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Tensile Properties and Interfacial Bounding Strength of TiC Reinforced Aluminium Alloy

Sayuti. M, Suraya. S, Sulaiman. S, Vijayaram. T.R, Arifin. M.K.A and B.T.H.T. Baharudin

Abstract— **This paper describes an experimental investigation of the tensile properties and interfacial bounding strength of titanium carbide particulate reinforced LM6 aluminium alloy composite. In this experiment, titanium carbide particulate reinforced LM6 composite were fabricated by carbon dioxide sand moulding process with particulate variation of 0.2, 0.6, 1 and 2% by percentage weight. Tensile tests were conducted to determine the tensile strength and modulus of elasticity, which was then 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 increased with increasing of titanium carbide 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 mechanical behaviour of the composite materials processes and it was well supported by the fractographs taken using the scanning electron microscope (SEM).**

Keywords: mechanical properties, Hardness, LM6 alloy

I. INTRODUCTION

Composite material is a combination of two or more chemically distinct and insoluble phases with its properties and structural performance superior to those of the constituents acting independently. Composites by definition, being a combination of different materials, offer a particular challenge when preparing it by liquid metal processing method [1]. They are considered as an important class of materials that have numerous attractive properties.

Sayuti, M. is with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia, (email : tgk_sayuti@yahoo.co.uk)

Suraya, S. is with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia (email : sue_bahira@yahoo.com)

Sulaiman, S. is with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia (E-mail: suddin@eng.upm.edu.my)

Vijayaram, T.R. Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Ayer Keroh, Melaka. Malaysia (vijayaram1@gmail.com)

Arifin, M.K.A. is with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia (E-mail: khairol@eng.upm.edu.my)

Baharudin, B.T.H.T. is with the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia E-mail: (tuah@eng.upm.edu.my)

Three major categories are fiber-reinforced plastics, metal matrix composites and ceramic matrix composites [2]. Metal matrix composites often consist of a soft aluminum or aluminum alloy matrix with brittle particles of, for example, tungsten carbide, titanium carbide, aluminium silicate or quartz [3]. These particles can vary in size, distribution and concentration in the matrix. MMCs could also consist of a soft matrix with reinforced strands or whiskers of silicon carbide or alumina, and these strands being aligned longitudinally and / or transversely to the direction of investigation [4]. One of the advantages of composite materials is that they can be engineered for specific applications [5].

Researchers have reported that some composites exhibit a higher compressive strength due to the dominance of the presence of the reinforcement phase since the compressive strength of the reinforcement particulate is very high.

In this work, MMC consisting of pure aluminium reinforced with Titanium Carbide (TiC) particles were produced by sand casting, and their mechanical behaviour and fracture surface characteristic were investigated in details. Tensile testing and Scanning Electron Microscopy were employed to evaluate the maximum load, Young's modulus, tensile strength and to characterize the morphological features of the fracture surfaces of TiC - particulate reinforced LM6 alloy composites after the tensile testing.

II. METHODOLOGY

2.1 Material preparation

The materials used in this work were Aluminium LM6 alloy as the matrix and TiC as reinforcement particulates with different percentages. The tensile test specimens were prepared according to ASTM standards B 557 M-94 [6]. Sodium silicate and CO_2 gas was used to produce CO_2 sand mould for processing composite casting. The aluminium alloy used was BS 1490-1988 LM6.

The mechanical, thermal and electrical properties of LM6 are shown in the Table-1 and composition of LM6 in the Table 2.

Table 1 the 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
Poissons ratio	0.33
Fatigue strength (MPa)	130
Machinability	30
Shear strength (MPa)	170
Hardness (BHN)	50
Modulus of elasticity (N/sq.mm)	71000
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 of 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 the composition of LM6

Chemical constituents	**wt.%**
Al	85.95-87.95
Cu	0.1
Fe	0.6
Mg	0.1
Mn	0.5
Ni	0.1
Pb	0.1
Si	10-13
Sn	0.05
Ti	0.2
Zn	0.1

2.2 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 finish. Carbon dioxide moulding process was used to prepare the specimens as per the standard moulding procedure. Titanium carbide-particulate reinforced MMCs were fabricated by casting technique. Four different weight fractions of TiC particle in the range from 0.2%, 0.6%, 1%, 2% were used. An induction furnace was used to melt the aluminium alloy at ~800^{0}C and TiC was mixed in it after the alloys attains the liquid state. The main concern was to maintain the temperature while transferring the molten metal to the mould 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 quality of cast being cast. Tensile test specimens were made as per the ASTM standard B557 M-94 specifications as shown in Figure 1. Fracture surface analysis by using SEM was conducted after the tensile testing. Tensile tests were carried out by using a universal testing machine to determine the tensile properties of the material such as ultimate tensile strength and Young's modulus.

