Mechanical Properties of Al-Si-SiCp Composites

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ABSTRACT - This study investigated the effects of silicon and silicon carbide particles contents on the mechanical properties of Al-Si-SiCp composites. 16 samples of the composite were produced by stir casting with silicon contents of 1, 2, 3 and 4 wt.%, and silicon carbide particles contents of 0.5, 1, 1.5 and 2.0 wt.% for each composition of silicon. Samples from each composition were machined into standard tensile and impact test pieces. They were then subjected to homogenizing annealing heat treatment. Tensile test and impact test were then carried out on the samples. The results obtained showed that for a particular silicon content, impact strength of the Al-Si-SiCp composites increased when the SiCp content was increased from 0.5 to 2.0 wt.%. For a particular SiCp content, the composites exhibit an initial decrease in impact strength at 2 wt.% silicon, and then an increase in impact strength with increasing SiCp content. Also, increase in both SiCp and silicon contents caused an increase in the yield strength, ultimate tensile strength and elastic modulus, but a decrease in the ductility of the Al-Si-SiCp composites.

Keywords: Metal matrix composites, Impact strength, Tensile strength and Reinforcement

1. INTRODUCTION

Over the years, there has been an increased interest in metal matrix composites (MMCs), mostly light metal based, which have found their applications in many industries such as the aircraft and automotive industries, as well as in electrical engineering and electronics (Vukcevic and Delijic, 2002).

The metal matrix composite can be reinforced with particles, dispersoids or fibers. However, the biggest interest in composites materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological, heat or mechanical properties by selection of the volume fraction, size, and distribution of the reinforcing particles in the matrix (Mrowka- Nowotnik et al., 2007). They are used more often, compared with the composite materials of other metals, due to the broad range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials (Dobrzanski et. al., 2006). Particle reinforced metal matrix composite represent a group of materials where the hardness and wear resistance of the reinforcement are combined with the ductility and toughness of a matrix materials. Aluminum is the most frequently used matrix material for MMCs because of the combination of its light weight, environmental resistance, and useful mechanical properties (Muller and Monaghan, 2001 and Davis, 1990). Applications of aluminium matrix composites (AMCs) include drive shafts, fan blades, and shrouds, springs, bumpers, interior panels, tires, brake shoes, clutch plates (Charles, 1992). The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminium Oxide (Al_2O_3) (Ramnath et al., 2014).

The casting process is the most economical process in producing MMCs. However, it has some restrictions due to the matrix alloy and density of the reinforced phases. Therefore, the volume fraction and the size of the reinforcements that can be added are very limited (Yilmaz and Buytoz, 2001). Among discontinuous metal matrix composites, stir casting, currently practiced commercially, is generally accepted as a particularly promising route. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product.

There have been numerous researches on the mechanical properties of particle reinforced aluminium matrix composites. Tamer et al. (2008) investigated the mechanical and machinability properties of SiC particle reinforced Al-MMC. With the increase in reinforcement ratio, tensile strength, hardness and density of Al MMC material increased, but impact toughness decreased. Sedat et al. (2007) investigated the impact behaviour of SiC particle reinforced AMC under different temperature conditions. Their results showed that the impact behaviour of the composites was affected by clustering of particles, particle cracking and weak matrix-reinforcement bonding. Maik et al. (2007) studied the properties of AMCs based on preceramic-polymer-bonded SiC preforms. Polymethylsiloxane (PMS) was used as a binder. A polymer content of 1.25 wt.% conferred sufficient stability to the preforms to enable composite processing. It is thus shown that the PMS derived binder confers the desired strength to the SiC preforms without impairing the mechanical properties of the resulting Al/SiC composites. Sujan et al. (2012) studied the performance of stir cast Al_2O_3 and SiC reinforced metal matrix composite material. The result showed that the composite materials exhibit improved physical and mechanical properties, such as low coefficient of thermal expansion as low as $4.6x10^{-6}/^oC$, high ultimate tensile strength up to 23.68%, high impact strength and hardness. Zhang et al. (2010) studied the effects of particle clustering on the flow behaviour of SiC particle reinforced AlMMCs. The results revealed that during the tensile deformation, the particle clustering has greater effects on the mechanical response of the matrix than the elastic response and also the plastic deformation is affected very much. Elmasry, et al.(2008) investigated the structure and mechanical properties of aluminum metal matrix composite produced by hot pressing technique. Their results revealed that increasing fiber volume fraction results in an increase in the ultimate strength while ductility and toughness are decreased. There have been various other researches on effects of volume fraction of reinforcement on the mechanical properties of AMCs (Guiqing *et al.*, 2010 and Aigbodion, and Hassan, 2006). Although, there are numerous studies on the mechanical behaviour of particles reinforced MMCs but very few studies only have been explored on the mechanical properties of Al-Si-SiC_p composites. Thus the present study investigates the mechanical properties of Al-Si-SiC_p composites.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The major materials used during the course of the study are aluminium scraps, silicon and silicon carbide particles. Also, the major equipment used include: furnaces, Izod impact testing machine and universal tensile testing machine.

