Investigations on LM6 Metal Matrix Composite with borosilicate Glass Reinforcement for Aerospace applications

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Abstract—The recycling of glass wastes from the industries and society holds a threat to the environment and leads to the need for new applications. While producing a metal matrix composite production cost is an important factor which decides the suitable application. So, while developing a new material with this low-cost has great importance in this competitive world. In this study, an metal–matrix composite fabricated from an aluminum alloy (LM6) and Borosilicate glass powder particles with % addition of 2.5%, 5%, 7.5%, and 10% were produced by liquid Processing (stir casting) technique. The variations in the mechanical properties like toughness, compressive strength, hardness, and tensile were examined. The microstructures of the fabricated metal matrix composite have been obtained by using Metallographic microscope. The addition of the borosilicate glass indicated an improved behavior in the hardness and toughness properties. The Rockwell hardness value of fabricated metal matrix composite increases with the increase in % of reinforcement. The compressive and tensile strength of the fabricated MMC increases until reinforcement reaches a maximum of 7.5%. The microstructure of the fabricated MMC shows that the reinforcements were homogeneously distributed in the fabricated metal matrix composite.

Keywords—Borosilicate Glass; LM-6; metal matrix composites; Heat treatment;

I. INTRODUCTION

Metal matrix composites were used in the fields of automotive and aeronautical applications due to their attractive properties compared to monolithic materials [8]. Applications of aluminium alloys in various fields have been increased due to its light weight material and good corrosion resistance properties. The aluminium matrix composites have emerged from the lower mechanical properties of the pure aluminium. The high strength, and light weight made the AMC desirable in many applications, mainly on automobile products such as engine piston, cylinder liner, brake disc/drum etc [6]. Also, the ceramic reinforcement will create much strong and hard phases in aluminium matrix which will give good wear resistance compared to pure metals [15]. Insitu process showed better results for manufacturing PMMC’s Impact of Zr B₂ reinforcement particles in Al 6061 were discussed [14]

While producing a metal matrix composite cost is the key factor in their wider application in various fields. It mainly depends on two factors that are the type of reinforcement using and the technique which is being used to produce the MMC. Only simpler fabrication methods, higher production volumes, and use of cheaper reinforcements can reduce the cost of MMCs [5]

It is found that most of the aluminium metal matrix composite uses reinforcements such as SiC, TiC, Al₂O₃ which are costlier and have a higher density [10]. This will increase the total weight of the components. The stir casting method improves the homogeneous dispersion of the glass particulates and it will provide a good surface finish and better cooling rate [3].
II. MATERIALS

A. Matrix material

First, LM6 alloy is a eutectic alloy which is having a major composition of 85.95% of aluminium and 11% to 13% of silicon. Its ability to resist hot cracking, pressure tightness, die-filling capacity, and corrosion resistance makes it as a commonly used alloy for automotive as well as the aeronautical applications [2]. LM-6 has an excellent cast ability and fluidity which permits the alloy to be used of intricate and complex castings. It is best for service operating conditions require good resistance to corrosion it offers better corrosion resistance than LM-2 and LM-24. The chemical composition of LM6 aluminium alloy used is given in table 1.

Table 1: Chemical Composition of LM6

| Material  | Percentage     |
|-----------|----------------|
| Copper    | 0.1 max.       |
| Magnesium | 0.10 max.      |
| Silicon   | 10.0-13.0      |
| Iron      | 0.6 max        |
| Manganese | 0.5 max        |
| Nickel    | 0.1 max.       |
| Zinc      | 0.1 max.       |
| Lead      | 0.1 max.       |
| Aluminum  | Remainder      |
| Titanium  | 0.2 max        |

B. Matrix material

When producing a metal matrix composite cost is a main factor for their wider application in automotive and aerospace industries. Glass is a low-cost reinforcement material which easily available and will significantly reduce the cost of MMCs, which make this study a significant one. The borosilicate glass has good chemical and thermal resistance and is mainly used for making modern laboratory glassware. The lesser co-efficient of thermal expansion also provides a better bonding between aluminium matrix. The chemical composition of borosilicate glass is shown in table 2