2.3 Tensile Testing

Tensile test was conducted to determine the mechanical properties of the processed TiC particulate reinforced LM6 alloy composites. The dimensions of the test samples were decided according to B557 M-94 and Figure 1 shows the specimens before testing. Titanium carbide-particulate reinforced LM6 alloy composite cast specimens were processed by CO_2 process. Different weight fractions of (TiC) particulates are added to produce the cast test samples. A 100 KN servo hydraulic INSTRON 8500 UTM was used to conduct the tensile tests. The test samples were subjected to a tensile load and the mechanical properties were determined. Hence, the tensile strength, and Young's modulus values were calculated. A thin flat material with a constant rectangular cross-section was mounted and gripped in the INSTRON 8500 UTM testing machine and it was monotonically loaded in tension the load recorded. The test coupon strain was monitored for accuracy with displacement transducers where the stress-strain response of the material can be determined and hence the modulus of elasticity can be calculated. Figure 2 shows the specimens after testing.

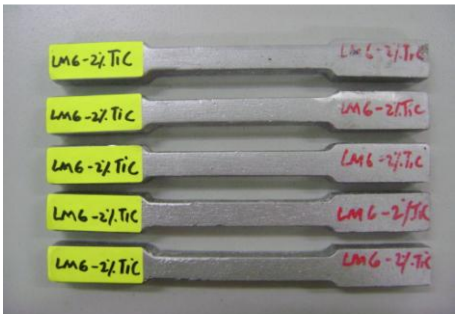

Fig. 1 Specimen before testing

Fig. 2 Specimen after testing

2.3 Scanning electron microscopy

Scanning Electron Microscope (SEM) using HITACHI S-3400N variable pressure microscope with Inca 300 Energy Dispersive X-ray (EDX) were used to analyze the fracture surfaces after tensile testing. Results and data obtained from the tensile tested samples are correlated with the reported mechanical properties for each weigh fraction of (TiC) silicon dioxide percentage addition to the LM6 alloy matrix.

3 RESULTS AND DICUSSION

The tensile testing of the samples was performed based on the following specifications and procedures according to the ASTM standards.

Type of testing : Tensile test
Crosshead speed : 2.00 mm/minute
Grip distance : 50.000 mm
Specimen distance : 50.000 mm
Temperature : 24^0 C

The Table 3, shows the effect of TiC on tensile strength and young modulus of the composite. The tensile properties of the LM6/TiC MMC for four different weight fractions at ambient temperature reveals an increases in tensile strength and modulus with increase in reinforcement content in the LM6 alloy matrix. The graph plotted between the average tensile strength and modulus or elasticity values variation in percentage weight of TiC particulate addition to LM6 alloy indicated that both the properties increases with increase of TiC particulate. The increases of tensile strength and young modulus of the TiC particulate reinforced LM6 alloy composite with increased addition in weight fraction of TiC particulate is explained as follow with reference to the Figure 3 and 4. The increase in tensile strength may be due to the TiC particles acting as barriers to dislocations in the microstructure. This dislocation increases the dislocation density, which provides a positive contribution to strength of the composite. This result was well supported and evidenced from the literature citation. [7,8]

Table 3. Tensile properties of MMC containing various amounts reinforcement content.

wt% of TiC	Tensile Strength (MPa)	Young modulus (MPa)
0	116.0743	1881.246
0.2	123.9025	7011.749
0.6	130.9343	1935.583
1	133.9486	1876.223
2	135.8325	5853.59

The examine fracture surface of an LM6 matrix composite surfaces exhibit a brittle cleavage fracture mechanism. The fracture surface of the grain refined composite showed broken Aluminium and TiC particles (Figure 5 - 9) and well-attached particles within the dimples, indicating rather good interface cohesion between matrix and reinforcing particles.

