Effect of Heat Treatment on Mechanical and Microstructure Properties of PbO Glass Reinforced Metal Matrix Composite

Akhil R

Department of Mechanical Engineering, Government Engineering College, Palakkad, Kerala, India

Abstract: ***Applications of Aluminum-based Metal matrix composites have increased in recent years as engineering materials due to their attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys. In particular, particulate reinforced MMCs have recently found special interest because of their specific strength and specific stiffness at room and elevated temperatures. The production method and the section of reinforcement will define the final properties of the Metal Matrix composite. The present work focuses on the production of aluminium based metal matrix composite with PbO glass as the reinforcement. For the uniform distribution of the reinforcement phase stir casting method is selected for the MMC production. The obtained MMC is then passed through a T6 heat treatment cycle to study the effect of heat treatment on the mechanical and microstructure properties of the composite. LM 6 alloy is selected as the matrix material for the aluminium metal matrix composite (AMMC). The mechanical properties of the AMMC increases as the % reinforcement increased and obtains the optimum values at 7. 5% addition of PbO glass reinforcement. The microstructure shows the homogenous distribution of reinforcement particles in the matrix. It also improves the hardness and impact strength of the composite.***

Keywords: Metal Matrix composite, Stir casting, PbO glass reinforcement, T6 Heat treatment

1. Introduction

Metal–matrix composites (MMCs) materials have an edge over monolithic materials because of their superior properties such as high specific strength and stiffness, increased wear resistance, and enhanced temperature performance together with better thermal and mechanical fatigue and creep resistance. So they are widely used in industrial applications. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. The reinforcement does not always serve a purely structural task, but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. The improvement in toughness by particulate reinforcement depends on the residual stresses surrounding the particles, the volume fraction of the particles and shape of the particles. Particles can be spherical, disk shaped, rod shaped, and plate-shaped. Each particle forces the crack to go out of plane, and can force the crack to deflect in more than one direction and thus increase the fracture surface energy. Plate shaped and rod-shaped particles can increase the composite toughness by another mechanism called as 'pullout' and 'bridging'. The residual stress around the particles results from thermal expansion mismatch between the particles and the matrix, which helps to resist the crack propagation.

2. Materials and Method

Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical property of steel are similar to those of pure iron).Metal Matrix Composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) ormetallic (lead, tungsten, molybdenum) phase.

2.1 LM 6

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, excellent corrosion resistance and wear resistance properties. 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. Chemical composition of LM6 aluminum alloy as shown 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

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2.2 PbO Glass Reinforcement

Lead glass is a variety of glass in which lead replaces the calcium content of atypical potash glass. Lead glass contains typically 18–40 weight% lead oxide (PbO),while modern lead crystal, historically also known as flint glass due to the originalsilica source, contains a minimum of 24% PbO. Lead glass is desirable owing to its decorative properties. The chemical composition of lead oxide glass is given in table 2

Table 2: Chemical Composition of PbO glass

Chemical composition	*Weight (%)*
Silica	59
Lead oxide (PbO)	25
Potassium oxide (K2O)	12
Soda (Na2O)	2
Zinc oxide (ZnO)	1.5
Alumina (Al2O3)	0.4

2.3 Stir Casting

Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order toprovide high level of mechanical properties of the composite, good interfacial bonding between the dispersed phase and the liquid matrix should be obtained.

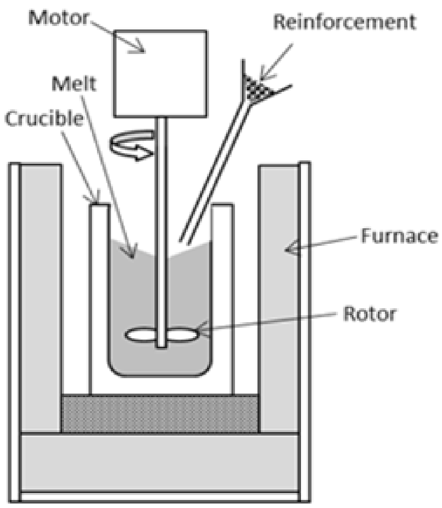

Figure 1: Stir casting process

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. 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. Wettabilty is a most significant problem when producing cast metal matrix 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.

