CHEMICAL ENGINEERING TRANSACTIONS
VOL. 63, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jeng Shiun Lim, Wai Shin Ho, Jiří J. Klemeš

ISBN 978-88-95608-61-7; **ISSN** 2283-9216

DOI: 10.3303/CET1863104

The Influence of Silicon Carbide Particulate Loading on Tensile, Compressive and Impact Strengths of Al-Sicp Composite for Sustainable Development

Hassan Mudathir Abdulsalam, Ofor Tochukwu. Charles, Babakano Ahmed, Moveh Samuel*

Department of Mechanical Engineering. Modibbo Adama University of Technology Yola, Adamawa State. Nigeria.
smoveh@mautech.edu.ng

Metal matrix composites reinforced with silicon carbide are potential materials for various applications owing to their excellent mechanical properties. This study investigated the effect of silicon carbide particulate loading on the tensile, compressive and impact strengths of Aluminium (6,063)–silicon carbide composite. The silicon carbide particulates were loaded at 10 wt% intervals between 10 wt% and 50 wt % SiCp with the 0 % loading as a control. The composites were produced by stir casting. Tensile strength, compressive strength and impact strength tests were conducted on samples of the produced composites. The result revealed a general pattern of increase in the tested parameters with an increase in percentage loading of SiCp up to a certain level after which declines were observed. The tensile strength increased from 131 MPa to a peak of 194.6 MPa after which it declined; compressive strength increased from 163.6 MPa to a peak value of 233.5 MPa and the impact strength increased from 140 kJ/mm^2 to 250 kJ/mm^2 as the silicon carbide content increased from 0 wt% to 40 wt%. The parameters observed for the 50 wt% loading were 10.40 %, 21.87 % and 8.96 % less than the peak values for tensile, compressive and impact strengths respectively. The 40 wt% loading of SiCp in Aluminium 6063 alloy produced the best-observed effect on the tensile, compressive and impact strengths of the composite studied. It was concluded that the composition of the studied composite with 40 wt% silicon carbide content is the more suitable for high-performance applications.

1. Introduction

Metal matrix composite materials (MMC) represent a good solution for environmental problems caused by the emissions of vehicles, thanks to the possibility to reduce their overall weight by increasing specific mechanical properties of structural materials (Danilo et al., 2017). And is fast gaining grounds in the manufacturing and industrial firms. It is imperative to study the composite materials because it is the material for advanced technology, a high-temperature application where high strength, the stiffness-to-weight ratio is required (Zweden, 1992). The composite technology combines essential properties required for an engineering part. Composite materials usually consist of two or more physically or chemically distinct phases, suitably arranged or distributed. It has the characteristics that are not depicted by any of its components in isolation. The continuous phase is referred to as the matrix, while the distributed phase is called the reinforcement (Folger, 1988).

Advances in production and manufacturing technologies are close-knitted with the availability of advanced materials, which are required for use in high-performance conditions, and often with tailorable properties. In the last three decades, studies have been carried out on composite materials, which, owing to their nature, are best suited to allowing designers to tailor the material used to the required properties in an application. Composite are generally formed by mixing two or more different materials without chemical reaction. Some composites are of metallic matrices mixed with ceramic additives to give Metal Matrix Composites (MMC); some have polymeric matrices mixed with reinforcements to form Polymer Matrix Composites (PMC) while others are of ceramic matrices with reinforcements to give Ceramic Matrix Composites (CMC).

Please cite this article as: Hassan Mudathir Abdulsalam, Ofor Tochukwu. Charles, Babakano Ahmed, Moveh Samuel, 2018, The influence of silicon carbide particulate loading on tensile, compressive and impact strengths of al-sicp composite for sustainable development, Chemical Engineering Transactions, 63, 619-624 DOI:10.3303/CET1863104

