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Mechanical properties of the as-cast quartz particulate reinforced LM6 alloy matrix composites

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ABSTRACT

Metal matrix composites are engineered materials combining two or more materials, one of which is a metal, where the tailored properties can be attained by systematic combination of different constituents. A variety of methods available for producing these advanced materials include the conventional casting process which is considered as the easiest processing technique. Preparation of these composite materials by foundry technology has the unique benefit of near-net shape fabrication in a simple and cost-effective manner. Besides, casting processes lend themselves to manufacture large number of complex shaped components of composites at a faster rate required by the automotive, transportation, sports and other consumer oriented industries. In this study, quartz–silicon dioxide particulate reinforced LM6 alloy matrix composites were fabricated by carbon dioxide sand molding process by varying the particulate addition by volume fraction on percentage basis. Tensile and hardness tests and scanning electron microscopic studies were conducted to determine the maximum load, tensile strength and modulus of elasticity. Hardness values are measured for the quartz particulate reinforced LM6 alloy composites and it has been found that it gradually increases with the increased in addition of the reinforcement phase. The tensile strength of the composites decreases with the increased in addition of quartz particulate. The fractographs taken after the tensile test illustrates the particle pullout from the matrix due to lack of bonding and load deformation characteristic mechanism.

1. Introduction

Metal matrix composites (MMC) are composed of an elemental or alloy matrix in which a second phase is embedded and distributed to achieve some property improvement. Based on the size, shape and amount of the second phase, the composite property varies. Particulate reinforced composites are often called as discontinuously reinforced metal matrix composites, constitute a large portion of these new advanced materials. The microstructures of the processed composites influence and have a great effect on the mechanical properties (ASTM, 1999; Burr et al., 1995). Generally, increasing the volume fraction of the second phase (reinforcement phase) in the matrix leads to an increased stiffness, yield strength and ultimate tensile strength. But the low ductility of particulate reinforced MMCs is the major drawback that prevents their usage as structural components in some applications (Kaczmara et al., 2000). Metal matrix composites (MMC) are considered as potential material candidates for a wide variety of structural application in the transportation, automobile and sport goods manufacturing industries due to the superior range of mechanical properties they possess (Hasyim et al., 2002).

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MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leads to greater strength in shear and compression and higher service-temperature capabilities (Clegg, 1991).

In the past, various studies have been carried out on metal matrix composites. SiC, TiC and TaC are the most commonly used particulates to reinforce in the metal or in the alloy matrix or in the matrices like aluminium or iron, while the study of silicon dioxide reinforcement in LM6 alloy is still rare and scarce. However, very limited studies have been reported and so the information and the data available on the mechanical properties and hence make this study a significant one. In this investigation quartz particulate reinforced LM6 alloy matrix composites test samples fabricated and processed by casting method chosen. So in this research work the parameter of different percentage of SiO_2 particulate addition in the LM6 alloy matrix is examined to study the mechanical behavior and fracture surface characteristic used tensile testing of the processed specimens.

2. Reinforcement of particulates

The improvement in toughness improvement by particulate reinforcement depends on the residual stresses surrounding the particles, the volume fraction of the particles and shape of the particles. Particles can be spherical, disk-shaped, rod-shaped, and plate-shaped. Each particle forces the crack to go out of plane, and can force the crack to deflect in more than one direction and thus increase the fracture surface energy (Matthews and Rawlings, 1997). Plate-shaped and rod-shaped particles can increase the composite toughness by another mechanism called as ‘pullout’ and ‘bridging’. The residual stress around the particles results from thermal expansion mismatch between the particles and the matrix, which helps to resist the crack propagation. The term ‘particulates’ is used to distinguish these materials from particle and referred as a large, diverge group of materials that consists of minute particles. The second phase particle can produce small but significant increase in toughness and consequently increases its strength through crack deflection processes. The particles, some times given a proprietary coating can be used for improving strength (Kaczmara et al., 2000). When compared to Whiskers-reinforcement systems, particle reinforcement systems have less processing difficulties and should permit to add higher volume fractions of the reinforcing phase. The orientations of particles appear as flat plates (Matthews and Rawlings, 1997).