2.2 Composite Preparation

The Al-Si-SiC_p composite material was prepared at the Federal Institute of Industrial Research Oshodi (FIIRO), Lagos, Nigeria, by stir casting method. Sixteen different compositions of the composite were cast by varying the silicon and silicon carbide particle (600 grits) contents. The silicon contents were 1, 2, 3 and 4% by weights, and for each composition of silicon, the silicon carbide content was varied from 0.5

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to 2.0% by weight at interval of 0.5% wt. The melted composite materials were then cast into cylindrical rods. The furnace charge calculations are as shown in Table 1.

Table 1 : Furnace Charge Calculation for Al–Si-SiC_p Composite with 2% Silicon

Composite	Al(kg)	Si(kg)	SiC(kg)	T_m(kg)
Al -2%Si – 0.5%SiC_p	1.4625	0.030	0.0075	1.5
Al -2%Si – 1.0%SiC_p	1.4550	0.030	0.0150	1.5
Al -2Si – 1.5%SiC_p	1.4475	0.030	0.0225	1.5
Al -2%Si – 2.0%SiC_p	1.4400	0.030	0.0300	1.5

2.3 Chemical Composition Analysis

The spectrometric analysis of the Al-Si-SiC_p composites was carried out at the quality control department of Manaksia Industries Nigeria Limited, Sango Ota. The analysis was carried out to determine the final elemental composition of the composites after stir casting.

2.4 Mechanical Tests

Standard impact test pieces were prepared from each composition of the cast Al-Si-SiC_p composites. The test pieces were prepared of square cross-section of size 10 mm × 10 mm × 75 mm with single v-notch of size 45^o and 2 mm depth. Also, samples from each composite composition were machined into standard tensile test pieces (Fig. 1). The test pieces were then annealed in order to homogenize the composition. They were heated in an OMSZOV electrical furnace which was set to a temperature of 420 ^{o}C. They were then soaked at this temperature for five hours and furnace cooled. Impact test was then carried on the samples using the Izod Impact Testing Machine. Also, tensile test was carried out on the samples using the Instron Universal Testing Machine.

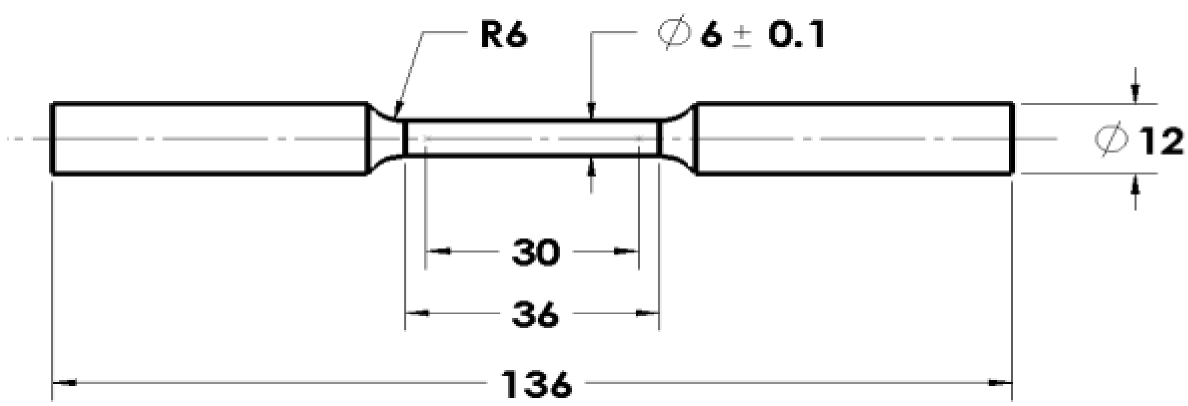

Fig. 1: Standard Specimen for Tensile Test

3. RESULTS AND DISCUSSION

3.1 Elemental Composition

The elemental composition of the samples with 4 wt.% silicon is presented in Table 2.

