

PAPER • OPEN ACCESS

## Wettability enhancement of aluminum metal matrix composite reinforced with magnesium coated silicon carbide particles

To cite this article: E M Gutema *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012179

View the [article online](#) for updates and enhancements.



**IOP | ebooks™**

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

# Wettability enhancement of aluminum metal matrix composite reinforced with magnesium coated silicon carbide particles

**E M Gutema, V Yu Bazhin and S N Fedorov**

St. Petersburg Mining University, 2, 21st Line, St. Petersburg, 199106, Russia

E-mail: fedorov.sn29@mail.ru

**Abstract.** The adhesion at the interface between the matrix and reinforcement plays a major role in determining mechanical properties of Aluminum Metal Matrix Composite (AMMCs). Various techniques are developed for better properties of AMMCs. Some are complex in nature and expensive. Simple and cheap methods are still to be found to satisfy the stringent demand of customers. In the present experimental study, extensive and inclusive laboratory experiment is done which possibly improves the wettability between the matrix and reinforcement. The first phase of the experiment is preparation of matrix material, reinforcement and fluxes. This includes composition analysis of aluminum, crushing particles of SiC and analyzing their size distribution. The second phase is the selection of the manufacturing process, which possibly enhances the wettability between the matrix and reinforcement. As a result, test samples of a composite having different content and compositions of reinforcement are prepared using squeeze casting.

## 1. Introduction

In a metal matrix composite, three important features determine its characteristics: viz. the matrix, the reinforcement, and the matrix-reinforcement interface. The matrix is the continuous phase and its properties are improved by converting it into a composite with the introduction of an appropriate reinforcement. The reinforcement is a hard secondary phase incorporated may be in the form of whiskers, particles, or rods into the alloy matrices to produce metal matrix composite which has better mechanical properties. The wettability between the matrix and reinforcement also plays a crucial role in the final properties of the composites. For adhesion, the matrix and the reinforcement must be in a close connection with each other [1]. Many methods proposed to improve the wettability between the matrix and hard carbide particles in the manufacturing process of Metal Matrix Composite (MMCs). Some of them are the addition of a wettability agent [1] and fluxes [2], preheating [3] and coating of ceramic particles [1]. The other technique used to enhance the wettability lowers the casting temperature and adding ceramic particles when the aluminum is in a semi-solid state [4].

In the present experimental investigation, an extensive and inclusive laboratory experiment is performed which possibly improves wettability. The process starts with composition analysis of the aluminum Al6063 alloy. Thereafter reinforcement preparation includes crushing/grinding particles of SiC, mixing with magnesium, particles size distribution analysis and microstructure analysis. Samples of different content and compositions were prepared.



The test result shows that the incorporation of magnesium as coating material for SiC increases the tensile strength, flexural strength and hardness properties of the composite largely. On the contrary, measured hardness values varies at different locations of the composites. These indicate the presence of porosity, which results from the increment in percentages of a hard and brittle phase of ceramic particles in the composites [5]. An optimum content of the SiC-Mg ratio with which the composites exhibit good mechanical properties is found to be Al+12%SiC+2Mg.

## 2. Experimental method

### 2.1 Material

The aluminum 6063 alloy has the chemical composition indicated in table 1, used as a matrix material. The average particle size and purity level of SiC-Mg used for the preparation of reinforcing materials are shown in table 2. Mastersizer 2000 ver.5.60 used to analyse particle size distribution. Accordingly, the average particles size of the reinforcement, which contains SiC-Mg shown in figure 1 (b) varies from 30.93  $\mu\text{m}$  to 31.49  $\mu\text{m}$ . The variability in each set of measurement is a result of manual grinding and crushing of the SiC particle. Figure 1 (a), (b) shows a reinforcement preparation process which starts from finely ground powder of SiC particles, analyzing the microstructure of SiC-Mg using a scanning electron microscope, investigation of the correlation between SiC-Mg and finally particles size distribution analysis.