3. Materials selected for processing composites

The main materials used in this project are Aluminum LM6 aluminium alloy as a matrix material and SiO_2–quartz as a particulate reinforcer added in different percentages. Sodium silicate (H2O) and CO_2 gas are used to produce CO_2 sand mold for processing composite castings. Pure (99.99%) aluminum has a specific gravity of 2.70 and its density is equals 2685 kg/m^3. It has a melting point of 660 °C, and its electrical and thermal conductivities equal to two-thirds that of copper (Brady et al., 2002; Jacobs and Kilduff, 1994; Fridlyander, 1995). The matrix material used in this research work is LM6 aluminum alloy. LM6 is based on British specifications that conform to BS 1490–1988 LM6. LM6 alloy 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, 11% to 13% of silicon. The details of the LM6 alloy composition is shown in Table 1.

Table 1 – Composition of LM6 (%)

Al	85.95
Cu	0.1
Mg	0.1
Si	12
Fe	0.6
Mn	0.5
Ni	0.1
Zn	0.1
Lead	0.1
Tin	0.05
Titanium	0.2
Other	0.2

3.1. *Silicon dioxide (SiO_2)/silica as a reinforcer*

Pure and fused silica is commonly referred as quartz. It has a relatively low specific gravity of 2.5–2.66. Quartz provides excellent hardness on incorporation into the soft lead-alloy, thereby making it better suited for applications where hardness is desirable. It also imparts good corrosion resistance and high chemical stability (Hasyim et al., 2002). It is a mineral of general composition SiO_2 (silicon dioxide), which is the most common among all the materials, and occurs in the combined and uncombined states. The melting point of pure fused silica is 1759 °C but it softens slightly at 1400 °C. Its density equals to 2.32 g/cc density (Brady et al., 2002; Kaczmar et al., 2000). The mesh size of silicon dioxide (SiO_2) particulate is 230 and the average particle size equal to 65 μm and its molecular weight equals to 60.08. The presence of excellent dielectric and thermal properties in SiO_2 makes it an ideal candidate to use it as an antenna window material (Clegg, 1991; Campbell, 1991).

3.2. *Sodium silicate (CO_2 process) for mold preparation*

CO_2 process is adopted to make the sand molds for pouring the chosen composite slurry mixture. Sand casting process consists of placing a pattern (having the shape of the desired casting) in sand to make an imprint (replica) by incorporating a gating system. The pattern used in this process is shown in Fig. 1. After this, the cavity is filled with the molten metal and it is further allowed to get cooled until it solidifies. Then the sand mold is broken and the casting is removed.

Fig. 1 – Pattern.

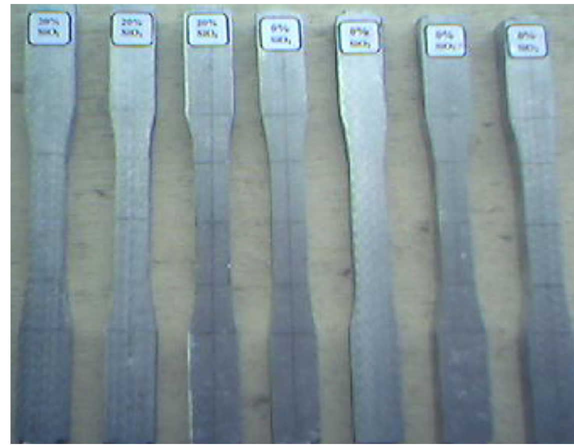

Fig. 2 – The specimen before test.

