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Processing and characterisation of particulate reinforced aluminium silicon matrix composite

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Properties

ABSTRACT

Purpose: This paper describes and discusses the processing and characterization of quartz particulate reinforced aluminium-silicon alloy matrix composite.
Design/methodology/approach: In this regard, quartz-silicon dioxide particulate reinforced LM6 alloy matrix composites were fabricated by carbon dioxide sand molding process with different particulate volume fraction. Tensile tests and scanning electron microscopic studies were conducted to determine the maximum load, tensile strength, modulus of elasticity and fracture surface analysis have been performed to characterize the morphological aspects of the test samples after tensile testing.
Findings: Hardness values are measured for the quartz particulate reinforced LM6 alloy composites and it has been found that it gradually increases with increased addition of the reinforcement phase. The tensile strength of the composites decreases with the increase in addition of quartz particulate.
Research limitations/implications: The results allows to determine the structure and properties of the aluminium silicon matrix composite materials.
Originality/value: 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 behavior and it was well supported by the fractographs taken using the scanning electron microscope (SEM).
Keywords: Mechanical properties; Quartz particulate; LM6 alloy; Fractograph; Hardness; Interfacial bonding

1. Introduction

Industrial technology is growing at a very rapid rate and consequently there is an increasing demand and need for new materials. Particulate reinforced composites constitute a large portion of these new advanced materials. The choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects [1].

Incorporation of hard second phase particles in the alloy matrices to produce MMCs has also been reported to be more beneficial and economical [2, 3] due to its high specific strength and corrosion resistance properties. In the past, various studies have been carried out on metal matrix composites. SiC, TiC, TaC, WC, B4C 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 fracture surface analysis are scarce 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 are chosen [4,5]. So in this research work the parameter of different percentage of SiO2 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. In this study, tensile testing and Scanning Electron Microscopy are employed to evaluate the maximum load, Young's modulus, tensile strength and to characteristic the morphological features of the fracture surfaces in Silicon Dioxide (quartz) - particulate reinforced LM6 alloy composites after the tensile testing.

2. Experimental work

The materials used in this work are Aluminum LM6 alloy for the matrix and SiO2 as particulates with different percentages based on the variation in volume fraction. The tensile test specimens of SiO2 particulate reinforced LM6 alloy composites that we use here is prepared according to ASTM standards B 557 M-94 [6]. The toughness and formability of Aluminum -11% silicon alloy can be combined with the strength of quartz particles. Sodium silicate and CO2 gas is used to produce CO2 sand mould for processing composite castings.LM6 is based on British specifications that conform to BS 1490-1988 LM6.

The mechanical, thermal and electrical properties of LM6 are shown in the Table-1. 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 aluminum, 11% to 13% of silicon [7-9]. The details of the LM 6 alloy composition is shown in Table -2. Quartz is a hard mineral and provides excellent hardness on incorporation into the soft lead-alloy, thereby making it better suited for applications where hardness is desirable. The mesh size of Silicon dioxide particulate is 230 and the average particle size equal to 65 microns (65 μm). The properties of pure SiO2 are in the Table -3.

The presence of excellent dielectric and thermal properties in SiO2 makes it an ideal candidate to use it as an antenna window material [10-11].

Carbon dioxide molding process is used to prepare the test moulds as per the standard moulding procedure. SiO2-particulate reinforced MMCs are fabricated by casting technique. Six different percentage volume fractions of SiO2 particle in the range from 5%, 10%, 15%, 20%, 25% and 30% are used. The total weight ratio of silicon dioxide to Al-11% silicon alloy is show in Table-4.

An induction furnace is used to melt the aluminum alloy and SiO2 is mixed in it after the alloy attains the liquid state. The main concern is to maintain the temperature while transferring the molten metal to the mold and hence to ensure the quality of the cast product. The metal handling equipment used to transfer the molten metal also depends on the mould size and the quality of cast being cast [12-14].

Tensile tests were conducted to determine the mechanical properties of the processed SiO2 particulate reinforced LM6 alloy Composites.