**Table 1.** Particle size and purity of reinforcement.

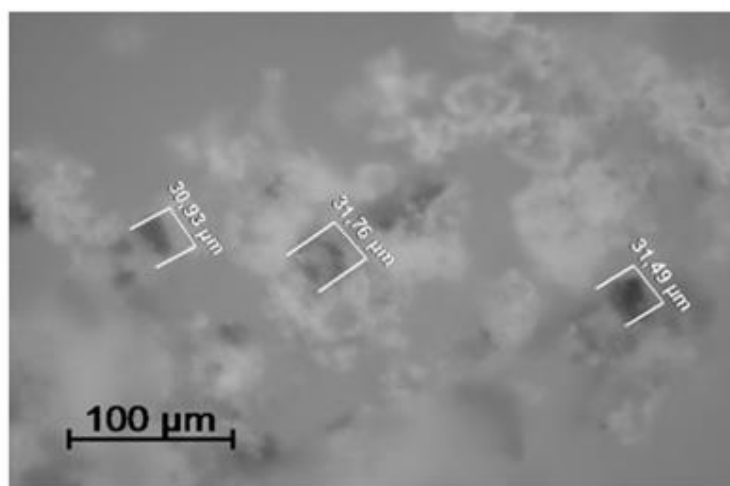
Reinforcement material		
Reinforcement	Average particle size	Purity
Silicon carbide	325mesh	99.7 %
Magnesium	270mesh	99.7 %

**Table 2.** Chemical composition of Al6063 alloy.

Alloy	Composition of Al6063 alloy								
Al6063	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
	0.35	0.21	0.02	0.05	0.45	0.10	0.10	0.02	98.7



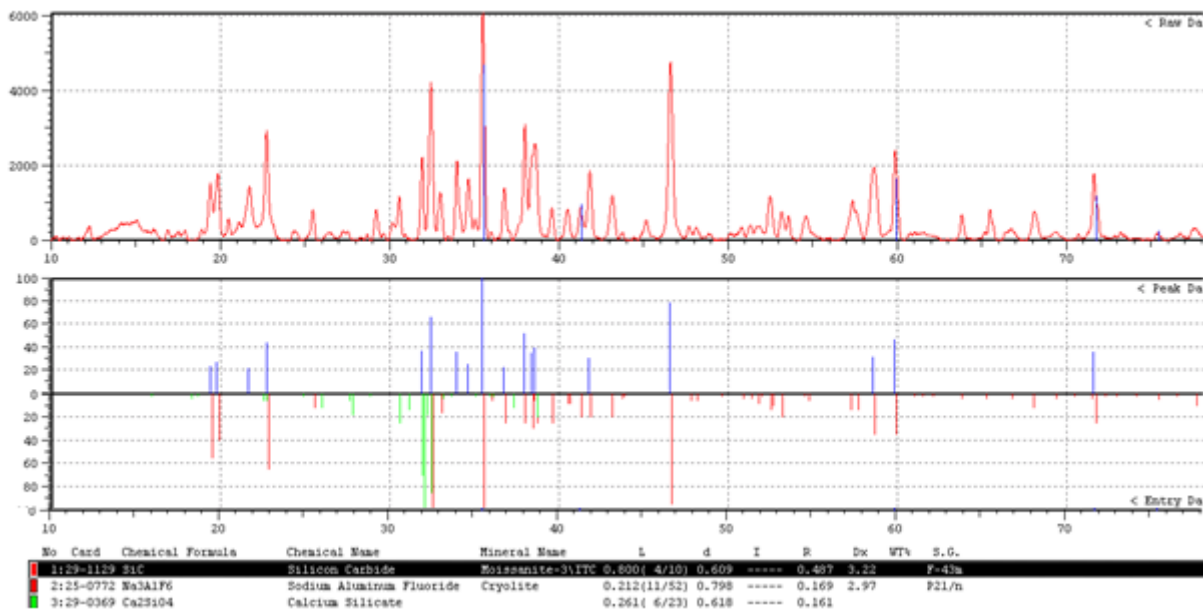
(a) Finely ground powder of SiC particles



(b) Microstructure of SiC-Mg

**Figure 1.** Reinforcement preparation.

XRD analysis is used to measure the average spacing between layers or rows of atoms to determine the orientation of a single crystal or grain and find the crystal structure of an unknown material [6]. The finely ground powder of SiC particles is analyzed using XRD analysis. A small amount of flux material such as calcium silicate and sodium aluminum fluoride are shown in figure 2. These fluxes are added to improve the wettability of the reinforcement with the metal matrix material. The intensity recorded versus  $2\theta$  and x-ray powder diffraction (XRD) analysis revealed characteristic peaks for SiC, sodium aluminum fluoride, and calcium silicate. Each peak represents diffraction from crystallographic planes.



