate. Increase in percentage of Fe_2O_3 increases the compression strength of composites. This is due to the hardening of the base alloy by Fe_2O_3 particulates and has highest weight percentage and this may increase the density of the material which cause in increase in compressive strength. The squeeze cast base alloy exhibit higher compression strength compared to gravity cast and this may be due to compaction pressure applied during squeeze made the casting finer grain size and low porosity.

3.4 Microphotographs

Fig.5 shows the SEM microphotographs of Fe_2O_3 particle reinforced MMCs. The application of pressure can affect the virtual elimination of shrinkage and other voids and discontinuities. Therefore, pressure applied during solidification of an alloy can result in fine grained equiaxed macro-structure with microstructure being characterized by small dendrite arm spacing, small constituent particles and more homogeneous distribution of structural components. The matrix structure of the composite shows a smaller

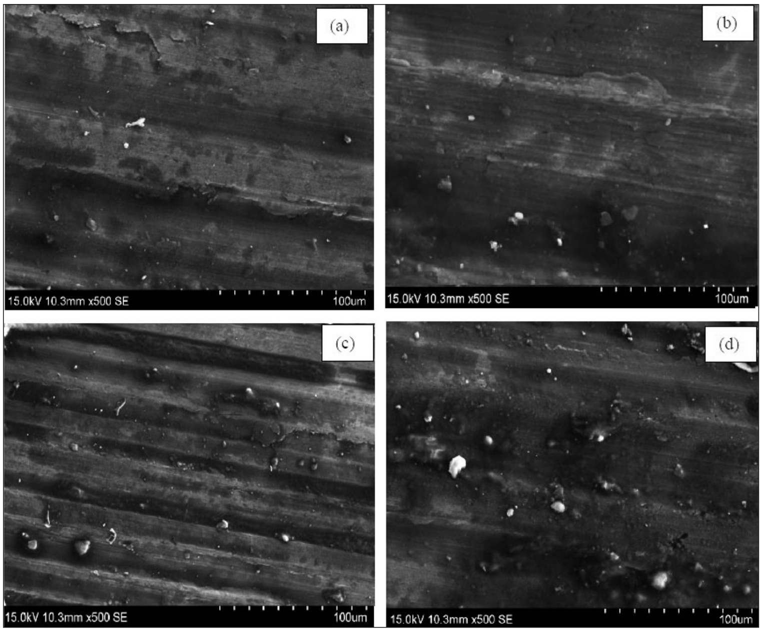

Fig.5. SEM of Al-4.5wt% Cu alloy reinforced Fe_2O_3 (100X):
(a) 3wt% Fe_2O_3; (b) 6wt% Fe_2O_3; (c) 9wt% Fe_2O_3; and (d) 12wt% Fe_2O_3.

grain size then that of base alloy. The increasing percentage of Fe_2O_3 particulate leads to a finer grain size. These results may be due to the presence of Fe_2O_3 which acts as sites of nucleation during solidification of the melt. The microstructure of this and similar composites shows the absence of voids and a uniform distribution of Fe_2O_3 in the matrix structure.

4. Conclusions

In the present study, the squeeze casting with 130MPa pressure and 350°C die plunger temperature was chosen. The gravity cast and squeeze cast of Al-Cu alloy with 3, 6, 9 and 12wt% Fe_2O_3 particulate reinforced matrix alloys have shown the followings:

1. The hardness of squeeze cast matrix alloy increased from 82 to 96 BHN with the applied pressure of 130MPa. In the composites hardness increased with increasing percentage of Fe_2O_3 with the recorded value of 143BHN for 12wt% reinforcements.
2. The ultimate tensile strength and compression strength of squeeze cast samples increases with increase in percentage of Fe_2O_3.
3. The gravity cast base alloy has lower UTS and compression strength when compare to all squeeze cast base alloy and composites.
4. SEM micrographs show the uniform dispersion of the reinforcements in MMCs with good bonding between the matrix and reinforcements.

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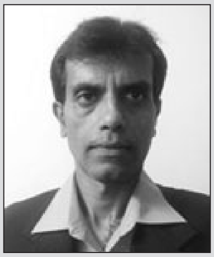

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