A Study on Mechanical and Microstructure Properties of T6 Heat Treated Glass reinforced LM6 Metal Matrix Composite

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Abstract: Various methods in the development of Metal matrix composites are now a days under serious considerations for many researchers because of its reliability and unique properties. Aluminium MMCs are preferred to other conventional materials in the fields of automotive, aerospace and marine applications owing to their improved properties like high strength to weight ratio, good wear resistance etc. The present work is focused on the development of a metal matrix composite using Lm6 aluminium alloy as the matrix material and borosilicate glass particulate as reinforcement. The development of MMC is mainly focused on liquid metallurgy route in particular stir casting technique. The added level of reinforcement varies from 2.5 - 10wt% in steps of 2.5 wt%. For each composite, reinforcement particles were preheated to a temperature of 400˚C and then dispersed into the vortex of molten Lm6. The specimens then pass through a T6 heat treatment cycle before testing.

Hardness, tensile strength, compressive strength, and energy absorbed during impact were determined after T6 heat treatment cycle. Microstructural analysis of the specimens reveals the homogeneous distribution of particles. From the strength to weight ratio analysis, it is found that borosilicate glass reinforced composite are superior compared to commonly used reinforcement materials.

Index Terms: **Aluminium Metal Matrix Composites, LM6, Borosilicate glass, Stir Casting, Heat Treatment**

INTRODUCTION

In general, composites can be defined as the combination of two or more materials in a configuration on a macroscopic scale to form a new material that contains the best features of each constituent so as to maximize certain properties [1]. Matrix is a relatively 'soft' phase with specific physical and mechanical properties, whose sole purpose is to bind the reinforcements together by virtue of its cohesive and adhesive characteristics, to transfer load to and between reinforcements. The reinforcement phase (or phases) have been usually stronger and stiffer than the matrix and mainly carries the applied load to the composite [5]. Depending on the matrix material composites are classified into Polymer Matrix Composites (PMC), Ceramic Matrix Composites (CMC) and Metal Matrix Composites (MMC). Among these composites, applications of aluminium-based MMCs have increased in recent years as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys.

I. MATERIALS AND METHOD

Aluminium is a light metal, about the third of the density of steel, copper, and brass. In its pure form, the metal is easily worked and possesses a high level of corrosion resistance, but its low strength reduces the number of applications for which it is suitable. When alloyed, however, aluminium becomes an extremely versatile and widely used material. Aluminium and its alloys have been the prime material for construction of the aircraft, car engines, wheels, radiators, rail cars (both passenger and freight), marine hulls and superstructures, military vehicles, electrical conductors, packaging, etc.

LM 6

LM6 alloys are normally used to produce lightweight castings. Aluminum-silicon alloys, as a matrix material, are characterized by light weight, good strength-to-weight ratio, ease of fabrication at reasonable cost, high strength at elevated temperature, good thermal conductivity, excellent castability, good weldability, and excellent corrosion resistance. LM6 alloy is actually a eutectic alloy having the lowest melting with 85.95% of aluminium, 11% to 13% of silicon as its main composition. The main chemical composition of LM6 aluminum alloy is shown in table 1. Having high resistance to corrosion and excellent castability, LM6 is suitable for most marine 'on deck' castings, water-cooled manifolds and jackets, motor car and road transport fittings, thin section and intricate castings such as motor housings, meter cases and switch boxes, for a very large aluminium casting, (cast doors and panels) where ease of casting is essential, for chemical and dye industry castings, (pump parts), and for paint industry and food and domestic castings. It is especially suitable for castings that are to be welded. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites.

Table1: 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

REINFORCEMENT

The key factor determining wider application of MMC in various fields is the cost. It mainly depends on two factors that are the type of reinforcement using and the technique which is being used to produce the MMC. By using simpler fabrication methods, higher production volumes, and use of cheaper reinforcements can reduce the cost of MMCs [4]. It is found that most of the aluminium metal matrix composite uses reinforcements such as SiC, TiC, Al_2O_3 which are costlier and have a higher density. This will increase the total weight of the components. The use of unwanted or useless solid materials generated from residential, industrial and commercial activities can significantly reduce the cost of metal matrix composite. Borosilicate glass is a type of glass with silica and boron trioxide as the main glass-forming constituents.. 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_2O_3	13.0
Na_2O	4.0
Al_2O_3	2.3