Most of the studies on MMC have focused on Aluminium (Al) as the matrix metal (Kon and Hoon, 2002), the combination of lightweight, corrosion resistance and adequate mechanical properties have made aluminium and its alloys very popular in making composites. The melting point of aluminium is high enough to satisfy many application requirements, yet low enough to render composite processing reasonably convenient. It can accommodate a variety of reinforcing agents. Discontinuous Al-SiC and Al-Al2O3 MMC have found widespread applications in aerospace, transport, military, energy and electric industries; for example, they have been used in electronic packaging, aerospace structures, aircraft and internal combustion engine components and a variety of recreational products (Abhijit and Krishna, 2015).
Conventional processing methods include powder metallurgy and molten metal methods (Hassan et al., 2014). Using the molten metal method, various reinforcing materials such as graphite, illite clay, Zirconia have been incorporated in Aluminium matrix composites. The fundamental limitation of this method is the poor wettability of ceramic reinforcement particles with liquid Al alloys (Mandal and Viswanathan, 2013). Wet-ability is the ability of a liquid to spread well on the solid reinforcement surface; it reflects the extent of intimate contact between the liquid and the solid, wet-ability enhances the tendency of reinforcement agglomeration. Poor wettability presents a significant challenge to the production of cast metal matrix composites. It usually results in poor distribution of reinforcement particles, high porosity, and poor mechanical properties (Kelly and Davies, 2000). Wettability can be improved by the introduction of suitable additives or by using other methods of production.
This study investigates the effects of SiCp loading on tensile, compressive and impact Strengths of Al-SiCp composites produced using stir casting. To enhance wettability and increase the speed of incorporation of the two phases, the reinforcement material was preheated before pouring into the molten matrix material.

2. Experimentations

In this study, Aluminium 6063 was used as the matrix while silicon carbide particulate was used as the reinforcement. The matrix was heated in a carbolite furnace to a temperature of 800 °C. To enhance the wettability and speed of incorporation, the reinforcement material was also separately heated to 800 °C. After the melt was obtained, it was stirred vigorously at a speed of 450rpm with a graphite stirrer while the required quantity of the preheated SiCp was introduced. The homogenised mixture was then cast in a sand mould. The composite samples were produced with SiCp loading varying between 10 % and 50 % at 10 % intervals. The samples produced were subjected to tensile, compressive and impact tests.

2.1 Tensile Test

Tensile test samples, shown in plate 1, were machined according to ASTM D638 standard. The tests were conducted at room temperature with the aid of Universal Instron Machine, model 3369 in the physics laboratory of Obafemi Awolowo University Ile-Ife, Nigeria. The stress-strain graphs, shown in Figure 1, were plotted automatically, from which the percentage elongation at yield and tensile strength were calculated.

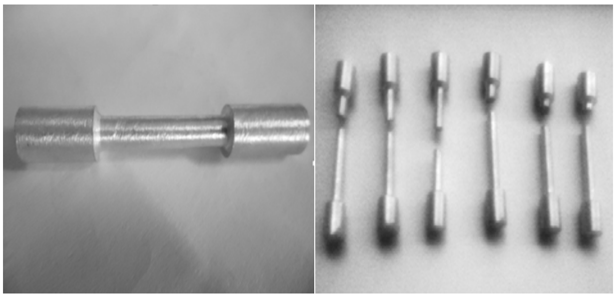

Figure 1: Tensile Strength Sample before and after test

2.2 Compressive Test

The compressive test was carried out to determine the amount of force required to crush or fracture the specimen during application of pressure. The test was conducted similar to tensile test, except that the force is compressive and the specimen contracts in the direction of the stress. The sample was cut to a thickness of about 20 mm x 20 mm x 20 mm, then the compressive test was carried out with a Mosanto Hounsfield Tensiometer testing machine. A graph paper which has a force versus extension axes meant for the Mosanto machine was fixed on a cylindrical roller at the head of the machine, then a load of 2,000 kg was also fixed at the load segment at the head of the machine. The reader meter was also changed to correspond to the load.

Mercury was poured in the indicator part of the machine after that the bubbles were removed by test running. The sample was then placed in the machine and was applied by rotating the handle of the machine in a clockwise direction, during the process, the pointer was plotting the graph through perforation as the graph paper rotates. It was then brought out and traced with a pencil. The same procedure was repeated for other samples.

2.3 Impact Test

The samples for impact tests were machined to a thickness of 6.5 mm based on ASTM D256 standard. The samples were notched with a fill to a depth of about 3 mm at an angle of 45° as in Figure 2. After that, the impact test was conducted on an Izod machine.

