Effect of TiC Particulates on the Microstructure and Mechanical Properties of Aluminium-Based Metal Matrix Composite

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Abstract. In this research, metal-matrix composites (MMCs) of aluminium-11.8% silicon alloy matrix reinforced with titanium carbides particulates were fabricated by the casting technique. Aluminium-11.8% silicon alloy is selected as the matrix material and titanium carbide as particulates are mixed in different weight percentages, 5%, 10%, 15% and 20%wt. The cylinder composite castings are made by pouring the composite mixture in copper permanent-molds. The microstructure and mechanical properties of these composite materials were investigated. The effects of reinforced materials on weight percentages addition of particulate on the particulate distribution in aluminium-11.8% silicon alloy composites and SEM observation of the fracture surfaces of tensile tested specimens were deliberate. Moreover, cylinder castings without particulate addition are made and compared with the result based on the properties and microstructural features. It is found that the microstructure and mechanical properties of composites significantly improved by the use of particle reinforced into aluminium alloy.

Introduction

The researches of metal matrix composites (MMCs) are entering a new demanding phase, which is being spurred by the trends of using lightweight, environmental friendly, high quality, performances and economical demands of the end-user [1-3]. Similar to this development, metal matrix composite (MMCs) have been attracting emergent interest because they give the best combination of strength, stiffness, ductility, wear resistance and toughness [2]. A metal matrix composite (MMCs) are composite material combining two or more materials, one of which is a metal, where the tailored properties can be attained by systematic combination of different constituents [4]. It is composed of an element or alloy matrix in which a second phase is embedded and distributed to achieve some property improvement [5]. Based on the size, shape and amount of the second phase, the composite property varies [6]. Particulate reinforces composites, often called as discontinuously reinforced metal matrix composites, constitute 5-20% of these new advanced materials. Particle reinforced metal matrix composites have higher stiffness, strength and wear resistance compared to the classical alloys. They also show some advantages over other composite types due to their isotropic behaviour and forming ability by conventional methods. Composite materials with a metal or an alloy matrix can be produced either by casting or by powder metallurgy methods [7] are considered as potential material candidates for a wide variety of structural application in the transportation, automobile and sports equipment industries due to the superior range of mechanical properties they possess [8-10].

This research is focus on the materials, the fabrication process, mechanical properties and microstructure of the aluminium-11.8% silicon alloy matrix reinforced with titanium carbide (TiC) particulates. It's cover the key areas of the experimental analyses of die casting process and specimens were carried out and a suitable benchmark test model is designed for the comparison and evaluation of the specimens. In this investigation, titanium carbide particulate reinforced aluminium-11.8% silicon alloy composites test sample were fabricated and processed by casting technique. In this research work, 5, 10, 15 and 20%wt weight percentages titanium carbide is added in aluminium-11.8% silicon alloy composites to produce cast test specimens. The main objectives of this experimental investigation are to investigate mechanical properties and microstructure analysis of aluminium-11.8% silicon alloy composites. Tensile test, hardness and scanning electron microscopy (SEM) are used to evaluate the maximum load, tensile strength, hardness and to understand more on the morphological features of the fracture surface in aluminium-11.8% silicon alloy matrix reinforced with titanium carbides particulates.

Experimental work

In this study, aluminium-11.8% silicon alloy were used for the matrix and titanium carbide as a particulate. Titanium carbide has high hardness and titanium carbide particulate's size is 325 mesh and the average particle size equal to 44 microns (μm). Titanium carbide particle can be combining with the toughness and formability of aluminium-11.8% silicon alloy. The combination of this material can fabricate great product. The process started when the aluminium-11.8% silicon alloy ingots were cut into small pieces and the process continue by melts the ingots in an induction furnace. The ingot is left to melt until the ingot's temperature reaches 750°C [11]. In the meantime, the particulates (TiC) were heated until the temperature 300°C in oven before being added in the alloy matrix by varying the weight percentages addition to the aluminium-11.8% silicon alloy [12]. The main concern is to keep the temperature while transferring the molten metal to the mould and therefore to ensure the quality of the cast product. After mixed, the composite slurry are poured into copper permanent mold as shown in Fig. 1 by gravity, and then allowed to solidify. Lastly, the casting is broken out of the mold to complete the process. The composite product used in this research is a cylinder shaped. The dimensions of the cylinder's diameter are 40mm and the length is 170mm.