Due to its good chemical and thermal resistance it is mainly used for making modern laboratory glasswares. They are also known for having very low coefficients of thermal expansion which can result in better bonding between the aluminium matrix. Different borosilicate glasses cover a wide range of different thermal expansions, enabling direct seals with various metals and alloys like molybdum, tungsten and Kovar etc, because of the matched CTE with the sealing partner. Development of material with an ‘adjustable’ CTE is essential for electronic applications and it depends upon the volume fraction of the reinforcement particles [5]. Mechanical and Physical properties of typical reinforcement particles are listed in table 3along with Borosilicate glass.

Table 3: Comparison of Mechanical and Physical properties of various reinforcement particles with Borosilicate glass

Ceramic	Density (g/cm^3)	Elastic Modulus		Compressive Strength (Mpa)		Thermal Conductivity (W/mK)	Co - efficient of thermal expansion (10^{-6} / K)
		(Gpa)	10^6 psi	(Mpa)	ksi		
TiC	4.93	345	50.0	2500	362.6	20.5	7.4
Al_2O_3	3.92	350	50.8	2500	362.6	32.6	6.8
SiC	3.21	430	62.4	2800	406.1	132	3.4
B_4C	2.52	450	65.3	3000	435.1	29	5

Borosilicate glass	2.23	80	12	2000	290	1.14	3.3

STIR CASTING PROCESS (VORTEX METHOD)

The various processes using for the production of Metal Matrix Composites can be classified as liquid-phase processes, two phase (solid-liquid) processes, deposition techniques and in situ processes. Stir casting process is comes under the classification of liquid-phase processes which involves incorporation of dispersed phase (Borosilicate glass) into a molten matrix metal (LM6), followed by its solidification. The vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy [2]. The figure 1 shows a schematic diagram of a stir casting method. In this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry has been casted. There are different designs of mechanical stirrers. Among them, the turbine stirrer is quite popular. During stir casting for the synthesis of composites, stirring helps in two ways: (a) transferring particles into the liquid metal, and (b) maintaining the particles in a state of suspension [6]. Wettabilty is a most significant problem when producing cast metal matrix composites. Wettability can be defined as the ability of a liquid to spread on a solid surface. The particle –matrix interface have important effect on the mechanical properties of the composites, as good bonding promote load transfer to the higher strength ceramic particles. On the other hands, extensive inter facial reactions may deteriorate the mechanical properties of the composites. The magnesium played an important role during the synthesis of aluminum alloy matrix composites with dispersoids. Magnesium addition to aluminium reduces its casting fluidity at the same time as it reduces the surface tension of the aluminium sharply. Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix [3].

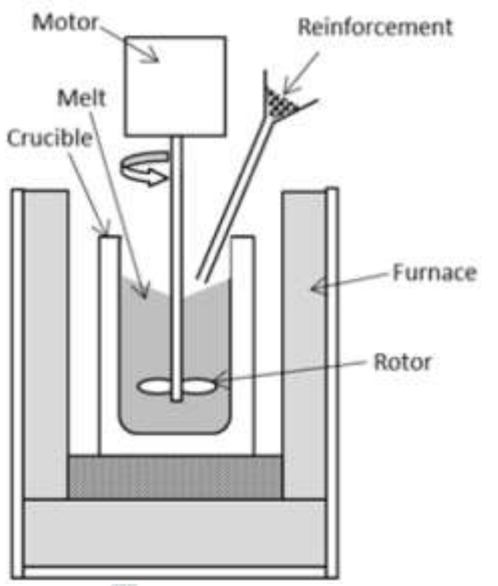


Figure 1:Stir casting process

HEAT TREATMENT CYCLE

The Lm6 aluminium alloy comes under the class of a eutectic alloy. A eutectic alloy is characterized by having a single melting point. This melting point is lower than that of any of the constituents, and no change in the mixture will lower the melting point any further. When a molten eutectic alloy is cooled, all of the constituents will crystallize into their respective phases at the same temperature. T6 heat treatment cycle contains 3 stages - Solution treatment, Quenching, Ageing. Solution treatment is the process of heating the material above 500 ˚C to form uniform grain structure. As cast structure does not have a uniform grain structure due to the non uniform cooling. In order to maintain the uniform grain structure the heated material is quenched in to the water thus it maintains the structure created by solution treatment. Sometimes, when a precipitation hardening alloy is quenched, its alloying elements will be trapped in solution, resulting in a soft metal. Aging a "solutionized" metal will allow the alloying elements to diffuse through the microstructure and form intermetallic particles. These intermetallic particles will nucleate and fall out of solution and act as a reinforcing phase, thereby increasing the strength of the alloy [6.7]