Figure 2: Notched specimen just before and after the impact (Izod) test

3. Results and Discussion

The results of tensile strength test are given in Table 1. Table 1 reveals that the tensile strength increases with increase in the percentage weight of silicon carbide particulate content up till a peak value of 194.60 MPa after which the tensile strength value starts to decrease. The observed trend conforms to observations of Usman et al. (2014a) which reported similar trends for the tensile strength of Al-Bagasse ash MMC. In another work, Usman et al. (2014b) reported a similar observed trend on the effect of rice husk ash loading on the tensile strength of a composite formed using rice husk ash as reinforcement. The 40 wt% loading of silicon carbide was observed to have the highest tensile strength value while the tensile value drops at 50 wt%. This decrease could be as a result of slow cooling rate, and embrittlement of the material to reduced bonding at the matrix-reinforcement interface as a result of the fact that reinforcing SiCp are getting overcrowded (Tham et al., 2001).

Table 1: Result of Tensile Strength test

Specimen	Compressive strength (MPa)			
(% Composition of SiC_p)	Sample 1	Sample 2	Sample 3	Average
0	131.4721	131.2011	131.0192	131.2308 ± 0.45
10	145.6801	145.6921	146.2505	145.8732 ± 0.19
20	156.5840	158.7351	158.5210	156.9462 ± 0.69
30	180.1701	183.0345	183.4302	182.1433 ± 1.03
40	190.2585	197.1235	196.3341	194.6022 ± 2.17
50	172.3214	174.8902	175.8316	174.3477 ± 0.44

The tensile stress-strain plots for the composite samples with 0 %, 10 wt%, 20 wt%, 30 wt% and 50 wt% of SiCp loading are illustrated in Figures 3, 4, 5, 6 and 7. All the samples tend to conform to a general stress-strain shape with a clear suggestion that the samples increase in brittleness with an increase in SiCp loading. This is also an expected tendency as the increased quantity of the ceramic reinforcement reduces the material ductility. Compressive strength tests also reveal a behaviour similar to that shown by tensile strength tests regarding the relationship of strength values with percentage SiCp loading.

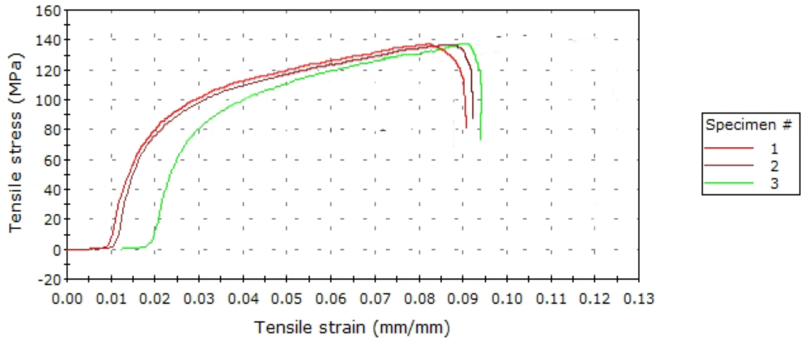

Figure 3: Tensile stress-strain plots for the composite samples with 0 wt% of SiCp loading

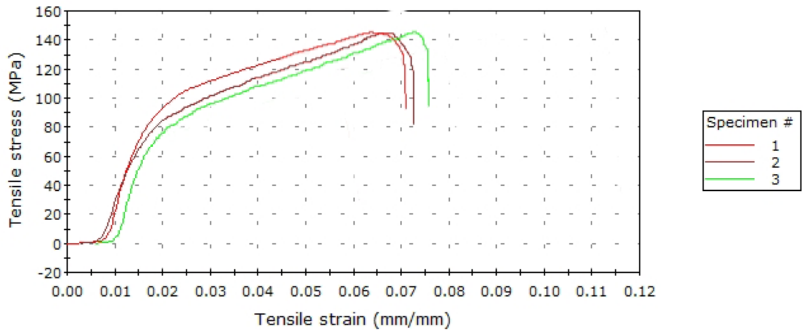

Figure 4: Tensile stress-strain plots for the composite samples with 10 wt% of SiCp loading

