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Effect of Quartz-Silicon Dioxide Particulate on Tensile Properties of Aluminium Alloy Cast Composites

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Abstract. This paper describes an experimental investigation of the tensile properties of quartz-silicon dioxide particulate reinforced LM6 aluminium alloy composite. In this experimental, quartz-silicon dioxide particulate reinforced LM6 composite were fabricated by carbon dioxide sand moulding process with variation of the particulate content on percentage of weight. Tensile tests were conducted to determine tensile strength and modulus of elasticity followed by fracture surface analysis using scanning electron microscope to characterize the morphological aspects of the test samples after tensile testing. The results show that the tensile strength of the composites decreased with increasing of quartz particulate content. In addition, this research article is well featured by the particulate-matrix bonding and interface studies which have been conducted to understand the processed composite materials mechanical behaviour. It was well supported by the fractographs taken using the scanning electron microscope (SEM). The composition of SiO^2 particulate in composite was increased as shown in EDX Spectrum and Fractograph.

Introduction

The metal casting industry had established aggressive performance especially in the industrial castings because of a wide variety of metals and alloys were processed by casting and consequently there are increasing demand and need for new materials. This make the particulate of reinforced composites or discontinuously reinforced metal matrix composites, constitute 5 – 20 % of these new advanced materials [1,2]. The choice of the processing method depends on the property requirements, cost consideration and future applications prospects [3]. The advantage of processing composites by casting technology leads to near-net shape manufacturing which is a simple and cost-effective process [4,5]. Incorporation of hard second phase particles in the alloy matrices to produce a metal matrix composite (MMC) has been reported to be more beneficial and economical [6-9] due to its high specific strength and corrosion resistance properties. Metal matrix composites have an outstanding benefits due to the combined metallic and ceramic properties, thereby yielding improved physical and mechanical properties [10,11]. Among the various types of MMCs, particulate-reinforced composites are the most versatile and economical one [12]. In the past, various studies have been carried out on MMC. Carbides, such as SiC, TiC, TaC, WC and B4C are the most commonly used particulates to reinforce the metal or alloy matrix while the study of silicon dioxide, SiO_2 reinforcement in LM6 alloy is still rare. Very limited studies have been reported and the information available on the mechanical properties and fracture surface analysis are scarce. In this study quartz particulate reinforced LM6 alloy matrix composite specimens were fabricated and processed by casting method [13,14].

This paper focuses in studying the process of Aluminium LM6 alloy with SiO_2 as particulates by sand casting. The parameter of different percentage of SiO_2 particulate addition in the LM6 alloy matrix was examined to study the mechanical behaviour and fracture surface characteristic. Tensile testing and scanning electron microscopy was employed to evaluate the young's modulus, tensile strength and SEM was used to characterize the morphological features of the fracture surfaces of Silicon Dioxide (quartz) - particulate reinforced LM6 alloy composites after the tensile testing.

Methodology

Materials preparation. The materials used in this work were Aluminium LM6 alloy as the matrix and SiO_2 as reinforcement particulates with different weight percentages. The tensile test specimens were prepared according to ASTM standards B 557 M-94 [15]. Sodium silicate and CO_2 gas was used to produce CO_2 sand mould for processing composite casting. The aluminium alloy, LM6, was based on British standards that conform to BS 1490-1988 LM6.

Alloy of LM6 is actually an eutectic alloy having the lowest melting point that can be seen from the Al-Si phase diagram. The main composition of LM6 is about 85.95% of aluminium and 11.8% of silicon.

The SiO_2 particulate used as a second phase reinforcement in the alloy matrix was added on the molten LM6 by different weights fraction such as 5%, 10%, 15%, 20%, 25%, and 30%. The mesh size of Silicon Dioxide particulate is 230 and the average particle size equal to 65 microns (65µm).

Fabrication of composites. Only one type of pattern was used in this project and the procedure for making the pattern involves the preparation of drawing, selection of pattern material and surface finishing. Carbon dioxide moulding process was used to prepare the specimens as per the standard moulding procedure. Quartz-particulate reinforced MMCs were fabricated by casting technique. Six different weight fractions of SiO_2 particle in the range from 5%, 10%, 15%, 20%, 25%, and 30% are used. In this research work, the particulates were preheated to 200 ^oC in a heat treatment muffle furnace for 2 hours and it is transferred immediately in the crucible containing liquid LM6 alloy. The casting processing steps show are shown in Fig. 1.

Tensile testing. Tensile test was conducted to determine the mechanical properties of the processed SiO_2 particulate reinforced LM6 alloy composites. Test specimens were made in accordance to ASTM standard B557 M-94. A 250 KN servo hydraulic INSTRON 8500 UTM was used to conduct the tensile tests. The tensile testing of the samples was performed based on the following specifications and procedures according to the ASTM standards, the which one crosshead speed of 2.00 mm/minute, grip distance 50.000 mm, specimen distance 50.000 mm and temperature 24^0 C.