A test specimen is the most important part of tensile testing for it determines the actual physical properties of the material being tested. Test specimens were prepared according to ASTM B557 M-94 specification using CNC machine. The CNC machine is used to cut the cylinder casting to match the specifications dimension as shown in Fig. 2. This is to ensure the accuracy tensile specimens. Displacement rate for the tensile tests was 2.00mm/min. Tensile test of MMCs were conducted on the 100 KN servo hydraulic INSTRON 8500 UTM testing machine while hardness test were conducted on the Mitutoyo ATK-600 Rockwell/ Rockwell Superficial Type Hardness Testing Machine to determine the mechanical properties of the processed TiC particulate-reinforced aluminium alloy composites. Each test result reported in this paper is the average obtained from at least three test specimens. From the testing, the value of tensile strength and hardness are calculated.

Investigation of the fracture surface of titanium carbide particulate reinforced aluminium-11.8% silicon alloy matrix composites after tensile is performed by LEO VARIABLE PRESSURE SEM 1455 VP Series. The purpose is to obtain some qualitative evidences on the particle distribution in the matrix and bonding quality between the particle and matrix. Samples for microstructure investigation were cut into size 10mm x 10mm from each specimen after tensile testing to fit in the specimen chamber for Scanning Electron Microscopy (SEM) test. By using this method, the fractures surfaces of the tensile test samples are observed at higher magnifications to characterize the features of the failure and the type of failure. Then further studies on the inter-phase and bonding are performed to observe the formation of any interfacial reaction and hence to predict the type of bonding between the particulate surface and the matrix surface.

Fig. 1: Pouring the composite slurry into the metallic moulds

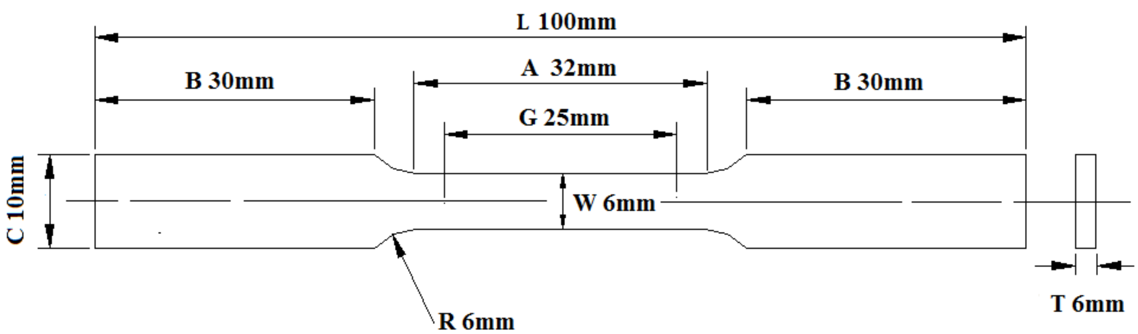


Fig. 2: Tensile specimen as ASTM B557 M-94 [6], G is gage length, W is width, T is thickness, R is radius of fillet, L is overall length, A is length of reduced section, B is length of grip section and C is width of grip section.

Result and Discussion

Tensile Strength and Hardness. Results of mechanical properties of tensile test and hardness are shown in Table 1. Variation of tensile strength and hardness of samples with TiC quantity are shown in Fig. 3 and Fig. 4. These results explain well the important effect of the fabrication methods, distribution of particles-homogeneity, and the size of reinforcement. From the graph plotted in Fig 3, it clearly seen that the addition of particle increased the properties of tensile strength compared without addition the particle. The properties of tensile strength are gradually decreased by increasing particle quantity followed the weight percentage (5 to 20%wt). Fig. 4 shows that the hardness value is increased gradually from 0 to 10%wt. and after 10%wt. the value of hardness is start decrease. The maximum hardness value obtained is 86.90 for 10 percentages. The improvement in hardness shows that the effect of TiC particulate is apparent. The behavior of the hardness result is partly due to the contribution of the constrained metallic matrix material as well as replacing some of the LM6 alloy matrix by the harder TiC particles.