Table 2: Chemical Composition of Borosilicate glass

| Material  | Percentage |
|-----------|------------|
| SiO$_2$   | 80.6       |
| B$_2$O$_3$| 13.0       |
| Na$_2$O   | 4.0        |
| Al$_2$O$_3$| 2.3       |

III. EXPERIMENTAL PROCEDURE

The borosilicate glass from a recycling plant was taken and cleaned by using water. The dried glass sample was crushed with the help of a ball mill and sieved to the size of 105µm. 1Kg of commercially available LM 6 and desired amount of Glass particles were taken in the preparation of each sample. The Glass particle was preheated to 400°C for 30 min to remove moisture. LM 6 was melted in a resistance furnace. The melt temperature was raised up to 850°C. Small amount of magnesium was added to the molten metal to increase the wettability of the aluminium melt. The melt was stirred with the help of a stainless steel stirrer. The stirring was maintained between 5 min at an impeller speed 300 rpm.
A. **Tensile testing**
The tensile tests were conducted on the UTM at room temperature. The samples were prepared as per the standard ASTM B557. The test has been performed to find out the ultimate strength of the composite material. The results from the test are given in table 4.

![Figure 1: Tensile test specimens](image)

B. **Impact test**
The impact tests were conducted at room temperature and the specimens were made according to ASTM standard E23. Both Izod and Charpy impact test were performed on the borosilicate glass reinforced samples.

![Figure 2: Impact test specimens](image)

C. **Rockwell hardness test**
The hardness test was conducted in the Rockwell hardness testing machine. Hardness Specimen of dia 20mm and length 20 mm were cut from the cast samples and the surface were ground using a grinding machine. The indenter has 1.588 mm diameter and a force of 100Kgf was applied on the surface for 30 Sec.

D. **Compression test**
The specimens for compression test were prepared according to ASTM standard E9–89a. The test was performed by using Universal Testing Machine (UTM) at room temperature. The ultimate compression strength that it can withstand ware found out.

IV. **RESULTS AND DISCUSSION**

A. **Density analysis**
The densities of the MMC were determined by using the Archimedes principle. The samples were weighed by using a digital weighing scale. The volumes of the samples were measured by the rise in water level. The results are tabulated in table 3.

| No | % Reinforcement of Glass | Actual Density (g/cm³) |
|----|--------------------------|------------------------|
| 1  | 0                        | 2.68                   |

Table 3: Density of the composite material
The result shows that the densities of the sample were decreasing as the % reinforcement increases. This will help to reduce the overall weight of the component.

**B. Tensile test**

The tensile test results are shown in Table 4. From the results it is found that the LM6 is having a tensile strength of 105.185 MPa at room temperature.

| No | % Reinforcement of Glass | Tensile strength (MPa) |
|----|--------------------------|-----------------------|
| 1  | 0                        | 105.185               |
| 2  | 2.5                      | 112.270               |
| 3  | 5.0                      | 126.712               |
| 4  | 7.5                      | 147.695               |
| 5  | 10                       | 135.160               |

The tensile strength tends to increase as the % reinforcement increases and reaches a maximum of 147 MPa at 7.5 % of reinforcement and then it started to decrease due to the clustering borosilicate glass which permits crack propagation.

**C. Rockwell Hardness test**

The hardness test results were shown in Table 5. It shows that the Rockwell hardness of pure LM6 has 51 HRB at room temperature. The hardness of the metal matrix composite increases as the % reinforcement increases and achieved a maximum value of 70 HRB.
Table 5: Rockwell Hardness the composite material

| No | % Reinforcement of Glass | Trial | HRB |
|----|----------------------------|-------|-----|
|    |                            | 1     | 2   | 3   |
| 1  | 0                          | 51    | 51  | 51  |
| 2  | 2.5                        | 56    | 56  | 56  |
| 3  | 5.0                        | 62    | 62  | 62  |
| 4  | 7.5                        | 67    | 67  | 67  |
| 5  | 10                         | 70    | 70  | 70  |

D. Impact test
Both Izod and Charpy impact tests were conducted on the borosilicate glass reinforced specimens at room temperature. The impact test results were shown in the table 6 and 7. The results shows by adding borosilicate glass the impact strength increases from the pure LM6 and get a maximum of 4 J in charpy and 4.7 J in Izod.

