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EFFECT OF PARTICLES SIZE ON THE MECHANICAL PROPERTIES OF SiC-REINFORCED ALUMINIUM 8011 COMPOSITES

VPLIV VELIKOSTI DELCEV NA MEHANSKE LASTNOSTI S SiC OJAČANIH ALUMINIJEVIH 8011 KOMPOZITOV

Nagaraj Ashok, Palanisamy Shanmughasundaram

Karpagam Academy of Higher Education, Karpagam University, Department of Mechanical Engineering, Coimbatore 641021, India
sunramlec@rediffmail.com, ashok2488@rediffmail.com

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The effects of the SiC particle size on the mechanical properties of aluminium 8011-SiC composites are reported. Three different particle sizes of SiC (63, 76, 89) μm with two different mass fractions of 2 % and 4 % reinforced with aluminium 8011 were processed using the stir-casting method. The mechanical properties, like hardness, tensile strength, yield strength, ductility, and toughness, of the composites and the unreinforced alloy were tested. It was observed that the hardness, tensile strength, yield strength, ductility, and toughness increase with a decrease in the particle size of the SiC. The increase in weight fraction of the SiC improves all the mechanical properties, except for the ductility and toughness of the composites. The results reveal that the fine 63 μm (220 mesh) SiC particles introduced superior mechanical properties compared to the intermediate 76 μm (180 mesh) SiC particles and the coarse 89 μm (150 mesh) SiC.

Keywords: composites, particle size, stir casting method, weight fractions, mechanical properties

Delo poroča o učinkih velikosti delcev SiC na mehanske lastnosti aluminijevih 8011 kompozitov. Tri različne velikosti delcev SiC (63, 76, 89) μm z dvema različnima deležema teže (2 in 4) %, ojačane z aluminijem 8011, so bile obdelane z metodo mešanja in litja. Testirane so bile mehanske lastnosti, kot so: trdota, natezna trdnost, meja tečenja, duktilnost in žilavost kompozitov in neojačane zlitine. Ugotovljeno je bilo, da se trdota, natezna trdnost, meja tečenja, duktilnost in žilavost povečajo z zmanjšanjem velikosti delcev SiC. Povečanje deleža masnega odstotka SiC izboljšuje vse mehanske lastnosti razen razteznosti in žilavosti kompozitov. Rezultati kažejo, da drobni 63 μm (220 mesh) SiC delci pokažejo nadpovprečne mehanske lastnosti v primerjavi z vmesnim 76 μm (180 mesh) SiC delci in grobimi 89 μm (150 mesh) SiC.

Ključne besede: kompoziti, velikost delcev, metoda mešanja in litja, masni deleži, mehanske lastnosti