Scanning electron microscopy. The Scanning Electron Microscope (SEM) using LEO 1455 variable pressure microscope with Inca 300 Energy Dispersive X-ray (EDX) was used to investigate the morphological features. Results and data obtained from the tensile tested samples are correlated with the reported mechanical properties for each volume fraction of silicon dioxide percentage addition to the LM6 alloy matrix.

Density measurement. The density of a material is defined as its mass per unit volume. A&D-GR 200 – Analytical Balance was used to conduct the density measurement. The theoretical density of each set of composites was calculated using the rule of mixtures [16]. Each pellet was weighed in air (Wa), then suspended in Xylene and weighed again (W). The density of the pellet was calculated according to the formula :

$$\text{Density} = {Wa}/{(Wa - Ww)} \text{ x } density\ \ of\ \ Xylene \quad (1)$$

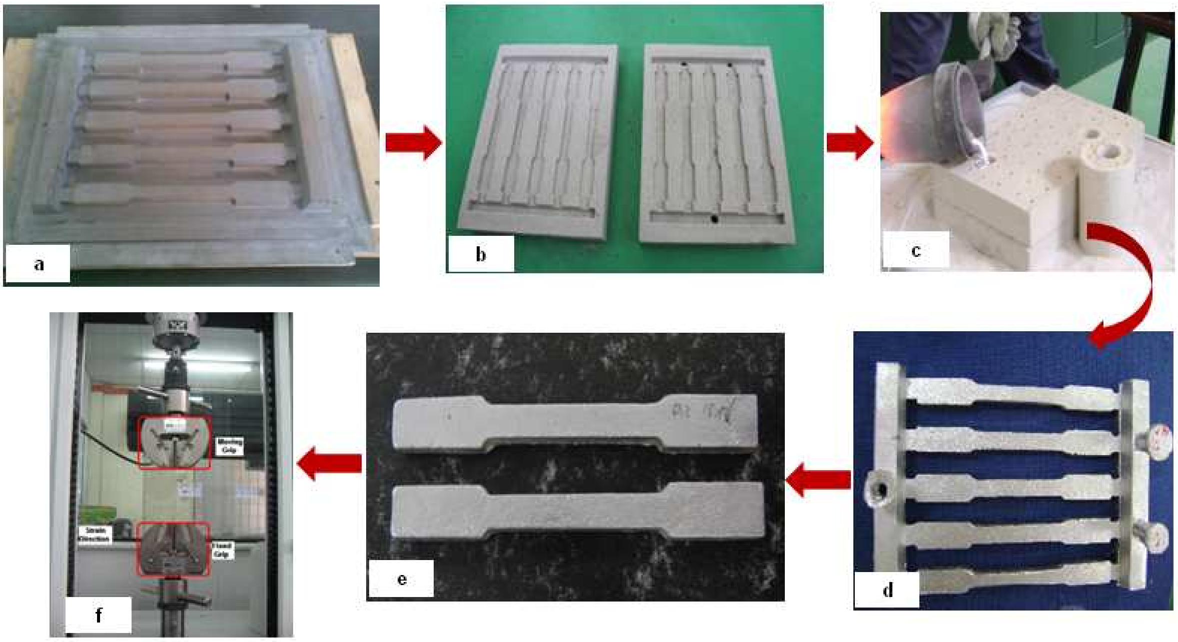

Fig. 1. The casting processing steps; (a) Pattern of mould (b) sand mould : drag and copper (c) melting and pouring in the sand mould (d) tensile specimens with gating system (e) tensile specimen after removing of gating systems (f) tensile testing.

Results and Discussion

Tensile test Properties. The average value of tensile strength (MPa) and Young's Modulus (MPa) versus weight fraction of SiO_2 is shown in the Fig. 2 and Fig. 3.

