Production and mechanical properties of Al-SiC metal matrix composites

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Abstract. The usage of Al-SiC Metal Matrix Composites is constantly increasing in the last years due to their unique properties such as light weight, high strength, high specific modulus, high fatigue strength, high hardness and low density. Al-SiC composites of various carbide compositions were produced using a centrifugal casting machine. The mechanical properties, tensile and compression strength, hardness and drop-weight impact strength were studied in order to determine the optimum carbide % in the metal matrix composites. Scanning electron microscopy was used to study the microstructure-property correlation. It was observed that the tensile and the compressive strength of the composites increased as the proportion of silicon carbide became higher in the composites. Also with increasing proportion of silicon carbide in the composite, the material became harder and appeared to have smaller values for total displacement and total energy during impact testing.

1. Introduction

Metal Matrix Composites consist of a metal matrix reinforced with particles or fibers of a second phase. The mechanical properties of the Metal Matrix composites depend on many factors such as matrix material, weight fraction, reinforcement phase material and the production method of the composite.

Al-SiC is a metal matrix composite consisting of an aluminium matrix and silicon carbide as the reinforcement phase. Silicon carbide is a low cost material with a high elastic modulus and it is very often used as a reinforcement phase. It can be found in particle or whisker form.¹ The properties of Al-SiC are notable such as light weight, high strength, high specific modulus, high fatigue strength, high hardness and low density.² One of the most important points in the production of these composites is the achievement of a good distribution of the reinforcement phase in the matrix.

For better distribution of the reinforcement phase a novel variation method of stir-casting is used. The matrix is in semi-solid condition when the reinforcement particles are added and then it is completely melted followed by mechanical stirring. A better distribution of particles in the microstructure is achieved with this method compared to conventional stirring. In addition, the thin gas layer of particles is broken which improves wetting between matrix and reinforcement.³ Wetting
of the reinforcement can also be improved by adding alloy elements to the molten metal, such as Cu, Mg and Fe.

In the present study material production methods, mechanical behavior and microstructure of the composite were studied in order to determine the optimum carbide % in the metal matrix composites and to investigate the distribution of the reinforcement material.

2. Experimental
2.1. Metal Matrix
Aluminium alloy is used as the matrix material. The chemical analysis of the aluminium matrix is shown in Table 1 and Figure 1 shows the pure aluminium alloy used as the matrix material.

Table 1. Chemical analysis of the aluminium alloy matrix.

| Title | % percentance |
|-------|---------------|
| Si    | 0.84          |
| Fe    | 0.72          |
| Cu    | 0.04          |
| Mn    | 0.03          |
| Mg    | 0.02          |
| Cr    | 0.12          |
| Zn    | 0.05          |
| Ti    | 0.03          |

Figure 1. Part of the aluminium alloy used as matrix.

2.2. Reinforcement phase
The material used as the reinforcement phase was α-SiC particles of 325 mesh size. 0.8% Copper (150 mesh) was also used as a wetting agent. Both the silicon carbide and the copper particles were produced by Alfa Aesar Company.

2.3. Experimental details
The tensile – compressive strength tests were carried out at room temperature on Instron 5989 Floor Model Testing System, using the Bluehill 3 software, Figure 2. The impact tests were carried out on Instron CEAST 9350 Drop Tower Impact System and the CEAST VisualIMPACT software, Figure 3. The impact tests were performed at a speed of 5m/sec. In the experiments for the compressive strength, the specimens were compressed to 30% of their original length.
3. Production method

The method used for the production of the composites was a combination of melt-stirring and compo-
stirring [3]. This combination method was used in order to obtain a better dispersion of the particles and to avoid particle agglomeration and sedimentation in the melt. Casting took place in a centrifugal machine. Figure 4 shows the molds which were produced by the lost wax casting method. An electric furnace equipped with an electric drill was used for the stirring process.

The silicon carbide particles were heated to 1076 °C for one hour and 30 minutes in order to remove the absorbed hydroxide and other gases leading to improved wetness properties. In addition, the molds and the stainless steel stirrer were preheated and the aluminum matrix was melted in an electric furnace at 720 °C. 0.8% copper was added as a wetting agent. For the slurry being in a semi-
solid condition, the furnace temperature was adjusted below the melting point of the aluminum and it was stirred with an electric drill at 50 rpm. When the reinforcement particles were added the matrix was in a semi-solid condition. After the addition of the SiC particles, the mixture was completely melted (above 720 °C). The stirring process was carried out at 150 rev/min by the stainless steel stirrer for 20 min. Then the slurry was poured in the molds, which were on the centrifugal machine and centrifugal casting took place. The rpm of the centrifugal machine was adjusted to 280 rpm, since segregation of the particles either at the inner or the outer periphery of the casting was noticed at higher rpm [4].
The dimensions of the specimens were 135mm x 20mm for the tensile strength experiments and 30mm x 20mm for the compressive strength, impact and hardness tests. All the specimens were of cylindrical shape (Figures 5, 6). The composite contents were adjusted so as to contain 3%, 6%, 9%, 12%, and 15% of silicon carbide. For reliability in the measurements, three samples for every experiment were made and the average values of were used.