1 INTRODUCTION

Aluminium metal-matrix composites are being used as materials for automobile and aerospace applications. Aluminium- and magnesium-based Metal-Matrix Composites (MMCs) are an important class of high-potential engineering materials.[1] Aluminium alloy reinforced with silicon carbide displays better mechanical and tribological properties than the unreinforced alloy because of their high strength-to-weight ratio. Silicon carbide is often the preferred reinforcement in the production of aluminium powder composites.[2] Stir casting can be used to fabricate the composites for a better homogenous distribution of reinforcement particles in the matrix. P. Shanmughasundaram et al.[3] investigated the effect of the addition of fly ash on the mechanical and wear behaviour of Aluminium–fly ash composites. The composites were prepared with the varying weight percentage of fly ash (5, 10, 15, 20 and 25) by a two-step stir-casting method. They concluded that hardness, tensile strength and compressive strength of the composites increases up to the addition of 15 % of mass fractions of fly ash, so it is the maximum reinforcement level to obtain the desired property. S. G. Kulkarni et al.[4] investigated the effect of fly ash and alumina on the mechanical property of aluminium 356 alloy. They have concluded that the addition of fly ash and alumina increases the mechanical properties like hardness, tensile strength and compressive strength of the composites. Sudarshan et al.[5] analysed the mechanical properties of Al356-fly ash composites prepared by stir casting and hot extrusion. They used narrow-size-range (53–106 μm) and wide-size-range (0.5–400 μm) fly ash particles as reinforcement. Their results revealed that small size particles (53–106 μm) display higher mechanical properties than the larger size particles. P. Shanmughasundaram et al.[6] applied ANOVA and Taguchi methods for the selection of optimum level of parameters to obtain the maximum mechanical properties of Al-fly ash composites. They concluded that a modified two-step stir-casting method enhances the uniform distribution of fly ash particles in the aluminium matrix and improves the mechanical properties. Baradeswaran et al.[7] investigated the mechanical and wear properties of Al 7075/Al_2O_3/graphite hybrid composites. The hybrid composites were prepared with the reinforcement of different weight percentages of alumina (2, 4, 6, and 8) and 5 % mass fractions of graphite. They concluded that the mechanical properties increased due to the increase in solid-solution strengthening. V. Ramnath et al.[8] analysed the mechanical behaviour of aluminium-boron carbide-alumina composites produced by the stir-casting method. They concluded that the hardness and toughness of the aluminium-boron carbide (3 % of mass fractions) alumina (2 % of mass fractions) composites exhibit superior properties than the other composites and unreinforced alloy. Veereshkumar et al.[9] have studied Al6061-SiC and Al7075-Al_2O_3 composites produced by liquid metallurgy technique. R. Harichandran et al.[10] investigated the effect of micro and nanoparticle reinforcement of boron carbide on the aluminium alloy by ultrasonic cavitation-assisted stir casting. T. Thirumalai et al.[11] analysed the aluminium matrix composites reinforced with boron carbide and graphite fabricated by the stir-casting method. Different weight fractions of boron carbide (3, 6, 9, and 12 % of mass fractions) and graphite (3 % of mass fractions) were reinforced with LM25Al alloy. Their results revealed that the hardness of the composites was higher than that of the unreinforced alloy. J. Hashim et al.[12] analysed the low-cost stir-casting method for the preparation of high-quality aluminium-SiC composites. They found that by controlling the various process parameters like position of the impeller, size of the impeller, holding temperature, stirring speed and addition of weight percentage of reinforcement a wide range of mechanical properties were obtained. P. Pugalenthi et al.[13] conducted tests on the mechanical properties of 7075 aluminium alloy reinforced with 2 % of mass fractions of SiC and (3, 5, 7, 9) % of mass fractions of alumina hybrid composites. Their result revealed that the hardness and tensile strength of the composites increase with an increase in the reinforcement of SiC and alumina. S. M. L. Nai et al.[14] analysed the effect of stirring speed on the synthesis of Al/SiC based functionally gradient materials. They concluded that an increase of the stirring speed will lead to a more homogeneous distribution of SiC particulates alongside the deposition direction. N. Radhika et al.[15] analysed the mechanical properties and tribological behaviour of LM25/SiC/ Al_2O_3 composites with reinforcement of (5, 10, 15) % mass fractions of SiC and (5, 10, 15) % of mass fractions of alumina. It was found that the composites with reinforcement of 30 % (15 % SiC and 15% alumina) have higher hardness and tensile strength than the unreinforced base alloy. K. Komai et al.[16] investigated the tensile and fatigue fracture behaviour of Al7075/SiC composites. They reported that the mechanical properties of Al7075/SiC composites were superior to the unreinforced alloy. T. J. A. Doel et al.[17] analysed the tensile properties of Al-SiC composites. The three different particle size of SiC (5, 13, 60) μm, were used as reinforcement. They concluded that coarse SiC particles fracture easily at low load than the fine and intermediate SiC particles. C. Sun et al.[18] investigated the effect of SiC particle size on the mechanical properties of aluminium-SiC composites. They concluded that the tensile strength and yield strength of the composites increases due to the addition of fine SiC particles. H. C. Anilkumar et al.[19] investigated the effect of fly ash particle size (4–25, 45–50 and 75–100) μm and reinforcement weight fractions (10, 15 and 20) % on the mechanical properties of Al6061 composites reinforced with fly ash. Their result reveals that the tensile strength, compressive strength and hardness of the aluminium alloy (Al 6061) composites increased with an increase in the weight fraction of reinforced fly ash and decreased with an increase in the particle size of the fly ash. M. Kok[20] analysed the effect of particle size and the weight fraction of alumina on the mechanical properties of Al2024-alumina composites. Three different particle sizes (16, 32 and 66) μm and three different mass fractions (10, 20 and 30) % of alumina were used as the reinforcement to produce composites by the vortex method, followed by applied pressure. The results reveal that the reinforcement of fine alumina particles exhibits a higher mechanical property than the intermediate and coarse particles. M. Rahimian et al.[21] investigated the effect of particle size and weight fraction of alumina on the mechanical properties of aluminium matrix composite produced by powder metallurgy. Three different weight fractions (5, 10, 15) and three different particle sizes of alumina (3, 12, 48) μm were used as the reinforcement. Their results show that the finer particle (3 μm) has the highest yield strength, hardness, compressive strength, elongation than the intermediate (12 μm) and coarse particle (48 μm) reinforcement. M. Kok et al.[22] examined the effect of two different particle sizes of alumina on the mechanical and wear behaviour of the Al 2024 alloy. They revealed that the hardness and tensile strength of the smaller particle reinforcement were much higher than the larger particle size. S. Mahdavi et al.[23] analysed the hardness and wear behaviour of Al6061 composites with the reinforcement of three different SiC particles (19, 93, 146) μm. Their result shows that the hardness increases with a decrease in the particle size of the SiC reinforcement. From the literature it was observed that the mechanical properties of the composites depend on the size and quantity of the reinforcement particles. Earlier studies indicated that the mechanical properties of the composites can be improved with a decrease in the particle size and an increase in the reinforcement content. Hence, a systematic study has to be carried out to study the effect of particle size and weight fraction of reinforcement on the mechanical behaviour of the composites. In this present work Al8011-SiC composites with the reinforcement of three different particle sizes of SiC (63, 76 and 89) μm and two different weight fractions (2 and 6) % of SiC were fabricated using the stir-casting method and its various mechanical properties like hardness, tensile strength, yield strength, ductility and toughness were tested.

