EXPERIMENTAL INVESTIGATION ON THE EFFECT OF PARTİCLE LOADING ON MICROSTRUCTURAL, MECHANICAL AND FRACTURAL PROPERTIES OF Al/Al₂O₃ FUNCTIONALLY GRADED MATERIALS

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ABSTRACT
The objective of this work was to examine the micro structural, mechanical properties and fracture behaviour of an Al₂O₃ particle reinforced aluminium alloy FGM fabricated by centrifugal casting. The mechanical properties such as tensile, compression, ductility and fracture behaviour were evaluated as a function of distance from the centre. Microstructure analysis show that most of Al₂O₃ particle segregate to the external circumference of the cylinder and also the relation between microstructure and FGM composition is also described. Mechanical properties of Al/ Al₂O₃ FGM connected with not only the particle loading but also the distribution of Al₂O₃ particles in matrix alloy. The microscopic failure of the FGM sample is discussed in light of the mutually interactive influences of SEM images and deformation characteristics of the MMCs.

KEY WORDS: Al₂O₃, FGM, Mechanical properties, Metal Matrix Composite, Functional Graded Material

1. INTRODUCTION
Centrifugal casting is one of the most effective methods for processing functionally graded materials (FGMs) made of aluminum [1–3], and it has been demonstrated that a compositional gradient can be obtained by using centrifugal casting to segregate phases with different densities [4–5]. The addition of particles to the melt drastically changes the viscosity of the melt, and this has implications for casting processes. Solidification influences the particle distribution depending on whether particles act as solidification nuclei or are rejected ahead of the meniscus, resulting in significantly different microstructure. It is also important the solidification occur before appreciable setting in significantly different microstructure [5].

The principal advantage of the centrifugal casting method is good mold filling combined with good microstructural control, which usually results in excellent mechanical properties [6]. In general the segregation caused by the difference of density between the particle and the melt is supposed to be avoided from the viewpoint of homogeneity [7]. Particular emphasis was placed on correlating the presence of increasing amount of particulates on the values of density, porosity and microhardness along the deposition direction for each stirring speed and correlating the influence of stirring speed on the nature of the particle gradient formed along the deposition direction [8]. Based on previous considerations, this research work aims to segregate Al₂O₃ particles in liquid aluminum alloy to local region using up to 20 wt%. Al/ Al₂O₃ composites fabricated by centrifugal casting to achieve FGM.

Microstructural characteristics, mechanical and fracture properties of the cylinder sample along radial direction were presented in detail.

2. Experimental Studies
2.1 Materials
The raw material used in this study was an Al6061/ Al₂O₃ MMCs reinforced up to 20% wt. Al₂O₃ particles which were synthesized by centrifugal casting. The chemical composition properties of Al6061 are given in the Table 1. The reinforcement particles were chosen as commercial Al₂O₃ with 99.5% purity, and a mean particle size of 30-50 µm.

2.2 Fabrication and characterization
A centrifugal machine contains a power rotation system and a mould fixed on the centrifugal casting equipment for forming cylinder samples. The mould is made of graphite, and unidirectional solidification is enforced directly by the unidirectional heat transfer of outer circumference of the mould. In this experiment, the mould was pre-heated to 500 °C, and the pouring temperature of Al6061/ Al₂O₃ composite slurry was 750 °C. A centrifugal casting was performed at 200 rpm, which corresponded to the maximum centrifugal acceleration of 54g. The dimensions of the cylinder are 40 mm diameter and 200 mm length, weighing 2500 g each approximately. The loading reinforcement was varied from 0 to 20 wt. % with interval of 5 wt. %. The specimens for optical microscopy were prepared according to ASTM E3 standards. The samples were first subjected to grinding and polishing followed by etching by nital. Optical micrographs were taken using the Olympus metallurgical microscope, fitted with a camera.

| Table. 1 Chemical Composition of Matrix alloys |
| Mg | Si | Fe | Cu | Ti | Cr | Zn | Mn | Be | V | Al |
| 0.92 | 0.76 | 0.28 | 0.22 | 0.10 | 0.07 | 0.06 | 0.04 | 0.003 | 0.01 | Bal |
effects on ductility and the fracture properties of the composite billet. Thus, the gross fracture plane was perpendicular to the loading direction of the composite billet. The cylindrical tensile specimens conformed to standards specified in ASTM E8-82, with threaded ends and a gauge section, which measured 10 mm in diameter and 36 mm in length as shown in Fig. 2. To minimize the effects of surface irregularities and finish, final surface preparation was achieved by mechanically polishing the gauge section of the test specimens with progressively finer grades of silicon carbide impregnated emery paper is used to remove all circumferential scratches and surface machining marks. Tensile tests were conducted at room temperature using UTM in accordance with ASTM E8-82. Five specimens were tested and the average values of the ultimate tensile strength and ductility were measured. Compression tests were conducted on specimens of 10 mm diameter and 20 mm length machined from the cast FGM (as same as tensile specimen), by gradually applied loads and corresponding strains were measured until failure of the specimen. The tests were conducted according to ASTM E9 standards at room temperature. Fractography is useful in studying the microstructural effects on ductility and the fracture properties of the composites. Fracture surfaces were investigated and analyzed using Scanning Electron Microscope.