Table 1.
Mechanical, thermal and electrical properties of LM6

PHYSICAL PROPERTIES	VALUES
Density (g/cc)	2.66
MECHANICAL PROPERTIES	VALUES
Tensile strength, Ultimate (MPa)	290
Tensile Strength, Yield (MPa)	131
Elongation %; break (%)	3.5
Poisons ratio	0.33
Fatigue Strength (MPa)	130
Machinability	30
Shear Strength (MPa)	170
THERMAL PROPERTIES	VALUES
CTE, linear 20^{o}C (μm/m-^{o}C)	20.4
CTE, linear 250^{o}C (μm/m-^{o}C)	22.4
Heat Capacity (J/g- ^{o}C)	0.963
Heta Fusion (J/g)	389
Thermal Conductivity (W/m-K)	155
Melting Point (^{o}C)	574
Solidus, (^{o}C)	574
Liquidus (^{o}C)	582
ELETRICAL PROPERTIES	VALUES
Electrical Resistivity (Ohm-cm)	0.0000044

Table 2.
Composition of LM6 (%)

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

Table 3.
Properties of SiO2

Molecular weight	60.08
Melting Point °C	1713
Boiling Point °C	2230
Density G/Cm^3	2.32
Mohs Hardness @ 20 °C	7 Modified Mohs
Si %	46.75
O %	53.25
Crystal Structure	Cubic
Mesh size	230
Size	65 microns (65 µm)

The specifications dimension, and shape of the specimen used are shown in the Figure-1 and a clear explanation in given below. SiO2-particulate reinforced LM6 alloy composite cast test specimens are processed by CO2 process. Different volume fractions of SiO2 particulates are added to produce the cast test samples. The photograph of the tensile test specimens cast by CO2 process before and after testing is shown in the Figure-2 and Figure-3. A 250 kN servo hydraulic INSTRON 8500 UTM is used to conduct the tensile tests. The test samples are subjected to a tensile load and the mechanical properties are determined. Hence, the tensile strength, and young's modulus values are calculated.

Hardness values of composites are determined for different volume fraction of quartz containing LM6 alloy and a graph is plotted between the harness value and the silicon dioxide particulate addition.

The fracture surface of the composites is examined using LEO 1455 variable pressure microscope with Inca 300 EDX (Energy Dispersive X-Ray).

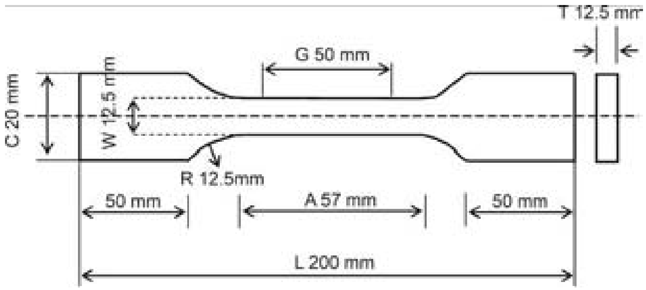

Fig. 1. Tensile Specimen as ASTM standard [ASTM, Annual handbook, 1999], G is gage length, W is width, T is thickness, R is radius of fillet, L is overall length, A is length of reduced section, B is length of grip section, C is width of grip section