**Figure 2.** X-ray diffraction analysis.

## 2.2 Experimental Procedures

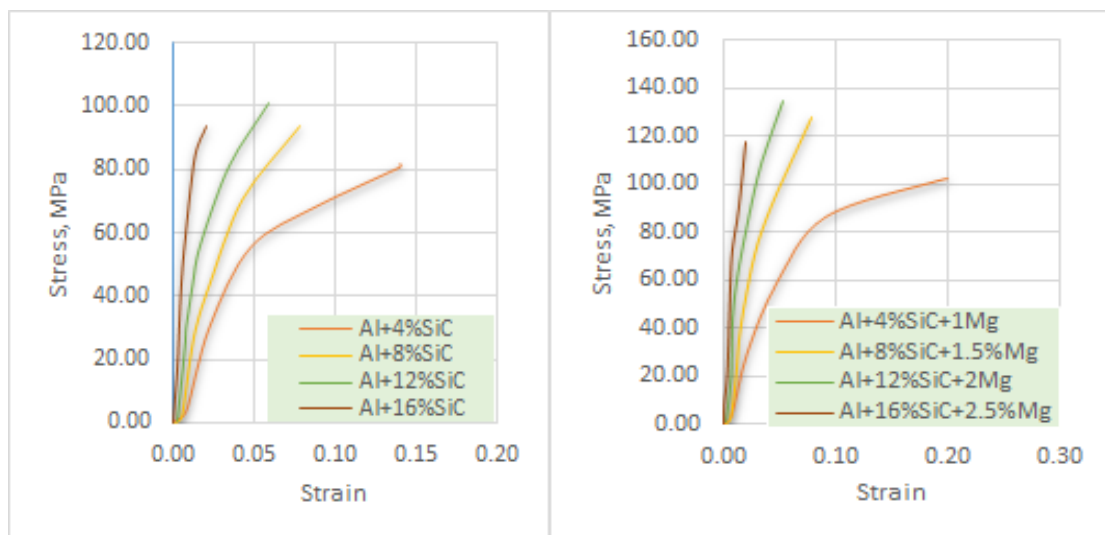
Samples of the aluminum metal matrix composite having different content and compositions are prepared using squeeze casting. The process starts with composition analysis of the aluminum Al6063 alloy. Thereafter reinforcement preparation includes crushing/grinding particles of SiC, mixing with magnesium, particles size distribution analysis and microstructure analysis. Powder of magnesium, mesh size indicated in table 2 were used for coating of reinforcement to protect interaction between particles, protect particles of SiC from an environmental reaction and to enhance the wettability of matrix with reinforcement [7]. First of all particles of silicon carbide are preheated up to a temperature of 650 °C to make their surfaces oxidized. Then, added to magnesium, slight below melting temperature, Mg at 500 °C and is mixed manually for 8-10 minutes in a separate furnace. At the same time, the temperature of the furnace, which contains the matrix material, has first raised 615 °C to melt the aluminum and then cooled down below the liquidus to keep the slurry in a semi-solid state. Thereafter, reinforcements are introduced to the aluminum matrix. The slurry of the composite, which contains the matrix and reinforcement material, is stirred at speed of 750 rpm for 15-20 minutes using a mechanical stirrer driven by an electric motor. Stirring was continued till particles were incorporated into the semi-solid aluminum. After the stirring process completed, the crucible is taken from the furnace and semi-solid composite melt poured into the preheated permanent die at room temperature. As the composite starts to solidify, the upper half of the die closes and starts applying pressure of 120 MPa for 60s. Cooling rates of the composite are inconsistent, as its function of other process variables are melt temperature, die temperature and cast geometry [8]. Hence, the composites allowed one to cool down to room temperature leaving the cooling rate approximately constant, which is 10 °C/s.

### 3. Result and discussion

#### 3.1 Tensile Strength

In the present experimental study, AMMCs reinforced with different content and composition of reinforcement are successfully produced using squeeze casting. Test samples are prepared as per ASTM-8 standard. The stress-strain diagram is plotted for AMMCs with different composition and content of reinforcement. The experimental result in figure 3 (a), (b) showed improvement of the tensile strength with increasing content and composition of reinforcement.