2.4 Heat Treatment Cycle

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-uniformcooling. 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]

3. Experimental Procedure

The reinforcement material (PbO glass) is crushed by using a ball mill and sieved to 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 placed in the furnace by using a crucible and preheated to 400˚C for 30 min before adding to the aluminium melt in order to remove any moisture present in it.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 after the addition of reinforcement. 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 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.

Figure 2: Stir Casting Equipment

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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.

4. Results and Discussions

4.1 Density Analysis

From the density analysis, it clear that the addition of PbO glass increases the density of the MMC as the % reinforcement of the glass increases. The results of density analysis are shown in the table 3.

Table 3: Density vs Percentage of Reinforcement

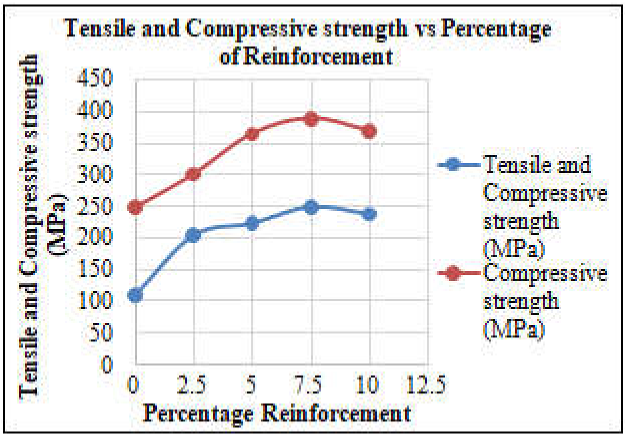
S No	*Composition*	*Measured density*
1	LM 6 + 0.0% PbO Glass	2.68
2	LM 6 + 2.5% PbO Glass	2.69
3	LM 6 + 5.0% PbO Glass	2.70
4	LM 6 + 7.5% PbO Glass	2.71
5	LM 6 + 10.0% PbO Glass	2.72

4.2 Tensile and Compressive Strength

The variation in the tensile strength and compressive strength by adding different percentage of reinforcement is shown in the table 4. It shows that the addition of reinforcement material increases as the tensile strength and compressive strength as percentage reinforcement reaches 7.5% and then decreases.

Table 4: Tensile and Compressive strength vs Percentage of Reinforcement

S No	Composition	Tensile strength (MPa)	Compressive strength (MPa)
1	LM 6 + 0.0% PbO Glass	110.213	248.581
2	LM 6 + 2.5% PbO Glass	204.691	301.449
3	LM 6 + 5.0% PbO Glass	223.458	365.548
4	LM 6 + 7.5% PbO Glass	249.230	390.117
5	LM 6 + 10.0% PbO Glass	238.125	370.516



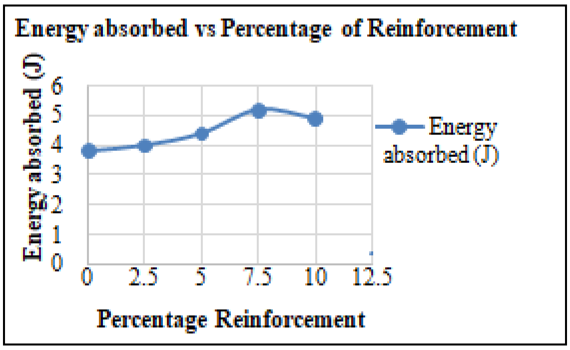
Graph 1: Tensile and Compressive strength vs Percentage of Reinforcement

4.3 Impact strength

Impact tests are used in studying the toughness of the material and values is recorded and shown in table 5.The impact test specimens were made as per the ASTM standard E23. The notches on the sample were cut by using the milling machine.