Table 2: The Chemical Composition of the Al-Si-SiC_p Composite Containing 4 wt.% Silicon

Element	Al	Si	Fe	Ti	Zn
Composition(%)	91.900	6.120	0.124	0.051	0.018

3.2 Impact Test

The results of the impact test are presented in Figures 2 and 3. Figure 2 shows the variation of impact strength of the Al-Si-SiC_p composites with varying SiC_p contents, while Figure 3 shows the variation of impact strength of Al-Si-SiC_p with varying silicon contents. The results show that for all the composites produced, impact strength varies with increase in SiC_p content (Fig. 2) and silicon content (Fig. 3). For a particular silicon content, impact strength of the Al-Si-SiC_p composites increased when the SiC_p content was increased from 0.5 to 2.0 wt.% (Fig.2). For a particular SiC_p content, the composites exhibit an initial decrease in impact strength at 2 wt.% silicon, and then an increase in impact strength with increasing SiC_p content. The increase in impact strength with increase in SiC_p content observed agrees with the results obtained by Singla et al. (2009) in a study to develop an aluminium based silicon carbide particulate metal matrix composite.

3.3 Tensile Test

The results of the tensile test are presented in |figures 4 to 11. Figure 4 shows the variation of yield strength of the Al-Si-SiC_p composites with varying SiC_p contents. For a particular silicon content, yield strength of the composites increased when the SiC_p content was increased from 0.5 to 2.0 wt.% (Fig. 4). Figure 5 shows the variation of yield strength of the Al-Si-SiC_p composites with varying silicon contents. For a particular SiC_p content, yield strength of the composites increased when the silicon content was increased from 1 to 4 wt.% (Fig. 5). Figure 6 shows the variation of ultimate tensile strength (UTS) of the Al-Si-SiC_p composites with varying SiC_p contents. For a particular silicon content, UTS of the composites increased when the SiC_p content

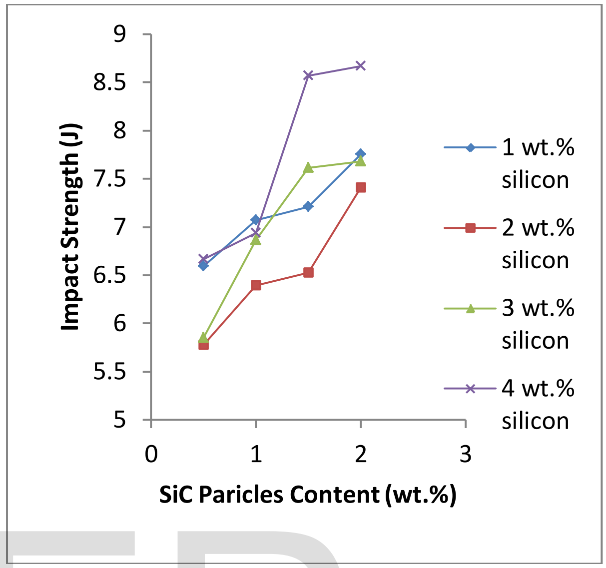

Fig. 2: Variation of Impact Strength of Al-Si-SiC_p Composites with SiC_p Content