II. EXPERIMENTAL PROCEDURE

Preparation of reinforcement material (borosilicate glass) is carried out by crushing it with the help of a ball mill. The borosilicate glasses are collected from a recycling plant which is then properly cleaned and dried. The crushed glass particles are then seived 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 particles ware preheated to 400˚C for 30 min before adding to the aluminium melt in order to remove any moisture present in

Figure 2:Stir casting equipment

it. The LM 6 alloy is then melted by using a resistance furnace. The melt temperature was raised up to 850˚C and a 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.

The specimens for different tests are prepared as per ASTM standards for material testing. The tensile test specimens are prepared as per the standard ASTM B557 to conduct the test at room temperature. The impact test specimens are made according to ASTM standard E23 (for both Izod and Charpy) and the specimens for compression test are prepared according to ASTM standard E9–89a.The hardness test is conducted in the Rockwell hardness testing machine. The specimen for the test is prepared (dia 20mm and length 20 mm) 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.

For heat treatment the samples are heated to 500 °C for 45 min for solution treatment and quenched in water at 65°C. These samples are then aged for 5 hours at a temperature of 190°C.

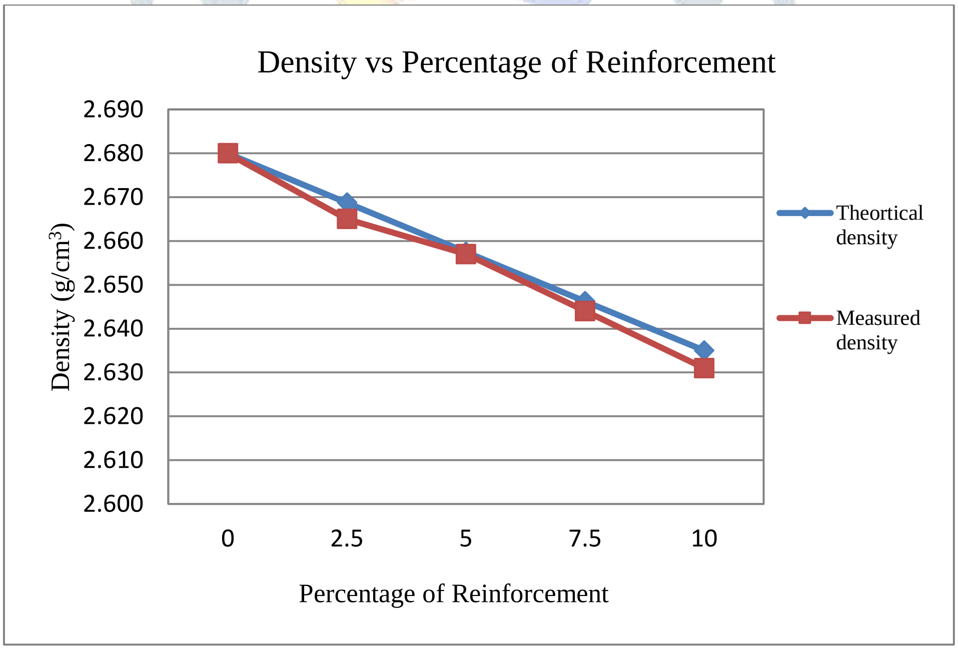
III. RESULTS AND DISCUSSIONS

Density Analysis

The density of the material produced forms an important role in the development of automotive and aerospace components. Being lighter means lesser the amount of fuel needed, which increases the economy. From the density analysis, it clear that the addition of borosilicate glass reduces the density of the MMC as the % reinforcement of the glass increases. The results of density analysis are shown in the table 4.