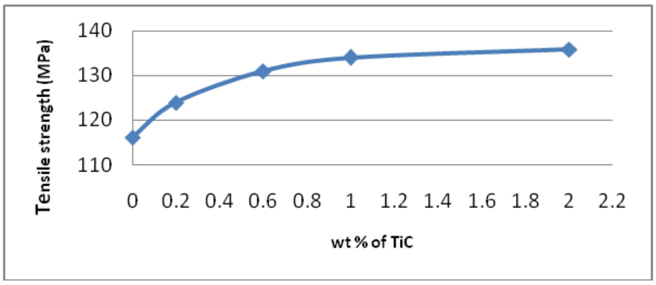

Fig. 3 Average tensile strength versus weight fraction of TiC

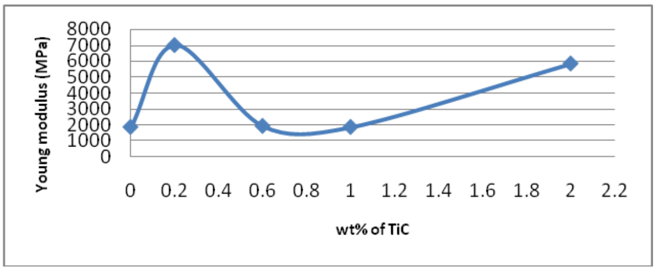

Fig. 4 Average young modulus versus weight fraction of TiC

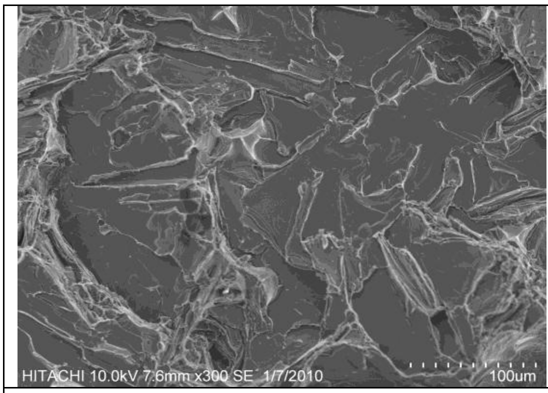

Fig. 5 Fractograph of LM6 at Fractograph of LM6 at 300X magnification by SEM after tensile testing

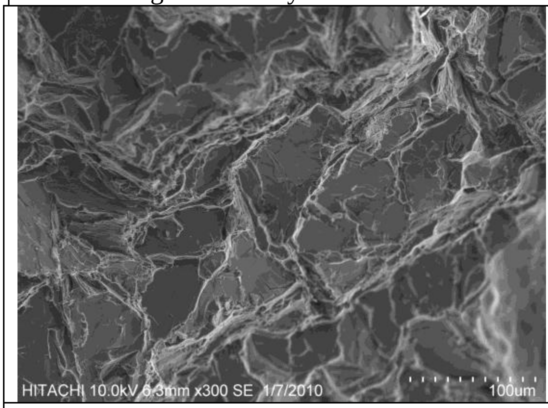

Fig. 6 Fractograph of 0.2% TiC particulate reinforced in TiC-LM6 matrix composite at 300X magnification by SEM after tensile testing

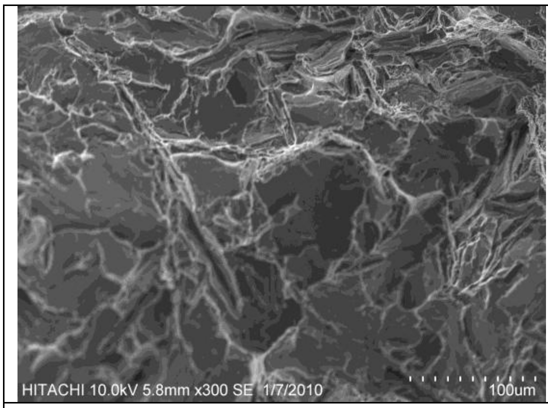

Fig. 7 Fractograph of 0.6% TiC particulate reinforced in TiC-LM6 matrix composite at 300X magnification by SEM after tensile testing

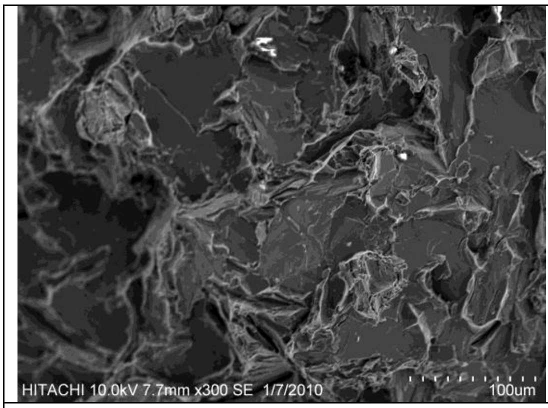

Fig. 8 Fractograph of 1% TiC particulate reinforced in TiC-LM6 matrix composite at 300X magnification by SEM after tensile testing

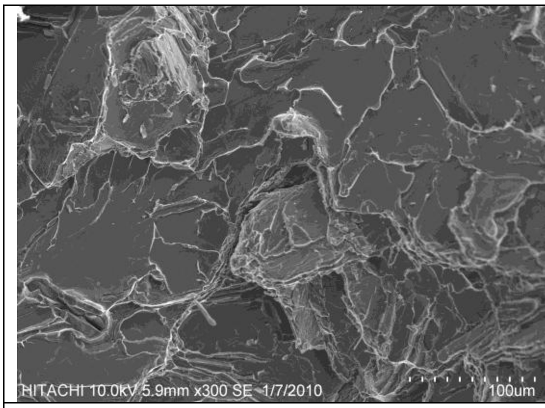

Fig. 9 Fractograph of 2% TiC particulate reinforced in TiC-LM6 matrix composite at 300X magnification by SEM after tensile testing

4 Conclusion

The split tensile strength and young's modulus values increased gradually as the TiC content in the composite increased from 0.2%, 0.6, 1 and to 2% by percentage weigh fraction. The tensile behavior of the processed composite had a strong dependence on the weight fraction addition of the second phase reinforcement particulate on the alloy matrix. The reason for this tensile behavior is due to the dominating nature of the compressive strength of the TiC particulate reinforced in the LM6 alloy matrix. Particle cracking of the reinforcement particulate was seen on both MMC fracture faces under tensile test, implying that there is sufficient interfacial bonding between the reinforcement particles and LM6 alloy matrix.

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