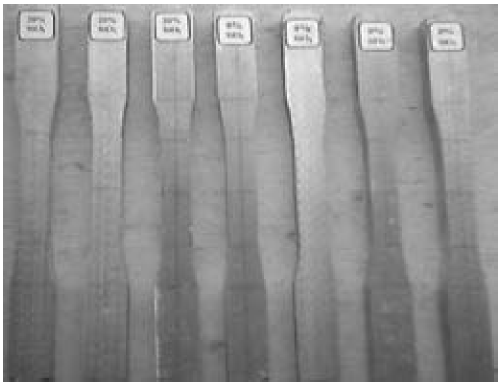

Fig. 2. The specimen before test

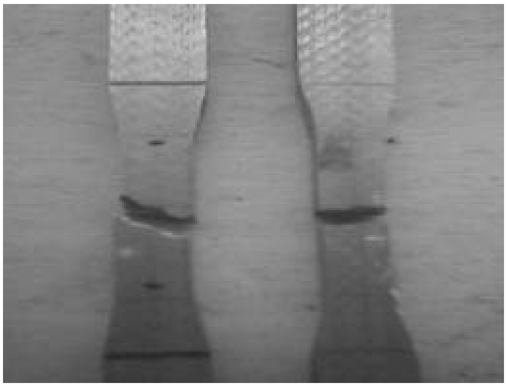

Fig. 3. Test Specimen tensile after testing

Table 4.
The weight ratio of SiO2 in Al alloy

Mixture	VOLUME FRACTION OF SIO2 PARTICLE											
	Mixture I		Mixture II		Mixture III		Mixture IV		Mixture V		Mixture VI	
Quantities	LM6	SiO_2	LM6	SiO2	LM6	SiO2	LM6	SiO2	LM6	SiO2	LM6	SiO2
Quantities (%)	95	5	90	10	85	15	80	20	75	25	70	30
Quantities (grams)	623.2	28.6	590.4	57.2	557.6	85.8	524.8	114.4	491.9	143	459.2	171.6

3. Results and discussions

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.

3.1. Tensile test

The average value of tensile strength and % of SiO2 is shown in the Figure-4. The increase in the percent of closed pores with increasing SiO2 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 SiO2 particulate increases, then the particles is no longer isolated by the ductile aluminium alloy matrix.

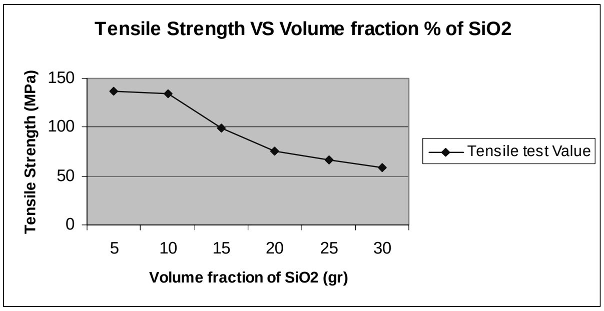

Fig. 4. Average tensile strength versus volume fraction of SiO2

Therefore cracks will not get arrested by the ductile matrix and would propagate easily between the silicon dioxide particulates. The fluctuation maybe due to the non-uniform distribution of SiO2 particulates, 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 be not arrested by ductile matrix and get would propagate easily between the SiO2 particulates. It is known that larger difference in 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 [15-17].

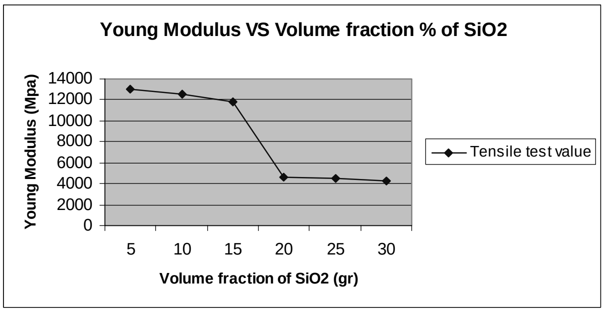

Fig. 5. Average young modulus versus volume fraction of SiO2

The graph plotted between the average tensile strength and modulus or elasticity values versus variation in volume fraction of SiO2 particulate addition to LM6 alloy indicates that both the properties decreases with increases addition of SiO2 particulate. The decrease of tensile strength and the average young modulus of the SiO2 particulate reinforced LM6 alloy composites with increased addition in volume fraction % of SiO2 particulate is explained as follows with reference to the Figure-5.