3. Results and Discussion

3.1 Microstructural characteristics

Fig. 3 shows the optical microstructures of centrifugal casting of Al6061/15% Al2O3 composites. The Al2O3 particles are dispersed uniformly in the aluminum matrix except some congregated Al2O3 particles, and only few voids can be observed. Fig. 3 shows optical microstructures of cylinder sample taken at different positions from the external circumference. As seen from Fig. 3 the cross-section of the sample along the radial direction of the cylinder is divided into external reinforced zone, middle free particle zone and inner reinforced zone, and the distribution of Al2O3 particles and microstructure of the matrix alloy are different in these three zones. Fig. 3 (0, 5& 10) show that Al2O3 particles in Al melt segregate to the external circumference of cylinder after centrifugal casting, and the Al2O3 particles from circumference have more uniform distribution compared with those in the sample. In addition, few congregated Al2O3 particles and voids can be observed in sample located at 25 mm. As seen in there is a distinct interface between external reinforced zone and free particle zone. Fig. 3 shows that there are no Al2O3 particles in visible, and thin granular eutectic Al2O3 phase presents among coarse dendritic primary α(Al) phases at those positions. There are many voids, congregated Al2O3 particles and a little alumina oxides. For the samples located in the external reinforced zone, because some congregated Al2O3 particles are scattered into isolated particles under centrifugal force, the distribution of Al2O3 particles in samples becomes more uniform compared with raw Al /Al2O3 composites after centrifugal casting, and more uniform distribution of Al2O3 particles with the larger centrifugal radius is found in this study. Because alloy solidification takes place in very restricted zone at the interfaces between particles, the quick transport process of solution elements in liquid aluminum alloy promotes the homogeneous nucleation of matrix alloy during solidification.

3.2 Tensile strength

To study the effect of wt. % Al2O3 and distance from the center on the mechanical properties Al/ Al2O3 FGM fabricated by using centrifugal casting shown in Figs. 4-7. The UTS (Fig. 4) of the specimens as can be seen, higher UTS were found for with a higher wt. % of reinforcements due to well-known dispersion-strength effect. The increase in UTS along the deposition direction in the case of both FGMs, can be attributed to the increase in the wt.% of Al2O3 and grain refinement. The presence of stiffer and stronger Al2O3. Lead to an increase in constraint to plastic deformation of the matrix during tensile test.
Moreover, with grain refinement, more grain boundaries are present. Grain boundaries being microstructural defects, will provide resistance to the dislocation motion, thus affecting the elongation during tensile test.

3.3 Young’s Modulus
The Young’s modulus results for the two FGMs investigated in this study was found to increase as a function of distance from the base of the ingot and percentage of reinforcement, as shown in Fig 5. The results revealed significantly different Young’s modulus values at the two ends of the ingot.

3.4 Ductility
Fig. 6 shows the ductility of samples at different positions from the external circumference of the cylinder. There is a corresponding decrease in ductility with the increase of wt.% Al₂O₃ particles gradually, a big gap in hardness from external reinforced zone to free particle zone, and a huge decrease at inner reinforced zone because of appearance of amounts of voids and congregated Al₂O₃ particles. These defects can destroy the microstructural continuity of composite material so that the ductility decreases greatly. So, the ductility of FGM is related with the number and the distribution of Al₂O₃ particles in the matrix alloy.

3.5 Compression strength
The increase in mechanical properties such as UTS, Young’s Modulus and ultimate tensile strength along the deposition direction in the case of both FGMs, can be attributed to the increase in the weight percentage of Al₂O₃ and grain refinement. The presence of stiffer and stronger ceramic reinforcement, lead to an increase in the constraint to plastic deformation of the matrix during microhardness test. Moreover, with grain refinement, more grain boundaries are present. Grain boundaries being microstructural defects, will provide resistance to the dislocation motion, thus affecting the indentation during microhardness testing.
Fig. 5 Effect of distance on Young's Modulus of Al/Al₂O₃ FGM

Fig. 6 Effect of distance on ductility of Al/Al₂O₃ FGM

Fig. 7 Effect of distance on Compression Modulus of Al/Al₂O₃ FGM
4. Fracture studies

Evaluation of the mechanical properties of composite material is essential, but the failure and deformation mechanisms and fracture modes need to be investigated simultaneously. Hence detailed SEM Examinations were conducted on the tensile fracture surface of a fractured specimen. The tensile fracture micrograph of as cast aluminium alloy observed by SEM shown in the Fig 8(a). The fracture surface shows excellent plasticity. The deformation is uniform and there are dimples of almost uniform size. Fig 8(b) shows the tensile fracture of a composite with 5 percent of $\text{Al}_2\text{O}_3$. The dimples are smaller and edges are teared and appear like edges and form a combination of ductile and brittle fracture. The Fig 8(c) shows there are some particles along the dimples, the deformation is inhomogeneous in the matrix near the $\text{Al}_2\text{O}_3$. The perfect bonding between the reinforcement and the matrix in the composite was observed. The crack was not generated at the interface but at the matrix near the interface. Since the dislocation density and growth are non-uniform the strength of the matrix is also non-uniform. The graph also shows that the clustering of the particles in the matrix and a small quantity of voids also presents and which may be the high stress concentration point and initiates the cracking.

Fracture surfaces of the Al/$\text{Al}_2\text{O}_3$ FGM
5. CONCLUSIONS

1) Most of Al$_2$O$_3$ particles in 20% Al$_2$O$_3$/Al FGM are enriched in the external zone of the cylinder under centrifugal force, and some congregated Al$_2$O$_3$ particles with low bulk density segregate to the inner reinforced zone of the cylinder.

2) The agitation of centrifugal force promotes the dispersion of congregated Al$_2$O$_3$ particles and the nucleation of amounts of primary phases in external reinforced zone.

3) Mechanical properties of FGM are increased with increasing Al$_2$O$_3$ particulate and distance from the centre of ingots but decrease ductility.

4) The fracture surface of the FGM at center ductile in nature and outer side brittle nature can be seen

REFERENCES