2 EXPERIMENTAL PART

2.1 Stir-casting method

In this research work, Al 8011-SiC composites were fabricated with three different particle sizes 89 μm (coarse), 76 μm (intermediate) and 63 μm (fine) and two different weight fractions (2 and 6) % of SiC were used as reinforcement by stir the casting method. The composition of Al 8011 alloy is presented in **Table 1**.

Table 1: Composition of Al alloy 8011 alloy

Element	In mass fractions, (*w*/%)
Al	97.14
Si	0.53
Fe	0.99
Cu	0.27
Mn	0.21
Mg	0.25
Cr	0.049
Zn	0.19
Ti	0.028
Pb	0.10
Ca	0.008
Ni	0.045

Stir-casting setup that was used to fabricate the composites is shown in **Figure 1**.

To remove the moisture content from the SiC particles, they were preheated for 60 min in a separate muffle furnace. Aluminium 8011 was added to the graphite crucible and the furnace temperature was maintained at 780 °C, then the Al scraps were melted completely. The melt temperature was reduced to 720 °C to obtain the semi-solid state, then the preheated SiC particles and 1.5 % of mass fractions of Mg was added to the molten slurry. Stirring was done for 5 min. Mg were added to the mixture to increase the wettability between the Al matrix and SiC particles. The stirring speed was maintained at 300 min^{-1} throughout the process. Then, finally again the temperature was raised to the liquid state and poured into the mould for solidification.