4. Material description for processing MMCs, fabrication method, specimen preparation and analysis procedure

The materials used in this work are Aluminum LM6 alloy for the matrix and SiO_2 as particulates with different percentages based on the variation in volume fraction. The first section is the specimen preparation and the second section is the specimen fabrication, and the third section is the specimen testing by tensile test (Matthews and Rawlings, 1997). SiO_2-particulate reinforced MMCs are fabricated by casting technique. The composition of the matrix is LM6. Six different percentage volume fractions of SiO_2 particle in the range from 5%, 10%, 15%, 20%, 25% to 30% are used. The most common tests performed on composite material are designed to determine the tensile properties. Tensile specimens are made to conduct the test. Because most composites have a high ratio tensile strength to shear strength, the "tab" area of dog bone geometry tends to shear off. If a straight-sided specimen is used, stress concentrations from gripping will cause failure. Therefore, many composite specimens require doublers tabs to be bonded to both sides at the ends. The tabs distribute gripping stresses and prevent specimen failure caused by grip jaws damaging the specimen's surface. The tensile test specimens of SiO_2 particulate reinforced LM6 alloy composites that we use here is prepared according to ASTM standards B557 M-94 (LM6, 2004).

5. Test description

Two types of tests are significant for this work, among them, one is the tensile test and the specimens are made as per the ASTM standard B557 M-94 specification. Tensile tests were carried out by using an UTM to determine the tensile properties of the material such as ultimate tensile strength and Young's modulus (Richardson, 1987). The photograph of the tensile test specimens cast by CO_2 process before and after testing is shown in Figs. 2 and 3. For every volume fraction addition of quartz particulate, four specimens are tested and all the steps are repeated for consecutive specimens which contain different volume fraction of SiO_2 particulates in LM6 alloy matrix.

6. Results and discussion

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.

The split tensile strength and Young's modulus value decreased gradually when SiO_2 volume fraction of LM6 alloy matrix is increased. The increase in the percent of closed pores with increasing SiO_2 particulate content would create more sites for crack initiation and hence lower down the load bearing capacity of the composite. Besides if the number of contacts between SiO_2 particulate increases, then the particles is no longer isolated by the ductile aluminium alloy matrix. Therefore cracks will not get arrested by the ductile matrix and would propagate easily between the silicon dioxide particulates. The fluctuation may be due to the non-uniform distribution of SiO_2 particulates, due to experimental errors and or also depends on the cooling rate of the castings. Particulates increase, then particles are no longer isolated by the ductile aluminium alloy matrix. Therefore cracks will not be arrested by ductile matrix and would get propagate easily between the SiO_2 particulates. Researchers Miller and Humphreys have proved that larger difference in

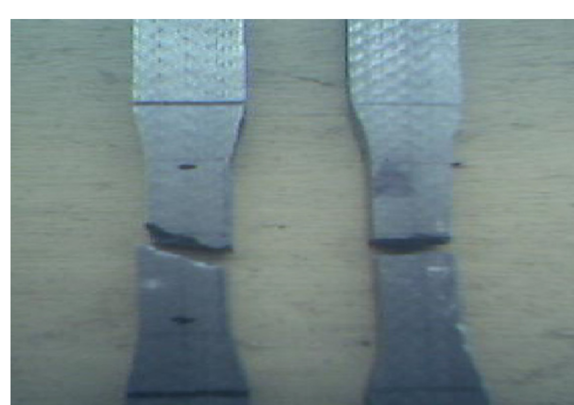

Fig. 3 – Test specimen tensile after testing.

Table 2 – Average tensile strength and young modulus value with variation in volume fraction of SiO_2 particulate addition

Volume fraction % Of SiO_2	Tensile strength (MPa)	Modulus of elasticity (MPa)
5	137.506	12990.232
10	134.433	12556.235
15	99.636	11777.071
20	76.126	4583.551
25	66.613	4495.659
30	59.238	4307.547

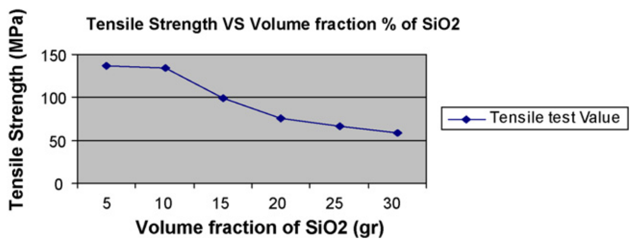

Fig. 4 – Average tensile strength versus volume fraction of SiO_2.