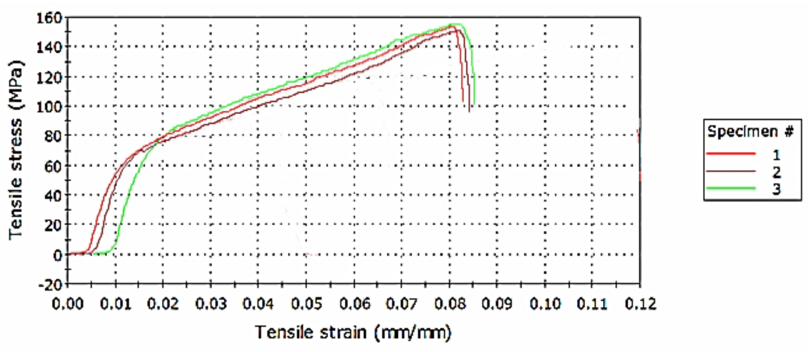

Figure 5: Tensile stress-strain plots for the composite samples with 20 wt% of SiCp loading

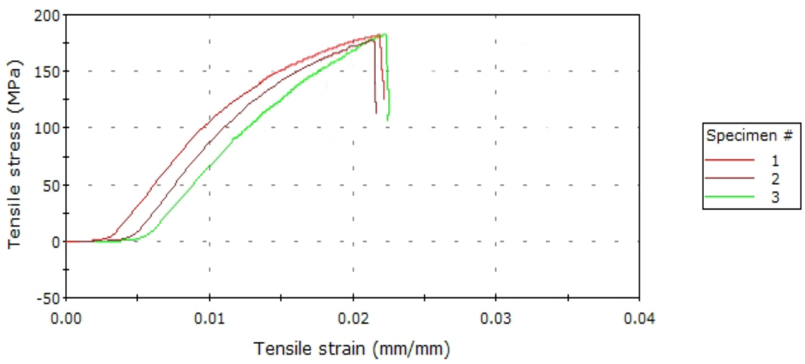

Figure 6: Tensile stress-strain plots for the composite samples with 30 wt% of SiCp loading

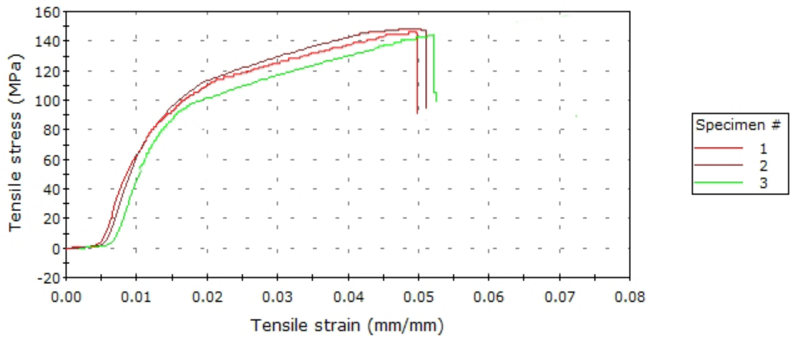

Figure 7: Tensile stress-strain plots for the composite samples with 50 wt% of SiCp loading

The compressive strength improved gradually with increased SiCp loading by up to 233.522 MPa for the sample containing 40 wt% SiCp as compared to the control which has a compressive strength of 163.64 MPa after which a decline in the compressive strength is observed (Table 2). This behaviour is also indicative of the improvement in the strength of the composite with an increase in the reinforcement loading. The decline in compressive strength showing after peak loading could be explained by the phenomenon of interfacial debonding which gets more pronounced with an increase in the quantity of reinforcement particles beyond a given limit in Shao et al. (2011).

Table 2: Result of Compressive Strength test

Specimen	Compressive strength (MPa)			
(% Composition of SiC_p)	Sample 1	Sample 2	Sample 3	Average
0	164.68	163.59	162.66	163.640 ± 0.58
10	174.22	175.56	176.33	175.049 ± 0.62
20	188.23	187.56	189.02	188.335 ± 0.42
30	217.55	219.08	218.32	218.572 ± 0.44
40	233.33	233.00	233.89	233.522 ± 0.26
50	177.09	178.01	177.73	182.446 ± 0.27

Impact strength of the studied materials also depend on the quantity of the reinforcement particle present in the composite with the dependence showing an initial improvement of impact strength with increased SiCp loading up to a certain loading level and then a decline in strength which could equally be explained as above. The control sample showed an average impact strength of 140.09 kJ/m^2. The observed impact strength values increased with SiCp loading up to 250.37 kJ/m^2 at 40 wt% loading after which it declined to 227.93 kJ/m^2 for the 50 wt% SiCp loading (Table 3). The observed trend in impact behaviour after reaching a peak value could be explained by particle clustering, particle cracking and weak interface bonds, which all tend to increase with an increase in reinforcement loading. This conforms to results reported in the literature (AKM and Dewan, 2016). However, Najeeb (2013) reported that impact strength of Al-SiC composite decreased with increasing SiC loading which observation could be as a result of the fact that he added Si particles in the process of making the composite to improve solubility.