Figure 1: Stir casting setup[3]

Figure 2: Examined hardness test samples of Al8011 and Al 8011-SiC composites

3 MECHANICAL PROPERTIES

3.1 Hardness test

The hardness tests of Al8011-SiC composites and unreinforced alloy were carried out using Rockwell hardness machine MSM model with ASTM E18:2014 standard with 1/16” inch ball indenter with a load of 980 N. The loading time for the test period was 15 s. The average of three readings was taken to eliminate the error at room temperature. The examined hardness test samples of Al8011 and Al 8011-SiC composites are shown in **Figure 2**.

3.2 Tensile test

Tensile tests were carried out using UTM testing machine M30 model as per ASTM E8:2015 standard for the Al8011 and Al8011-SiC composites. Three samples were taken and tested and the average of three test readings was taken and noted. The examined tensile test samples of Al8011 and Al 8011-SiC composites are shown in **Figure 3**.

3.3 Impact test

The toughness test was carried out by using charpy impact test machine (AIT-300-EN). The energy required to break the specimen was measured in terms of Joules. The final energy measured was the difference between the total energy supplied to break the specimen to the en-

Figure 3: Examined tensile test samples of Al8011 and Al 8011-SiC composites

ergy available after the specimen fracture. The test method used was ISO-148-1:2009. The standard specimen size for this impact test method was 10 mm × 10 mm × 55 mm. Three specimens were tested and the average of three readings was noted. Examined Charpy impact test samples of Al8011 and Al 8011-SiC composites are shown in **Figure 4**.

Mechanical properties of pure Al and Al8011-SiC Composites are presented in **Table 2**.

Table 2: Mechanical Properties of Al8011-SiC Composites

Sic (*w*/%)	Hardness (RHB)	Yield strength (MPa	Tensile strength (MPa)	Elonga-tion %	Tough-ness (J)
0	90	46	67	7	10
2 % (89 μm)	92	54	73	7.5	15
2 % (76 μm)	94	58	78	7.8	16
2 % (63 μm)	96	63	84	8.4	17
6 % (89 μm)	98	76	98	7.2	12
6 % (76 μm)	102	81	105	7.4	13
6 % (63 μm)	105	87	111	7.7	14

Figure 4: Examined Charpy impact test samples of Al8011 and Al 8011-SiC composites

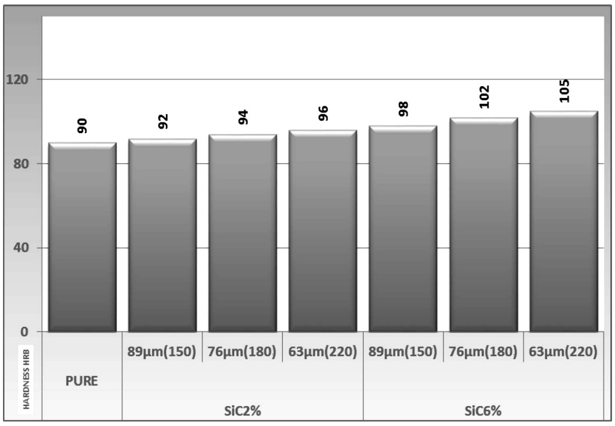

Figure 5: Effect of mesh size of SiC on the hardness of Al8011-SiC composites

4 RESULTS AND DISCUSSION

From **Figure 5** it can be observed that as the particle size decreases the hardness of the composite increases for 2 % and 6 % of mass fractions reinforcement of SiC. The hardness of Al8011-SiC-63 μm (220 mesh) for 6 % of mass fraction was observed to be 105 HRB, which was 16 % more than the unreinforced alloy (90 HRB). Hard SiC particles act as a barrier to the applied load. Hardness of the Al8011-SiC composites was greater than the unreinforced alloy because of the hard nature of the SiC particles. The addition of hard ceramic particles increased the bulk hardness of the aluminium alloy. Fine particle size 63 μm (220 mesh) reinforcement of SiC exhibit superior hardness than the intermediate SiC-76 μm (180 mesh) and coarse SiC-89 μm (150 mesh). This result was similar to the statement concluded by M. Kok.[20] M. Kok reported that the hardness of the composites increased with decreasing size and increasing weight fraction of the reinforcement particles. The increase in hardness was due to the presence of a larger interfacial area