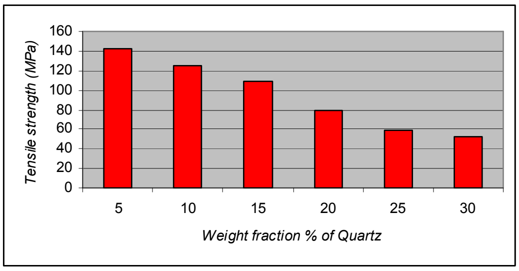

Fig.2. Tensile strength vs % weight fraction

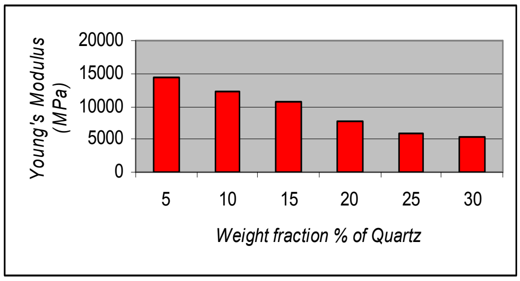

Fig.3.Young Modulus Vs % weight

The graph plotted between the average tensile strength and young modulus versus variation in weight fraction of quartz particulate addition to LM6 alloy indicates that both the properties decreases with increases addition of quartz particulate. The increase of closed pores content with increasing quartz particulate content would create more sites for crack initiation and hence lower down the load bearing capacity of the composite. The fluctuation maybe due to the non-uniform distribution of quartz particulates, due to experimental errors and or also depends on the cooling rate of the castings [14]. When particulates increase, particles are no longer isolated by the ductile aluminium alloy matrix, therefore cracks will be not arrested by ductile matrix and gap would propagate easily between the quartz particulates. This residual stress affects the material properties around it and the crack tips and the fracture toughness values would be altered.

Consequently, these residual stresses would probably contribute for the brittle nature of the composites. It should be noted that the compressive strength of the quartz particulate dominates and more than the tensile strength of the LM6 alloy matrix and so the tensile strength is decreasing with more addition of quartz particulate and this is well supported and evidenced from the literature citation [16, 17].

Density. Fig. 4 give the influence of quartz addition on density, respectively. The graph shows that as the quartz-silicon dioxide content was gradually increased, the density of the Aluminium composite decreased. Slight decrease was observed in the density because quartz-silicon dioxide has a slight lower density value than LM6 (the density of LM6 is 2.65grs/cc and of quartz is 2.23grs/cc) .

The investigation of aluminium composite is well documented. The percentage of the closed pores in the sintered composites increased with increasing quartz content. This can be attributed to silica being harder than aluminum and does not deform at all under the applied compaction load and the morphological features of quartz particles are significantly different from those of Aluminium and as a result, the interparticle friction effects are different. Therefore, the increase in the amount of closed pores with increasing quartz content would justify the observed decrease in density [16].

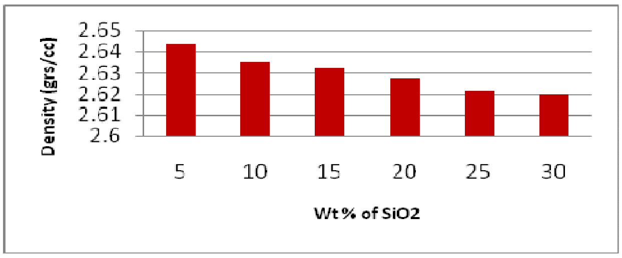

Fig. 4. Graph plotted on density versus weight fraction of S_iO_2

Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Scanning Electron Microscopy and energy dispersive spectroscopy was employed to obtain some qualitative evidences on the particle distribution in the matrix and bonding quality between the particulate and the matrix. Besides, the fracture surface of the composite was analyzed by using SEM to show the detail of chemically reacted interfaces. Thus, in order to increase the potential application of MMCs, it is necessary to concentrate on the major aspects, like particle size of quartz and quartz distribution concentration.

The fracture surfaces or fractographs are shown in the Fig. 5-10 after tensile testing of the specimens having different weight fraction of quartz particulate. It was observed that the increase of SiO_2 content would create more sites for crack initiation and would lower the load bearing capacity of MMCs. In addition the number of contacts between quartz particles would increase and more particles are no longer isolated by the ductile aluminium alloy matrix. Therefore, cracks are not arrested by the ductile matrix and they would propagate easily between quartz particulates. Decreasing of SiO_2 content less than 30% in the matrix and with the particle size of 230 mesh could increase the tensile strength, hence cracking on the surface is not too dominant This phenomenon is shown in Fig. 5. The problem on interfacial bonding between the particulate quartz and the matrix during the solidification of composites can be ignored because the phenomena cracking occurs only in a small part of the surface. Meanwhile the surface crack is not distributed to all of the parts. In contrast, when the content of quartz was increased (30%), interfacial bonding concept is an important phenomenon because the surface cracking will be distributed on the surface of the parts. The other problem caused by the interaction between Aluminium alloy and quartz particle is not a significant one and it is removed while solidification during the pouring process and due to slip inter bonding/ inter granular movement which is illustrated with the aid of Fig. 6 [17].

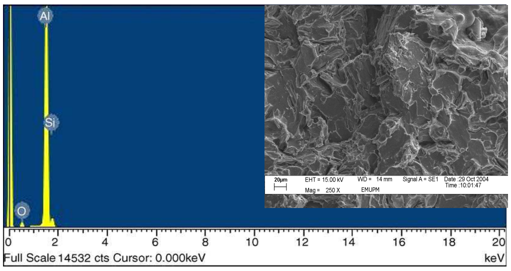

Fig. 5. EDX Spectrum and Fractograph of 5% quartz particulate reinforced in quartz -LM6 alloy matrix composite at 250X magnification by SEM after tensile testing.