Table 3: Result of Impact (IZOD) Test

Specimen	Impact strength (kJ/m^2)				
(% Composition of SiC_p)	Sample 1	Sample 2	Sample 3	Sample 4	Average
0	164.68	139.55	139.58	140.02	140.09 ± 0.33
10	174.22	156.34	160.08	156.02	157.51 ± 0.92
20	188.23	185.86	184.73	182.56	183.94 ± 0.82
30	217.55	211.99	209.27	212.56	210.59 ± 0.98
40	233.33	251.11	248.92	252.36	250.37 ± 0.83
50	177.09	244.53	223.91	220.45	227.93 ± 5.58

4. Conclusion

This study revealed that the extent of SiCp loading in Al-SiCp composites influences the resulting strength characteristics of the material. Increase in the quantity of silicon carbide increases the tensile, compressive and impact strengths of the produced metal matrix composite. The strength characteristics, however, start declining after the optimal loading value is exceeded. For the material studied, it was found out that the optimal load level of SiCp is 40 wt% at which point average strength values of 194.64 MPa, 233.52 MPa and 250.37 kJ/m^2 were obtained respectively from tensile, compressive and impact tests of the material.

Acknowledgements

The researchers wish to acknowledge the valuable contributions of Professors A. Raji and Ibrahim M.E. for painstakingly vetting the manuscripts. We also thank the authorities of Obafemi Awolowo University, Ile-Ife, Nigeria for allowing us to use their facilities. We thank the authorities of Modibbo Adama University of Technology, Yola, Nigeria for opportunities afforded us during the period of this research.

References

Abhijit D., Krishna M.P., 2015, Magnesium metal matrix composites – A review, Reviews on Advanced Materials Science, 42, 58-67.

AKM A., Dewan M.N., 2016, Effect of reinforcement on the mechanical properties of aluminium metal matrix composite: A review. International Journal of Applied Engineering Research, 11 (21), 10408-10413.

Danilo M., Virgilio G., Francesco M., Giovanni P., Marco V., 2017, Mechanical behaviour with temperatures of aluminum matrix composites with CNTs, Chemical Engineering Transactions, 60, 25–30.

Folgar F., 1988, Fiber FP/metal matrix composite, connecting rods: Design fabrication and performance, Ceramic Engineering and Science Proceedings, 9, 561-578.

Hassan M.A., Ofor T.C., Usman A.M., Godi N.Y., 2014, Development of aluminium metal matrix composite using stir casting method, The International Journal of Engineering and Science, 3 (8), 36-39.

Kelly A., Davies G.J., 2000, Optimum parameters for wetting silicon carbide aluminium alloys, Metallurgical and Materials Journal, 31, 565-573.

Kon B.L., Hoon K., 2002, Strength of Al-Zn-Mg-Cu matrix composite reinforced with SiC particles, Metallurgical and Materials Transactions, 33, 455-465.

Mandal D., Viswanathan S., 2013, Effect of re-melting on particle distribution and interface formation in SiC reinforced 2124Al matrix composite, Materials Characterisation, 86, 21–27.

Najeeb S.A., 2013, Experimental study of the mechanical and metallurgical behaviour of Al-SiC composite. Academic Research International, 4 (5), 22-29.

Shao J.C., Xiao B.L., Wang Q.Z., Ma Z.Y., Yang K., 2011, An enhanced FEM model for particle size dependent flow strengthening and interface damage in particle reinforced metal matrix composites, Composite Science and Technology, 71, 39–45.

Usman A.M., Raji A., Hassan M.A., Waziri N.H., 2014a, A comparative study on the properties of Al-7 % Si-rice husk ash and Al-7 % Si-bagasse ash composites produced by stir casting, The International Journal of Engineering and Science, 3 (8), 1-7.

Usman A.M., Raji A., Waziri N.H., Hassan M.A., 2014b, Production and characterization of aluminium alloy-bagasse ash composites, IOSR Journal of Mechanical and Civil Engineering. 11 (4), 38-44.

Zweden C. 1992, The attractive properties of metal matrix composite, Journal of Metals, 44, 15-18.