Table 1: The Mechanical Properties for 5, 10, 15 and 20%wt TiC particulates

Weight Percentages %wt	Tensile Strength, σ (MPa)	Hardness Rockwell Superficial HR-15Y scale (%wt.)
0	121.81	85.28
5	140.34	86.30
10	139.33	86.90
15	132.55	86.56
20	123.83	82.60

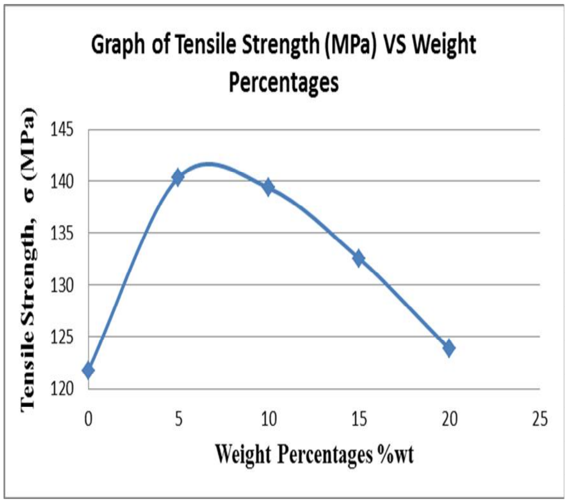


Fig. 3: Graph of tensile strength versus weight percentages

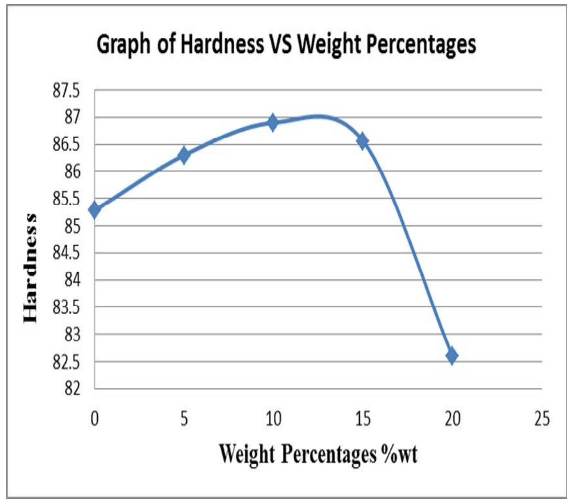
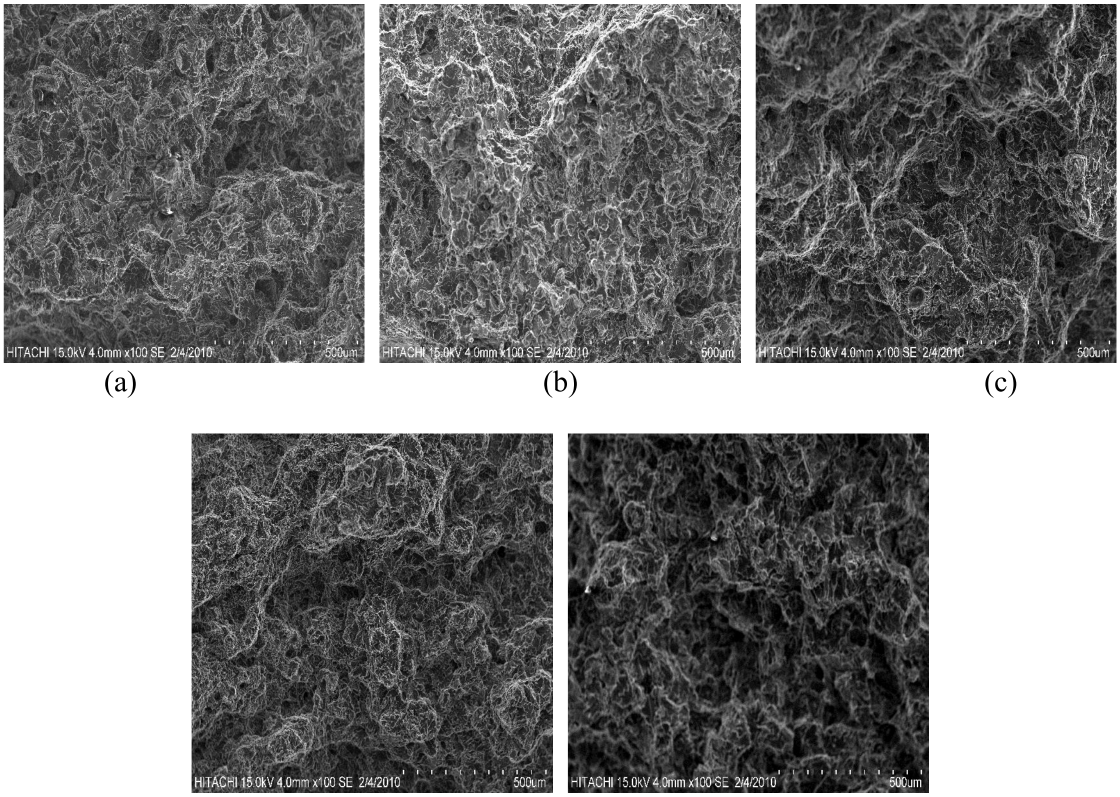