Table 6: Charpy impact test results

| No | % Reinforcement of Glass | Impact energy (J) |
|----|--------------------------|-------------------|
| 1  | 0                        | 1.5               |
| 2  | 2.5                      | 2.3               |
| 3  | 5.0                      | 2.6               |
| 4  | 7.5                      | 3.4               |
| 5  | 10                       | 4                 |

Table 7: Izod impact test results

| No | % Reinforcement of Glass | Impact energy (J) |
|----|--------------------------|-------------------|
| 1  | 0                        | 3                 |
| 2  | 2.5                      | 3.4               |
| 3  | 5.0                      | 4                 |
| 4  | 7.5                      | 4.3               |
| 5  | 10                       | 4.7               |

The results shows that impact strength increases as the % reinforcement increases.
E. Compression test

The Compression test results of the MMC are shown in the table 8. It shows the compression strength will increase by adding the borosilicate glass particulate in to the aluminium matrix at room temperature.

| No | % Reinforcement of Glass | Compression strength (MPa) |
|----|--------------------------|-----------------------------|
| 1  | 0                        | 266.069                     |
| 2  | 2.5                      | 303.024                     |
| 3  | 5.0                      | 369.541                     |
| 4  | 7.5                      | 384.323                     |
| 5  | 10                       | 376.932                     |

The compression strength of the composite increases as the reinforcement increases up to 7.5 % and then reduces. The maximum strength that it can with stand was found out to be 384.323(MPa)

F. Microstructure analysis

The figures show the optical microstructure of different % of glass reinforcement. From the microstructure it is observed that blocky Si phase with generally circular shape is distributed in aluminum dendrites because of rapid solidification. The glass particles were homogeneously distributed throughout the matrix and good bonding between the aluminium and glass particles were observed. During solidification the glass particle are pushed by the aluminum dendrites into the last freezing eutectic liquid and thus the glass particles are seen surrounded by the eutectic silicon.

Figure 1: Optical Microstructure of LM 6 – 2.5% glass reinforcement

Figure 2: Optical Microstructure of LM 6 – 5.0% glass reinforcement
V. CONCLUSION

- The uniform distribution of reinforcement of Borosilicate glass in LM6 alloy is confirmed through the microstructures. Hence MMC ingots can also be used for Automotive and aerospace industries.
- In the fabricated metal matrix composite materials As the percentage of reinforcement i.e. Borosilicate glass varies there is variation in the mechanical properties of like Hardness value, Impact energy, Tensile and compression strength.
- As the percentage of reinforcement increases i.e borosilicate glass the following observations were obtained in the impact energy there is a increases in charpy test in the range of 53.33%, 13.04%, 30.769% and 17.64%.
- As the percentage of reinforcement increases i.e. borosilicate glass the following observations were obtained in the Izod test impact energy gets consequently increases by 13.33%, 17.64%, 7.5% and 9.3%.
- While conducting the tensile test of metal matrix composite it increases up to 7.5% of borosilicate reinforcement while further addition shows an behavior of increasing pattern 6.735%, 12.86% and 16.55% and decreases up to 8.487%.
- Similarly for compressive strength of the MMC increases up to 7.5% of borosilicate reinforcement addition shows an behavior of increasing pattern 13.889%, 21.951% and 4.00% and then decreases upto 1.92%. Hence it is clear that addition of (Borosilicate glass) about 7.5%. In LM6 as reinforcement would provide better mechanical properties.

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