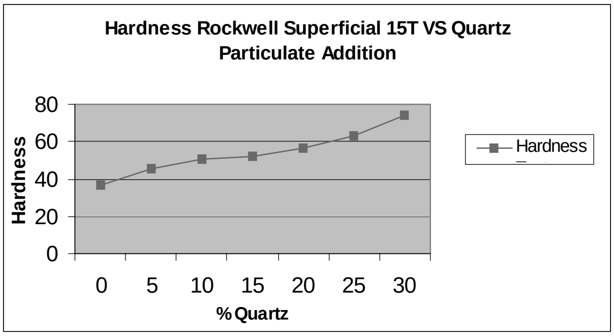

Fig. 6. Hardness value of the processed composites increases with the increase in addition of quartz particulate by volume fraction %

It should be noted that the compressive strength of the SiO2 particulate dominates and more than the tensile strength of the LM6 alloy matrix and so the tensile strength is decreasing with more addition of SiO2 particulate and it is well supported and evidenced from the literature citation. [11]. The variation of hardness values versus volume fraction of quartz particulate is illustrated in Figure-6. It is clear that the hardness value of the processed composites increases with the increase in addition of quartz particulate by volume fraction %.

3.2. Scaning electron microscopy (SEM)

Scanning Electron microscopy 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 SiO2, SiO2 distribution concentration. The observed increase of SiO2 content would create more sites for crack initiation and would lower the load bearing capacity of MMCs. The fracture surfaces fractographs are show in the Figures-7 to 12 after tensile testing of the specimens having different volume fraction of SiO2 particulate. In addition the number of contacts between SiO2 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 SiO2 particulates. Decreasing of SiO2 content less than 30% in the matrix and if the particle size is of 230 mesh it could have increased the tensile strength. This phenomenon is shown in the Figure-12 and cracking on the surface is not too dominant one. The problem on interfacial bonding between the particulate SiO2

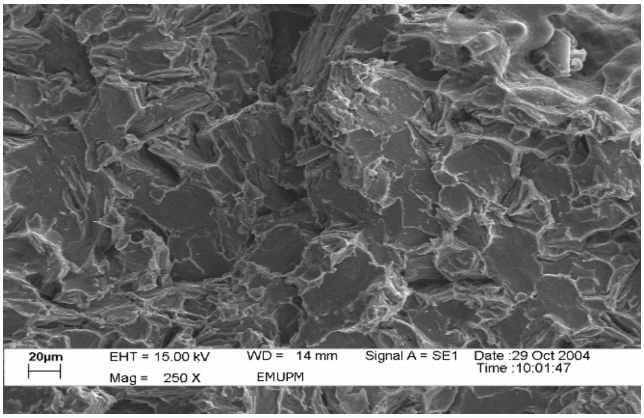

Fig. 7. Fractograph of 5% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 250X magnification by SEM after tensile testing

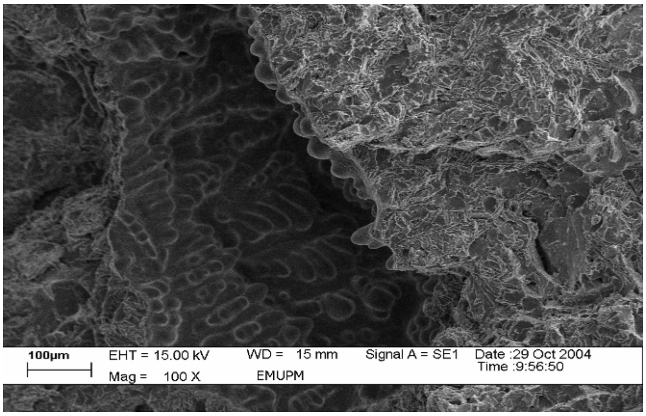

Fig. 8. Fractograph of 10% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 100X magnification by SEM after tensile testing

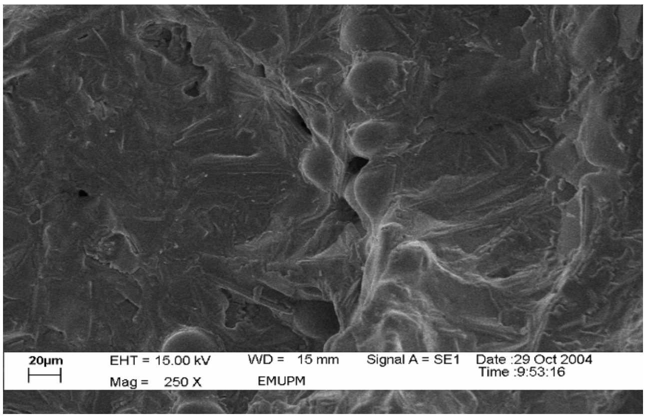

Fig. 9. Fractograph of 15% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 250X magnification by SEM after tensile testing which shows intergranular movement