The introduction of magnesium with other flux materials such as calcium silicate, sodium aluminate fluoride and cryolite reduces the melting point of the matrix material [9]. Moreover, promotes the wettability of metal-ceramic composite by inducing chemical reaction at the interface [10]. Silicon promotes the formation of intermetallic component  $Mg_2Si$  reacting with Mg which improves bonding of liquid aluminum with SiC particles. Then, the interfacial layer is formed due to the reaction between the matrix material and the reinforcing materials [11]. This results in increased load transfer from the matrix to the reinforcement. As figure 3 (b) shows, the incorporation of magnesium as reinforcement along with SiC increased the tensile strength to large extent. The maximum measured tensile strength of the composite was 135 MPa and the minimum 82 MPa. Further introduction of both SiC and Mg beyond Al+16%SiC+2.5Mg leads to declining of the strength and failure strain.



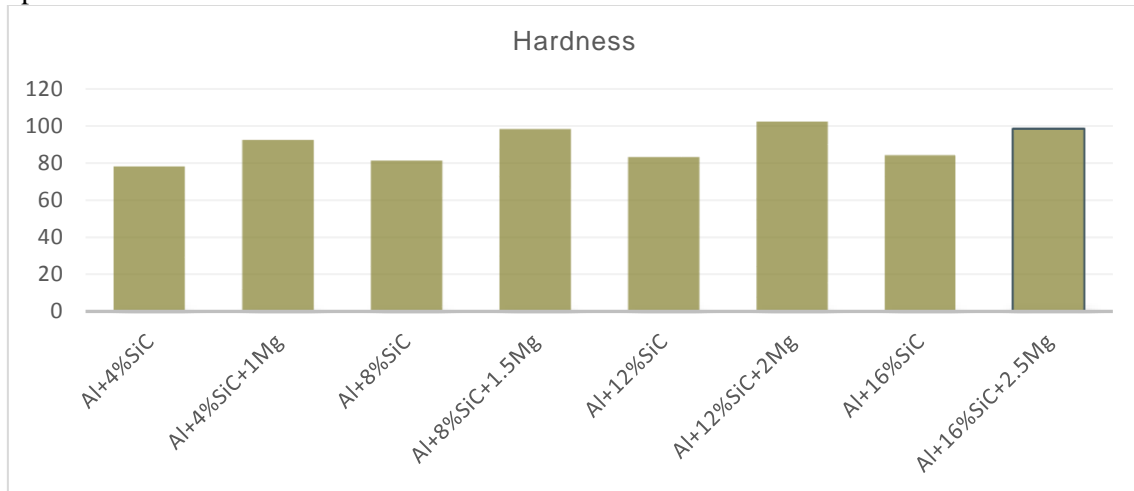
**Figure 3.** Stress-strain behavior of Al-SiC and Al-SiC-Mg composites.

#### 3.2 Hardness

The hardness tests carried out using Brinell [11-13] under a load of 750 kg for 15 sec as per ASTM standard [14-17]. Four measurements are taken on different areas of test samples and the mean hardness value is taken for each sample. The test result shows that the increasing trend of hardness with an increase in weight percentage of SiC which shows that particles of SiC act as an obstacle to dislocation motion. As a result, hardness of the composites raised from 78BH to 102BH for AMMCs containing Al+4%SiC and Al+12%SiC+2Mg respectively. Further addition of SiC changes the hardness trend of composites and starts decreasing as particles interact with each other leading to clustering of particles and lowering the hardness.

The hardness comparison shows that composites with the incorporation of Mg are higher than composites reinforced only by different weight fraction of SiC. This shows that the addition of Mg to the reinforcement improved the wettability and the hardness as well. However, the addition of SiC-Mg beyond 16% SiC and 2.5Mg shows a reducing trend of hardness. This results from the increment in the percentage of a hard and brittle phase of ceramic particles in the composite. As shown in figure 4 the