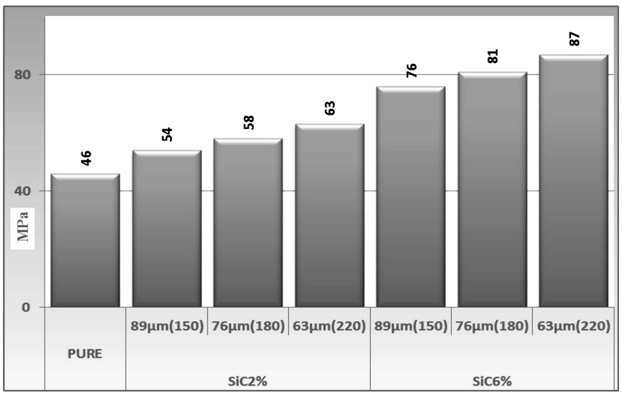

Figure 6: Effect of mesh size of SiC on the yield strength of Al8011-SiC composites

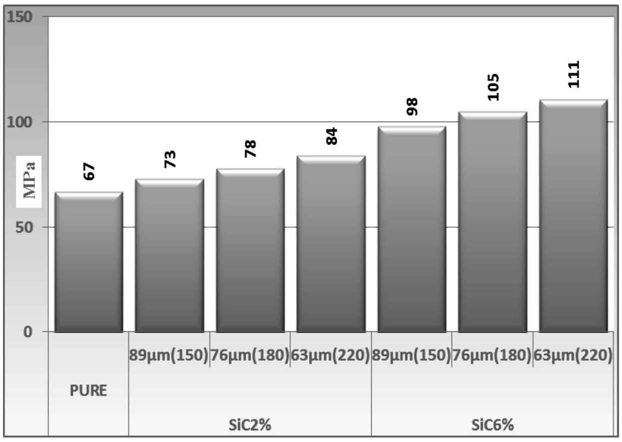

Figure 7: Effect of mesh size of SiC on the tensile strength of Al8011-SiC composites

between the soft and hard phases. Decreasing the alumina particle size increases the hardness. A similar observation was made by M. Rahimian.[21]

From **Figure 6** it is observed that yield strength increases as the weight fraction of SiC increases. The yield strength of Al8011-6 % of mass fractions of SiC-63 µm (220 mesh) was observed to be 87 MPa which was 89 % higher than the unreinforced alloy. The yield strength also increases with the decrease in particle size of SiC. It was noted that the value of yield strength was 54 MPa for Al8011-2 % of mass fractions of SiC-89 µm (150 mesh), 58 MPa for Al8011-2 % of mass fractions of SiC-76 µm (180 mesh) and 63 MPa for Al8011-2 % of mass fractions of SiC-63 µm (220 mesh), that was 16 % increase when compared to the 150 mesh size.

From **Figure 7** it is clear that the tensile strength of the composites was higher than the pure Aluminium 8011. The tensile strength of unreinforced Al8011 was 67 MPa and the value increased to 84 MPa for Al8011-2 % of mass fractions of SiC-63 µm (220 mesh). An increase of 25 % in tensile strength was observed. Similarly 111 MPa for Al 8011-6 % of mass fractions of SiC-63 µm