Table 4: Density vs Percentage of Reinforcement

Sl No	Composition	Theoretical density	Measured density
1	LM 6 + 0.0% Borosilicate Glass	2.680	2.680
2	LM 6 + 2.5% Borosilicate Glass	2.669	2.665
3	LM 6 + 5.0% Borosilicate Glass	2.658	2.657
4	LM 6 + 7.5% Borosilicate Glass	2.646	2.644
5	LM 6 + 10.0% Borosilicate Glass	2.635	2.631



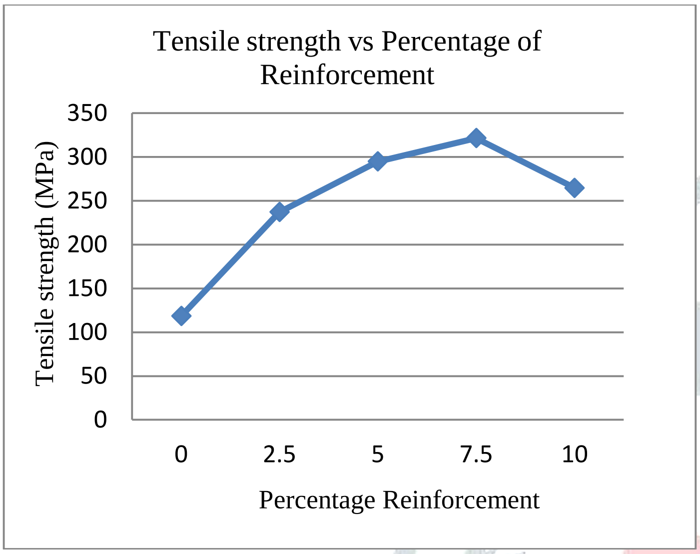
Graph 1: Density vs Percentage of Reinforcement

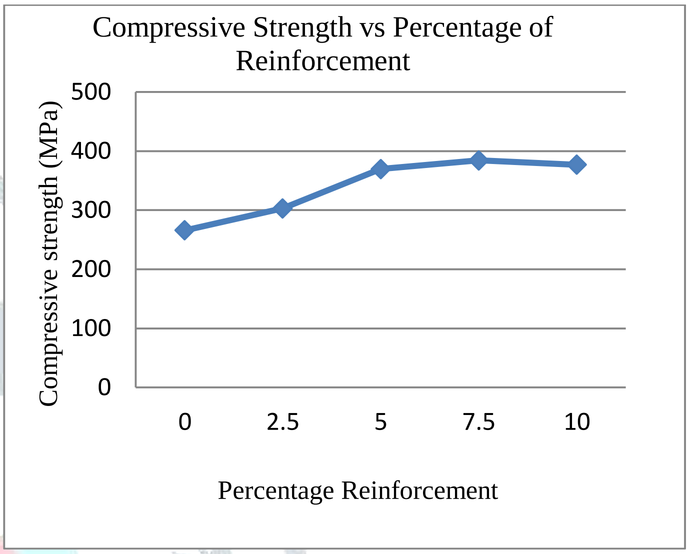
Tensile and Compressive Strength

The variation in the tensile strength and compressive strength by adding different percentage of reinforcement is shown in the table 5. It shows that the addition of reinforcement material increases as the tensile strength as percentage reinforcement reaches 7.5% and then decreases. The MMC produced is also superior in terms of compression strength. The compression strength also tends to increase as the percentage addition of reinforcement glass increases and reaches its maximum at 7.5% addition of borosilicate glass. After that it tends to decrease.

Table 5: Tensile and Compressive Strength

Sl No	Composition	Tensile strength (MPa)	Compressive strength (MPa)
1	LM 6 + 0.0% Borosilicate Glass	118.421	266.069
2	LM 6 + 2.5% Borosilicate Glass	237.223	303.024
3	LM 6 + 5.0% Borosilicate Glass	294.845	369.541
4	LM 6 + 7.5% Borosilicate Glass	321.469	384.323
5	LM 6 + 10.0% Borosilicate Glass	264.771	376.932





Graph 2: Tensile and Compressive Strength vs Percentage of Reinforcement

Impact strength

The impact test specimens were made as per the ASTM standard E23. The notches on the sample were cut by using the milling machine. Impact tests are used in studying the toughness of the material and values is recorded and shown in table 6.