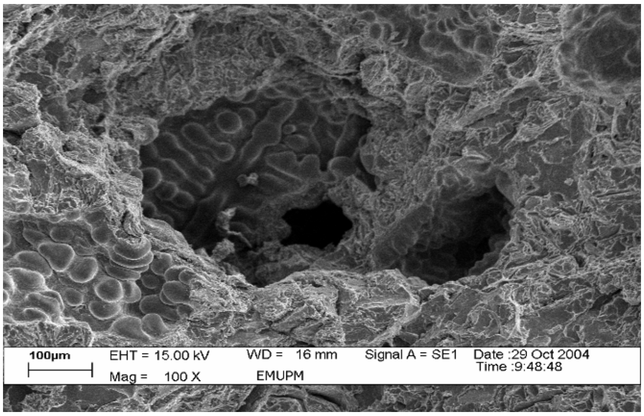

Fig. 10. Fractograph of 20% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 100X magnification by SEM after tensile testing which shows the crack propagation in the ductile matrix

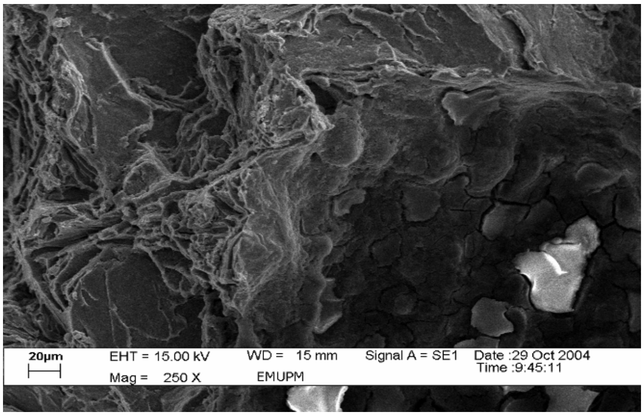

Fig. 11. Fractograph of 25% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 100X magnification by SEM after tensile testing which shows the peeled out particulate

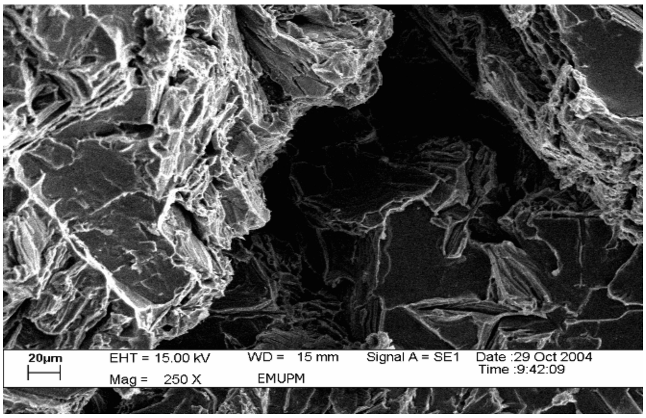

Fig. 12. Fractograph of 30% SiO2 particulate reinforced in SiO2-LM6 alloy matrix composite at 250X magnification by SEM after tensile testing

and the matrix during the solidification of composites can be ignored because the phenomenon cracking occurs only in a small part of the surface [36]. Mean while the surface crack is not distributed to all the parts. In the contrast, when the content of SiO2 is maximal (30%) and particle size in optimal. 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 Al alloy and SiO2 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 Figure-9.

4. Conclusions

In this experimental study, quantification of strength, Hardness and fracture surface morphological aspects of quartz-silicon dioxide particulate reinforced LM6 alloy matrix composites test specimens after tensile testing are described. Based on the experimental evidence from this research work the following conclusions are drawn:

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.
2. The hardness value of the silicon dioxide reinforced LM6 alloy matrix composites is 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 microns would increase the tensile strength but cracking on the surface might not be too dominant.

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