4. Results and Discussion
The mechanical test results are given in Tables 2-4 and Figure 7 shows the specimen surfaces as observed in the scanning electron microscope.

![Figure 5. Specimens of 3% Al-SiC.](image)

![Figure 6. Specimens of 6% Al-SiC.](image)

| Table 2. Tensile strength results. |
|-----------------------------------|
|                               | $\sigma_y$ MPa | $\sigma_t$ MPa |
|-------------------------------|---------------|---------------|
| aluminium                     | 12.42         | 62.97         |
| 3% average value              | 15.37         | 72.36         |
| 6% average value              | 18.03         | 81.32         |
| 9% average value              | 20.79         | 92.23         |
| 12% average value             | 23.38         | 105.44        |
| 15% average value             | 25.21         | 119.38        |

| Table 3. Compressive strength results. |
|----------------------------------------|
|                               | $\sigma_y$ MPa | $\sigma_{cs}$ MPa | $R$ % |
|-------------------------------|---------------|------------------|------|
| 3% average value              | 32.60         | 140.86           | 30   |
| 6% average value              | 35.63         | 146.98           | 30   |
| 9% average value              | 40.81         | 158.63           | 30   |
| 12% average value             | 47.13         | 181.35           | 30   |
| 15% average value             | 51.90         | 196.32           | 30   |

| Table 4. Impact test results. |
|-------------------------------|
| Peak force (kN) | Total Energy (j) | Total Displacement (mm) |
|-----------------|------------------|------------------------|
| 3% average value | 36.16           | 67.068                 | 3.040 |
| 6% average value | 34.73           | 66.595                 | 3.029 |
| 9% average value | 36.45           | 65.930                 | 2.823 |
| 12% average value | 36.80           | 64.106                 | 2.578 |
| 15% average value | 37.20           | 63.257                 | 2.471 |
Figures 8 and 9 show the yield and tensile strength curves where it is observed that as the silicon carbide particles have higher concentrations in the composite, the specimens improve their resistance to tensile stress. Notably the tensile strength value for the Al-SiC_15% specimen was almost doubled in comparison to the value of pure aluminium. The highest value for the tensile strength was exhibited by the specimen with 15% volume fraction of SiC particles. Other researchers [2,5] also noticed an increase in the values of tensile strength as the silicon carbide concentrations became higher in the composites.

Figure 10 shows that with increasing proportion of silicon carbide in the composite, the material improves its compressive strength. Maximum compressive strength was achieved with 15% of silicon carbide particles. The same result, improvement in the values of compressive strength as the % of SiC particles increased was obtained in other work where Al-SiC composites were fabricated by stir casting [6].

Also, the composite yield strength increased as the proportion of the silicon carbide particles became higher in the composites, Figure 11.

Figures 12 to 14 show that as the weight fraction of the SiC particles in the composites increased, the values for total displacement and for total energy are reduced in drop weight impact test whereas the peak force remained more or less the same. This can be attributed to the rise in hardness observed with increasing weight fraction of the SiC particles in the composite.
From Figure 15 it can be concluded that as the SiC particles have a higher weight ratio in the composite, the specimens become harder. Furthermore, the same was observed in other work\textsuperscript{[2,6]} where an increase in the hardness values of the composites as the weight fraction of the SiC particles in the composite increased is reported.

**Figure 8.** Tensile strength curve (MPa).

**Figure 9.** Yield strength curve (MPa).

**Figure 10.** Compressive strength curve (MPa).

**Figure 11.** Compressive strength yield point curve (MPa).

**Figure 12.** Peak force curve (kN).

**Figure 13.** Total energy curve (j).

**Figure 14.** Total displacement curve (mm).

**Figure 15.** HRB Hardness.
5. Conclusions

1. The experimental values for the three specimens of every experiment were similar in every proportion and this suggests that a very good distribution of the silicon carbides in the composites was achieved. The variation of the stir-casting method used is a low cost but very efficient method for the production of Al-SiC composites.

2. The mechanical properties of the Al-SiC composites are improved as the silicon carbide particles obtain higher volume fractions in the composites.

3. From the photos of the SEM microscopy, it is clear that many of the SiC particles are broken in smaller pieces. This has been caused by the stirring method which was used.

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