Table 6: Impact Test Results

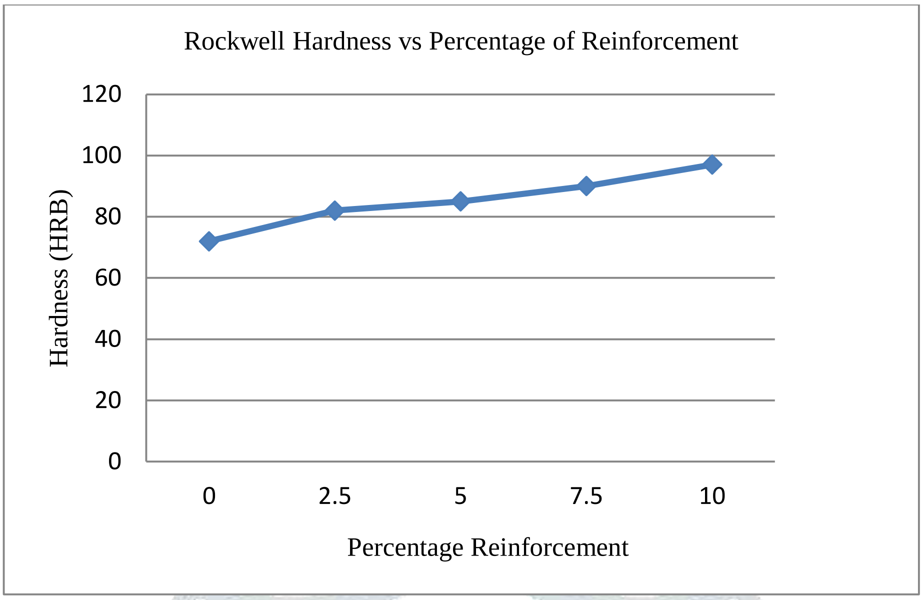
Sl No	Composition	Energy absorbed (J)
1	LM 6 + 0.0% Borosilicate Glass	4
2	LM 6 + 2.5% Borosilicate Glass	4.5
3	LM 6 + 5.0% Borosilicate Glass	4.9
4	LM 6 + 7.5% Borosilicate Glass	5.3
5	LM 6 + 10.0% Borosilicate Glass	5.5

Hardness Measurements

Hardness is very important property determining the application of the material in various fields particularly if the hardness of matrix metal is very low. The hardness of matrix metal enhances due to reinforcement of borosilicate glass particles with it. Hardness test has conducted on each AMMC specimen using ASTM standard E23. These experimental values show that the hardness of the samples tends to increase as the % addition of reinforcement increases.