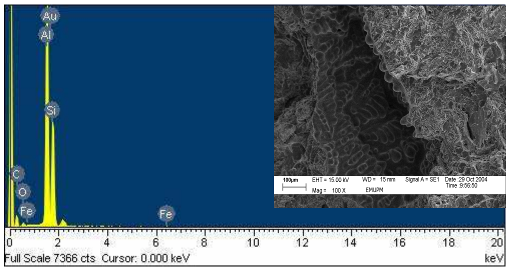

Fig. 6. EDX Spectrum and Fractograph of 10% quartz particulate reinforced in quartz -LM6 alloy matrix composite at 100X magnification by SEM after tensile testing.

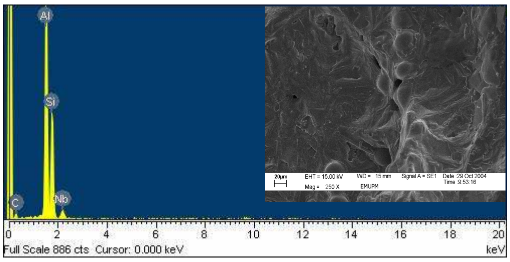

Fig. 7. EDX Spectrum and Fractograph of 15% quartz particulate reinforced in quartz -LM6 alloy matrix composite at 250X magnification by SEM after tensile testing.

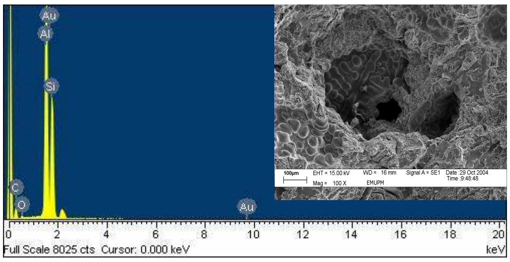

Fig. 8. EDX Spectrum and Fractograph of 20% quartz particulate reinforced in quartz -LM6 alloy matrix composite at 100X magnification by SEM after tensile testing

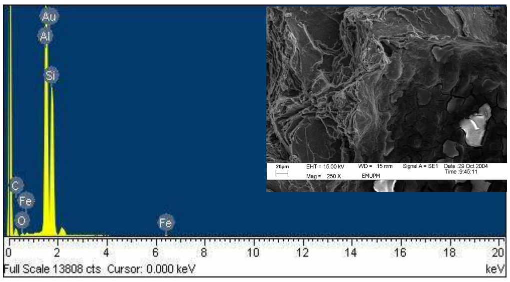

Fig. 9. EDX Spectrum and Fractograph of 25% quartz particulate reinforced in quartz -LM6 alloy matrix composite at 250X magnification by SEM after tensile testing

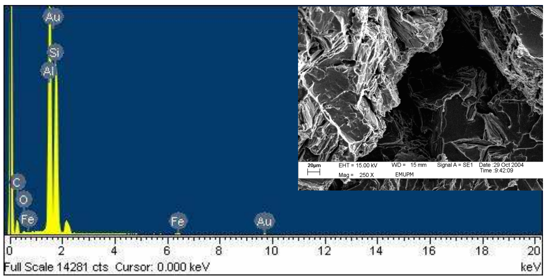

Fig. 10. EDX Spectrum and Fractograph of 30% quartz articulate reinforced in quartz -LM6 alloy matrix composite at 250X magnification by SEM after tensile testing

Summary

In this study, the compressive strength of the silicon dioxide particulate dominates and influences more effective than the tensile strength of the LM6 alloy matrix phase, hence the values of tensile strength and modulus of elasticity are decreased with the increased addition of silicon dioxide particulate from 5 to 30% by volume fraction basis. This fact from the experimental research is well supported and validated from the literature. The mechanical behaviour of the processed composite had a strong dependence on the volume fraction addition of the second phase reinforcement particulate on the alloy matrix. On the other hand, decreasing the silicon dioxide particulate content less than 30% along with the particle size constraint as 230 mesh-65 microns would increase the tensile strength and cracking on the surface might not be too dominant.

The density of these composites decreased slightly with increasing quartz content. Slight decrease was observed in the density because quartz-silicon dioxide has a slightly lower density value than LM6.

In future work, it is strongly recommended that tensile tests be performed by reinforcing the second phase quartz particulate addition to the LM6 alloy matrix limited up to 15%. In addition, compressive strengths testing of the processed composite samples can be done to highlight the benefits, advantages and applications of these composites. It is also worthwhile to conduct heat treatment studies of these processed composites and this will be taken for future research work.

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