Table 3 – Hardness test with varying % volume fraction of quartz particulate

Volume fraction of quartz %	Hardness value based on Rockwell superficial 15 T
0	36.4
5	45.8
10	50.6
15	52.2
20	56.4
25	63.4
30	74

the thermal expansion values between LM6 alloy and the reinforcing particulates leads to thermal mismatch. The elastic stresses generated due to the thermal mismatch put the particles into compression and the matrix into tension. This residual stress affects the material properties around in and the crack tips and the fracture toughness values would be altered. Consequently, these residual stresses would probably contribute for the brittle nature of composites (Rizkalla and Abdulwahed, 1996). Table 2 shows the average values of tensile strength (MPa) and Young's modulus (MPa) for variation in the volume fraction of SiO_2 particulate in the LM6 alloy matrix.

Figs. 4 and 5 plotted between the average tensile strength and modulus or elasticity values versus variation in volume fraction of SiO_2 particulate addition to LM6 alloy shown below indicates that both the properties decrease with increased addition of SiO_2 particulate.

The decrease of tensile strength and Young's modulus of the SiO_2 particulate reinforced LM6 alloy composites with increased addition in volume fraction % of SiO_2 particulate is explained as follows with reference to Figs. 4 and 5. It should be noted that the compressive strength of the SiO_2 particulate dominates and is more than the tensile strength of the LM6 alloy matrix. So the tensile strength is decreasing with more addition of SiO_2 particulate and it is well supported and evidenced from the literature citation (Rizkalla and Abdulwahed, 1996).

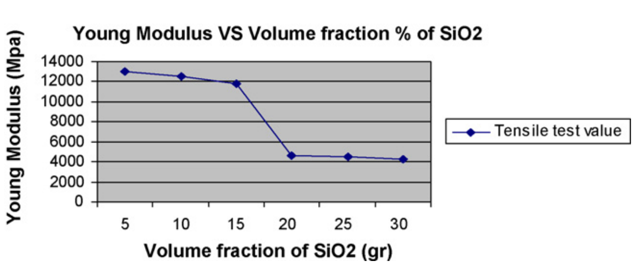

Fig. 5 – Average young modulus versus volume fraction of SiO_2.

Hardness values of the test samples of the quartz particulate reinforced LM6 alloy matrix composites having different volume fractions are tabulated in Table 3.

Based on the above hardness data, the variation in hardness value of the composites corresponding to the variation in volume fraction of quartz particulate can be known. It is clear in this table that the hardness value of the processed composites increases with the increase in addition of quartz particulate by volume fraction %.

7. Conclusions

In this experimental study, quantification of strength and hardness of quartz–silicon dioxide particulate reinforced LM6 alloy matrix composites test specimens after tensile testing is described. Based on the experimental evidence from this research work the following conclusions are made and it is listed below:

1. The split tensile strength and Young's modulus values decreased gradually as the silicon dioxide content in the composite increased from 5% to 30% by volume fraction. The reason for this mechanical behavior is due to the dominating nature of the compressive strength of the quartz particulate reinforced in the LM6 alloy matrix. It is concluded that 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 on volume fraction basis. This fact from the experimental research is well supported and validated from the literature (Rizkalla and Abdulwahed, 1996).

2. The hardness value of the silicon dioxide reinforced LM6 alloy matrix composites are increased with the increased addition of quartz particulate in the matrix and it is well supported.
3. The mechanical behavior of the processed composite had a strong dependence on the volume fraction addition of the second phase reinforcement particulate on the alloy matrix.
4. Decreasing the silicon dioxide particulate content less than 30% along with the particle size constraint as 230 mesh-65 μm would increase the tensile strength but cracking on the surface might not be too dominant.

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