Table 5: Impact Test Results

Sl No	Composition	Energy absorbed (J)
1	LM 6 + 0.0% PbO Glass	3.8
2	LM 6 + 2.5% PbO Glass	4.0
3	LM 6 + 5.0% PbO Glass	4.4
4	LM 6 + 7.5% PbO Glass	5.2
5	LM 6 + 10.0% PbO Glass	4.9



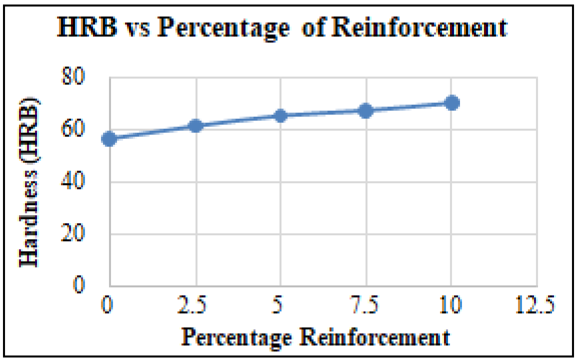
Graph 2: Energy absorbed vs Percentage of Reinforcement

4.4 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 PbO 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 6: Hardness Test Results

S. No	Composition	Hardness (HRB)
1	LM 6 + 0.0% PbO Glass	56
2	LM 6 + 2.5% PbO Glass	61
3	LM 6 + 5.0% PbO Glass	65
4	LM 6 + 7.5% PbO Glass	67
5	LM 6 + 10.0% PbO Glass	70



Graph 3: HRB vs Percentage of Reinforcement

4.4 Microstructure Analysis

The figures show the optical microstructure of different % of glass reinforcement. The glass particles were homogeneously distributed throughout the matrix and good bonding between the aluminium and glass particles were observed From the microstructure it is observed that blocky Si phase with generally circular shape is distributed in aluminum dendrites because of rapid solidification. During the rapid

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solidification the glass particles were pushed to the by the aluminum dendrites into the last freezing eutectic liquid

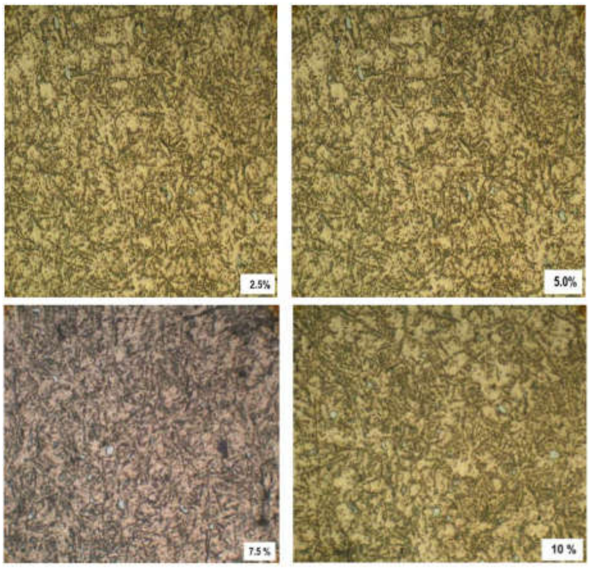

Figure 3: Optical Microstructure of LM6 with PbO Glass reinforcement

5. Conclusion

The PbO glass reinforced metal matrix composite is successfully manufactured by stir casting route.The addition of PbO glass and T6 heat treatment improved the mechanical properties of the MMC compared to the Pure LM 6.

Increasing the amount of PbO glass reinforcement will increase the hardness and toughness of the metal matrix composite. 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.

The T6 heat treatment does not have much effect in the pure material but the mechanical properties such as tensile strength, hardness, toughness etc. are tend to increases after heat treatment. Microstructure shows the uniform distribution of glass particles in the LM 6 matrix.

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