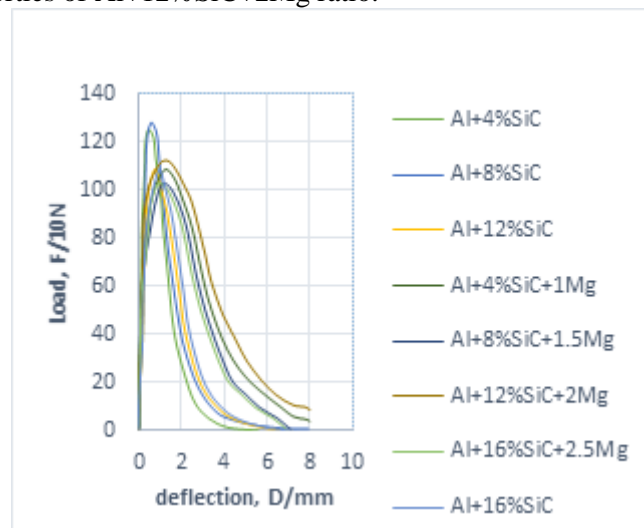
overall test result shows almost about 18% of improvement of hardness value over Al+4%SiC composites.



**Figure 4.** Hardness comparison (Al+wt %SiC vs Al+wt %SiC+Mg).

### 3.3 Flexural Strength

The test samples are prepared as per ASTM: A-370 and three-point-bending tests done on a universal testing machine. The corresponding load-deflection curves are recorded for all composites as shown in figure 5. The comparison between the two categories of composites indicates that Mg coated SiC particle reinforced composites shown a better ductile fracture compared to composites reinforced with SiC particles. The overall test result shows an optimum content of SiC-Mg at which the composites exhibit good mechanical properties of Al+12%SiC+2Mg ratio.



**Figure 5.** Load deflection curve.

## 4. Conclusion

The following conclusions are drawn from the test results:

The addition of magnesium as reinforcement along with SiC increases the tensile strength from 82 MPa to 135 MPa. An optimum content of SiC and Mg at which the composites exhibited good tensile strength is found to be Al+12%SiC+2Mg ratio.

The hardness of the composite with the incorporation of Mg is higher than that of composite reinforced only by different weight fraction of SiC. The Brinell hardness of the composite raised from

78BH to 102BH for AMMCs containing the reinforcement ratio of Al+16%SiC and Al+16%SiC+2Mg, respectively.

Mg coated SiC particle reinforced composites show better ductile fracture than those reinforced with SiC particles alone.

## 5. Acknowledgement

The authors gratefully acknowledge the Ministry of Education and Science of the Russian Federation for all support and encouragement in carrying out this research work.

## References

- [1] Abdallah W, Buckley J S, Carnegie A and Edwards J 2007 *Review* **19** 44-61
- [2] Casati R and Vedani M 2014 *Review Metals* **4(1)** 65-83
- [3] Gupta N and Satyanarayana K G 2006 *Journal of Materials Science* **58(11)** 91-93
- [4] Dhanasheka M and Senthil Kumar V S 2014 *Procedia Eng* **97** 412-420
- [5] Wessel J K 2004 *The Handbook of Advanced Materials*
- [6] Boopathi M, Arulshri K P and Iyandurai N 2013 *American J. of Applied Sciences* **10** 219-229
- [7] Gnjudi Z, Boi D and Mitkov M 2001 *Mater. Character* **147** 129-138
- [8] Dieter G E 1976 *Mechanical Metallurgy McGraw-Hill Series in Materials Science and Engineering* 282-293
- [9] Hashim J, Looney L and Hashmi M S 2001 *J. Mater. Process. Technol.* **119** 324-328
- [10] Jakes J E, Frihart C R, Beecher J F, Moon R J and Stone D S 2008 *J. Mater. Res.* **23(4)** 1113
- [11] Lucas J P, Stephens J J and Greulich F A 1991 *Mat. Sci. and Engineering* **131 (2)** 221-230
- [12] ASTM Int. 2012 *ASTM E10-15: Standard Test Method for Brinell hardness of Metallic Materials* ASTM Stand. pp 1-32
- [13] Bazhin V Yu, Gutema E M and Savchenkov S A 2017 **60(11-12)** 1267-72
- [14] Canakci A and Arslan F 2012 *International Journal of Advanced Manufacturing Technology* **63** 785-795
- [15] Endalkachew Mosisa, Bazhin V Yu and Savchenkov S A 2016 *Research Journal of Applied Sciences* **11** 188-196
- [16] Torralba J 2003 *Journal of Materials Processing Technology* **133(1-2)** 203-206
- [17] Syrkov A G 2015 *Journal of Mining Institute* [in Russian – Zapiski Gornogo Instituta] **216** 122-130