Table 7: Hardness Test Results

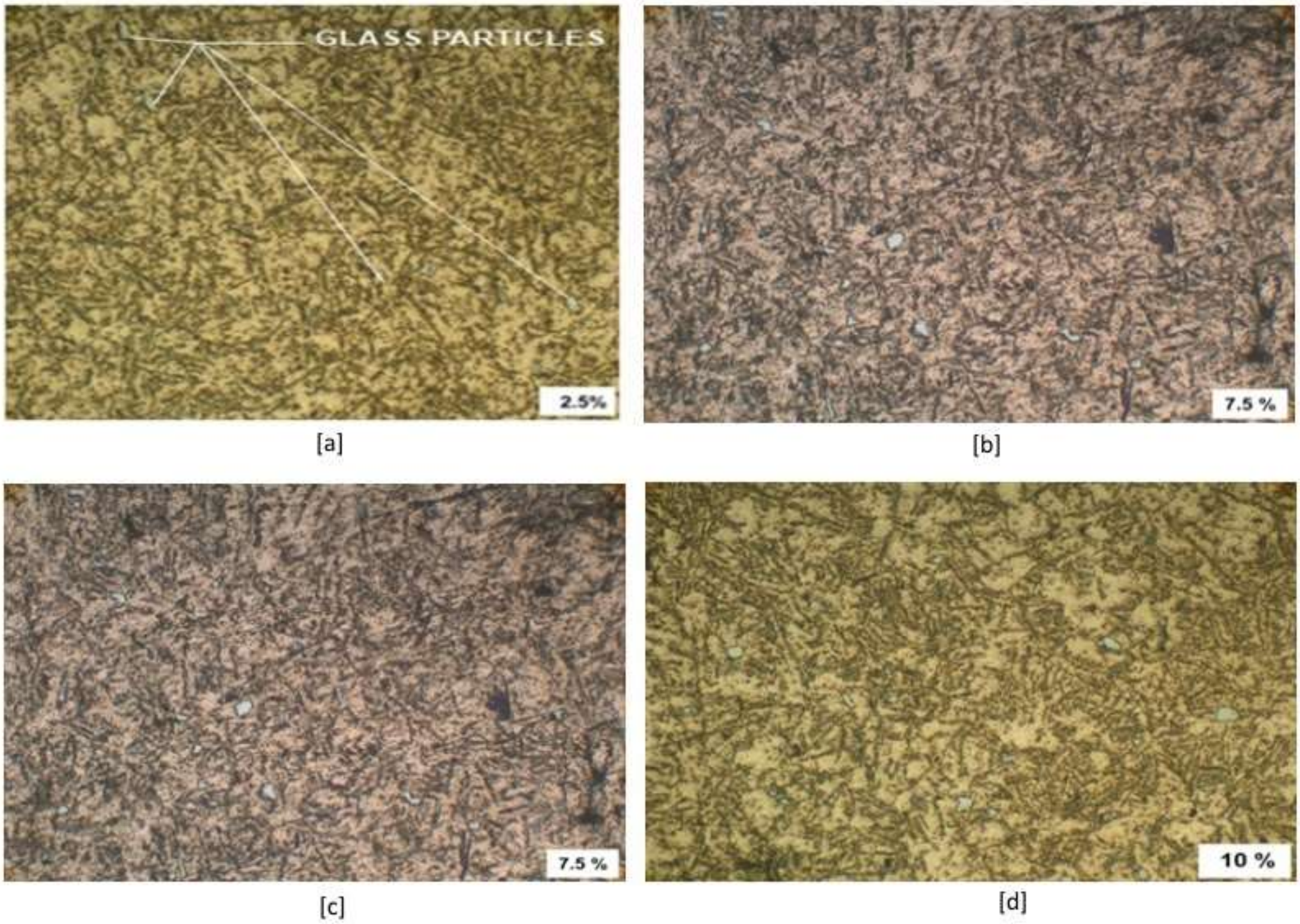
Sl No	Composition	Hardness (HRB)
1	LM 6 + 0.0% Borosilicate Glass	72
2	LM 6 + 2.5% Borosilicate Glass	82
3	LM 6 + 5.0% Borosilicate Glass	85
4	LM 6 + 7.5% Borosilicate Glass	90
5	LM 6 + 10.0% Borosilicate Glass	97



Graph 3: Rockwell Hardness vs Percentage of Reinforcement

Microstructure Analysis

The optical micro structures of different composition of metal matrix composite are shown in the figure 5. From the microstructure, it is observed that the glass particles were homogeneously distributed throughout the matrix and good bonding between the aluminium and glass particles were observed. During solidification the glass particles are pushed by the aluminum dendrites into the last freezing eutectic liquid and thus the glass particles are seen surrounded by the eutectic silicon.



[a] 2.5% Borosilicate Glass [b] 5.0% Borosilicate Glass [c] 7.5% Borosilicate Glass [d] 10.0% Borosilicate Glass

Figure 5: Optical micrographs of LM 6 with 0 - 10% Borosilica1te Glass

IV. CONCLUSION

Producing a less weight and high strength metal matrix composite with low cost will have greater applications in the automotive as well as aeronautical fields.

The selection of correct reinforcement material and the processing route defines the final properties of the metal matrix composite produced. The addition of the borosilicate glass satisfied to produce a low cost metal matrix composite with good mechanical properties. Based on the test results and interpretation following conclusions were reached

1. The required metal matrix composite was successfully manufactured by stir casting route.
2. The addition of borosilicate glass and T6 heat treatment has superior mechanical properties compared to the Pure LM 6 alloy as well as it reduces the density of the composites.
3. Increasing the amount of borosilicate glass reinforcement will increase the hardness and toughness of the metal matrix composite.
4. The tensile and compressive strength of the composite has been increased by adding the reinforcement material up to 7.5%, then decreases due to the clustering of the glass particulates.
5. Microstructure shows the uniform distribution of glass particles in the LM 6 matrix.

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