Fig. 4: Graph of hardness versus weight percentages

The strengths of the composites decrease with the increasing the amount of particle reinforcement. The composites reduce its resistance and create more sites for crack initiation and hence lower down the load-bearing capacity of the reinforcement [4]. The particles are no longer isolated with the ductile aluminum alloy matrix since the number of contacts between TiC particle increases. Therefore, cracks will not get arrested by the ductile matrix and would propagate easily between titanium carbide particulate [13]. The fluctuations of this result are affected by the experimental error and also depend on the cooling rate. It also caused by substantially non-uniform distribution of TiC particulates in the matrix under deformed condition. It is known that larger difference in the thermal expansion values between aluminum alloy matrix and the reinforcing particulates leads the mismatch. The elastic stresses generated due to the thermal mismatch put the particle into compression and the matrix into tension. This residual stress affects the material properties around in and the crack tips and the fracture toughness value would be altered. Consequently, these residual stresses would probably contribute for the brittle nature of composites [10].



(a) (b) (c) (d) (e)

Fig. 5: Factograph of (a) 0wt% (b) 5wt% (c) 10wt% (d) 15wt% (e)20wt% of TiC particulate reinforced in aluminium-11.8% silicon alloy matrix composite at 100X magnification by SEM after tensile testing

Fracture surface. In order to evaluate the character of failure and the bonding of the titanium carbide particles with the matrix, fractured surfaces of tensile specimens were examined using the Leo Variable Pressure SEM 1455 VP Series. By using it, the microstructures of tensile fracture surfaces are observed at 100X magnification to characterize the features of the failure and the type of failure. Fig. 5 shows the factograph of tensile fracture surface of without particles and 5, 10, 15 and 20 weight percentages addition of TiC particulate reinforced in aluminium-11.8% silicon alloy matrix. When microstructures of these samples were examined by SEM machine, brittle fracture was observed due to porous structure. It is clearly seen on Fig. 5. The thick, porous and bright structure of the matrix indicates brittle fracture of casting materials. It is observed that The particles are no longer isolated with the ductile aluminium alloy matrix during their addition due to titanium carbide particulate is pulled out due to poor bonding. Non uniform distribution of TiC particulates in the matrix under deformed condition also affected this result.

Conclusion

The results were obtained on the basis of the test carried out on the tensile and hardness specimens. It show improvements in term of mechanical properties of aluminium alloy 11.8% silicon when the particulate is added. Based on the experimental evidence from this research work the following conclusions are drawn. Aluminium alloy 11.8% silicon has been successfully developed with fairly dispersion of TiC particles. Addition of TiC particles significantly improves the value of tensile strength and hardness of LM6 alloy matrix reinforced with TiC particulates, when compared with that of unreinforced matrix, the tensile strength and hardness of aluminium alloy 11.8% silicon reinforced with TiC particulates composites is increased. However, the value of tensile strength and hardness begins to decrease above 10 wt% of TiC particles. Addition of TiC particles to aluminium alloy 11.8% silicon clearly improves the result of tensile strength and hardness. This is due to hard TiC particles dispersion in soft aluminium alloy matrix and enhanced the value of results due to distribution of the TiC particles are close with the aluminium alloy 11.8% silicon and the wettability ensure a good bonding between composites. The addition of 10%wt. to 20%wt. of TiC in aluminium alloy 11.8% silicon cause the decreasing value of tensile strength and hardness due to the lower resistance in the composites. These particles are no longer isolated with the aluminium alloy 11.8% silicon and will create more sites for crack initiation and decreased load-bearing capacity of the reinforcement. Scanning electron microscopic studies showed that the tensile fracture surface of aluminium alloy 11.8% silicon exhibits the ductile dimple structure. The poor bonding is due the interface are too weak to permit a transfer loads from matrix to particles.

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