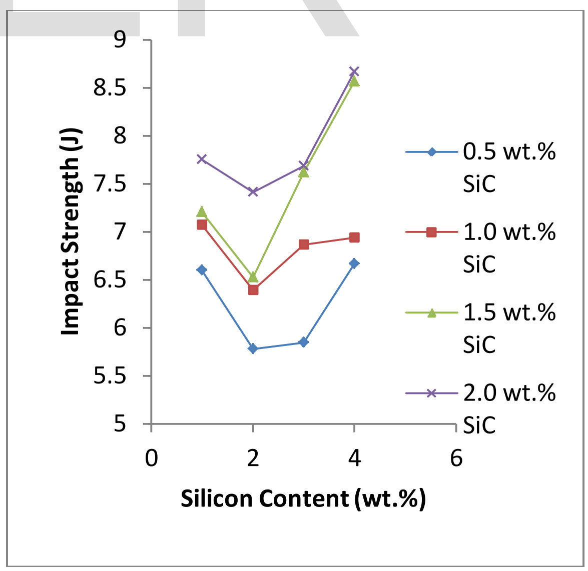

Fig. 3: Variation of Impact Strength of Al-Si-SiC_p Composites with Silicon Content

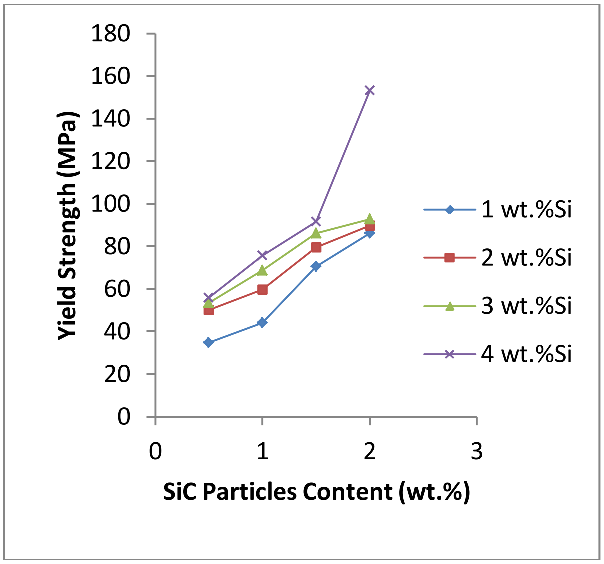

Fig. 4: Variation of Yield Strength of Al-Si-SiC_p Composites with SiC_p Content

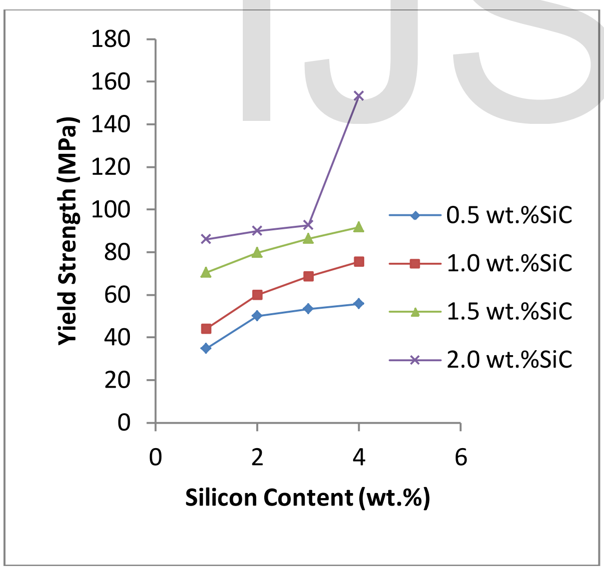

Fig. 5: Variation of Yield Strength of Al-Si-SiC_p Composites with Silicon Content

was increased from 0.5 to 2.0 wt.% (Fig. 6). Figure 7 shows the variation of UTS of the Al-Si-SiC_p composites with varying silicon contents. For a particular SiC_p content, UTS of the composites increased when the silicon content was increased from 1 to 4 wt.% (Fig. 7). Figure 8 shows the variation of the percentage elongation of the composites with varying SiC_p content. For a particular silicon content, percentage elongation of the composites decreased when the SiC_p content was increased from 0.5 to 2.0 wt.% (Fig. 8). Figure 9 shows the variation of the percentage elongation of the composites with varying silicon content. For a particular SiC_p content, the percentage elongation of the composites decreased when the silicon content was increased from 1 to 4 wt. %. For a particular silicon content, the elastic modulus of the composites increased with increasing the SiC_p content (Fig. 10). Also, for a particular SiC_p content, the elastic modulus of the composites increased with increasing silicon content (Fig. 11).