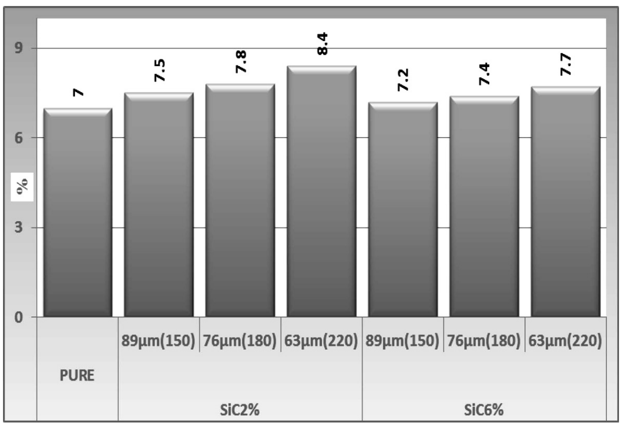

Figure 8: Effect of mesh size of SiC on the elongation of Al8011-SiC composites

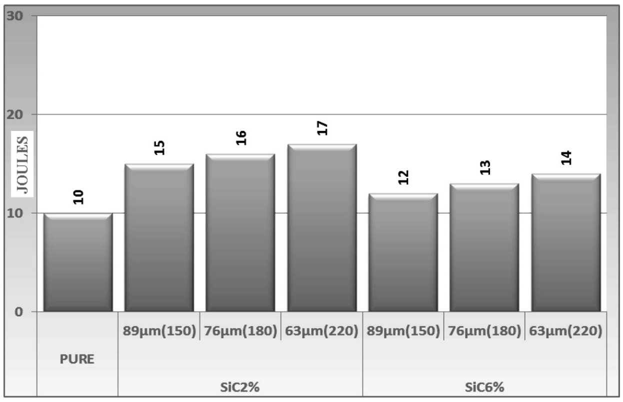

Figure 9: Effect of mesh size of SiC on the toughness of Al8011-SiC composites

(220 mesh), increase of 65 % was observed when compared to the unreinforced alloy.

From **Figure 8** it is clear that the elongation of the composites increases with the decrease in the particle size. The elongation tends to decrease when the amount of reinforcement increases. The Al 8011-2 % of mass fractions of SiC has a higher elongation than the Al8011-6 % of mass fractions of SiC composites. The elongation decreases to 7.7 % from 8.4 % drop of 9 % was observed. The increase in tensile strength and yield strength was due to the increase in dislocation density caused by the reinforcement of the hard SiC particles. As smaller reinforcement particle size reduces the distance between the reinforcement particles, the movement of dislocations tends to decrease, leading to a higher strength of the composites. The grain boundary acts as a barrier to the movement of dislocations caused by the plastic deformation. Therefore, at a higher mess size, high grain boundaries are formed, which act as a barrier against the movement of the dislocation.

From **Figure 9** it is observed that the highest toughness of 17 J was observed for Al8011-2 % SiC-63 µm (220 mesh). The value was 16 J for Al8011-2 % of mass fractions of SiC-76 µm (180 mesh) and 15 J for Al8011-2 % of mass fractions of SiC-89 µm (150 mesh). But the toughness decreases for the reinforcement of 6 % of mass fractions of SiC particles.

5 CONCLUSIONS

Al 8011-SiC composites were produced successfully by the stir-casting method and a homogenous distribution of SiC particles in the Al8011 matrix was obtained. From the tests conducted the following conclusions can be drawn:

1. Hardness increased with the decrease in SiC particle size. The highest hardness (105 HRB) was obtained for 6 % of mass fractions of SiC particle reinforced composites with 63 µm particle size.
2. The coarse particle size of SiC has a lesser yield strength and tensile strength. The highest amount of

yield strength and tensile strength were 87 MPa, 111 MPa for the sample containing 6 % of mass fractions of SiC with 63 μm particle size.

3. Elongation decreased as the weight fraction of SiC increases. The 6 % of mass fractions of SiC particle reinforced composite with 63 μm SiC particles has the elongation of 7.7 % which was 8 % less than the 2 % of mass fractions of SiC particle-63 μm (220 mesh).
4. Toughness increased with the decrease in particle size for both the 2 % and 6 % mass fractions of SiC particle reinforced composites. The highest amount of toughness was 17 J for the sample containing 2 % of mass fractions of SiC with 63μm SiC particles.

Hardness, yield strength, and tensile strength increase with the increase in weight fraction of SiC, while the toughness and ductility decrease. Fine reinforcement of SiC-63 μm (220 mesh) with Al 8011 exhibit superior mechanical properties than the coarse SiC-89 μm (150 mesh) and intermediate SiC-76 μm (180 mesh) particles.

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