Therefore, increase in both SiC_p and silicon contents caused an increase in the yield strength, ultimate tensile strength and elastic modulus of the Al-Si-SiC_p composites. The increase in the strength of the composites with increasing SiC_p content can be attributed to the number of SiC particles that are needed to initiate and propagate the cracks in the composites (MahendraBoopathi et al., 2013). Also, the decrease in the ductility of the composites with increase in SiC_p and silicon contents can be explained by fact that silicon and SiC particles are harder and more brittle phases than aluminium.

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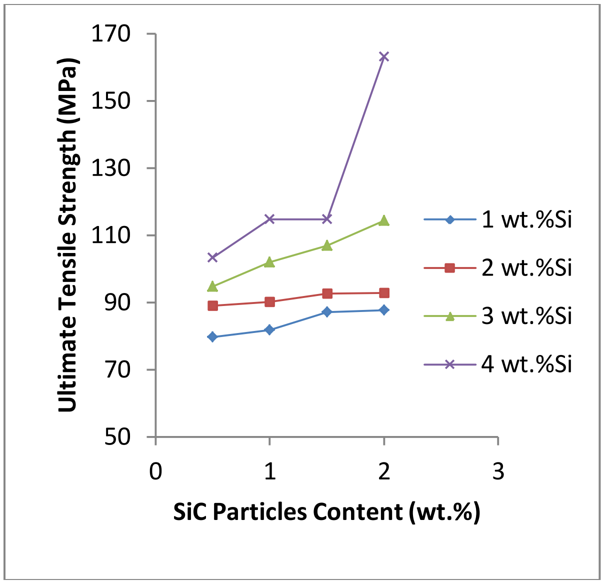

Fig. 6: Variation of Ultimate Tensile Strength of Al-Si-SiC$_p$ Composites with SiC$_p$ Content

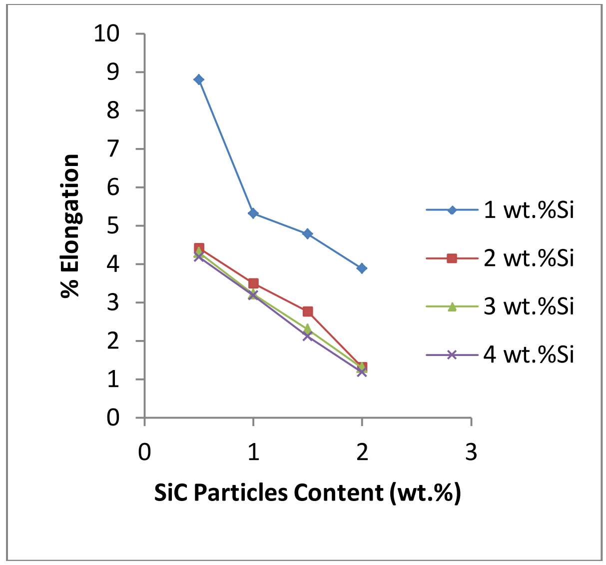

Fig. 8: Variation of Percentage Elongation of Al-Si-SiC$_p$ Composites with SiC$_p$ Content

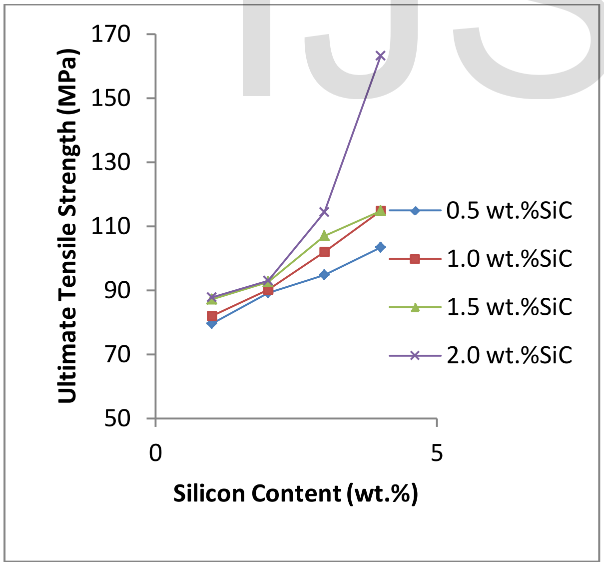

Fig. 7: Variation of Ultimate Tensile Strength of Al-Si-SiC$_p$ Composites with Silicon Content

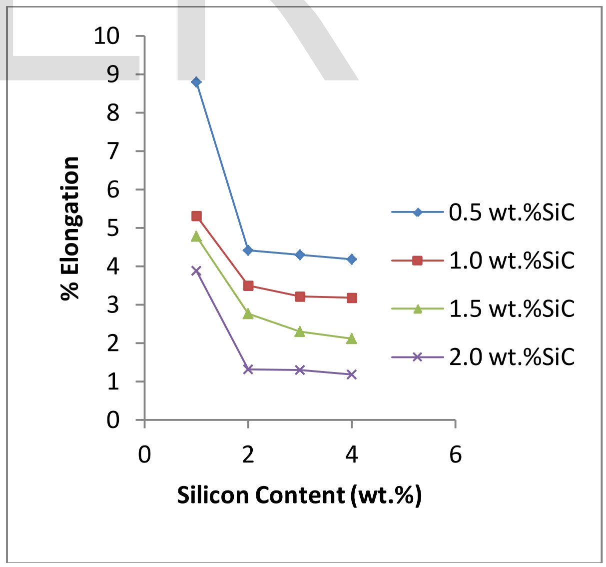

Fig. 9: Variation of Percentage Elongation of Al-Si-SiC$_p$ Composites with Silicon Content

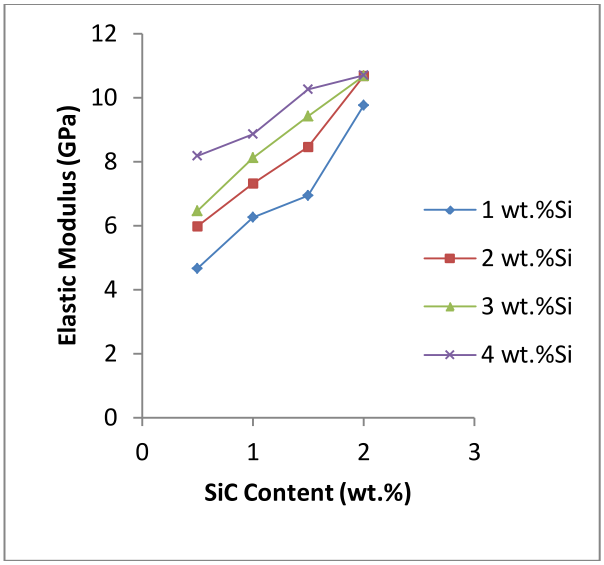

Fig. 10: Variation of Elastic Modulus of Al-Si-SiC_p Composites with SiC_p Content

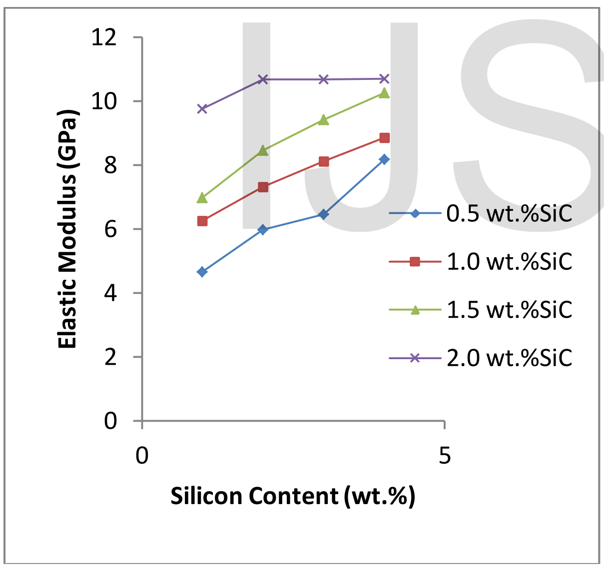

Fig. 11: Variation of Elastic Modulus of Al-Si-SiC_p Composites with Silicon Content

CONCLUSION

From the results obtained from the study, it can be concluded that varying the silicon and silicon carbide particles contents affects the mechanical behaviour of the Al-Si-SiC_p composites. When the SiC_p content is varied from 0.5 to 2.0 % and the silicon content is varied from 1 to 4 %, the yield strength, ultimate tensile strength and elastic modulus of the composites increased while the ductility decreased.

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