Tensile and Compressive Behaviour of Solid Glass Microspheres Reinforced LM13 Aluminum Alloy Based Metal Matrix Composites

Pankaj Singh, G. Dixit

Abstract: Aluminium compound materials saw to be the best choice with its exceptional utmost of sketching out the novel material for gaining desired properties. Aluminium alloy based composite materials are expanding broad affirmation for aeronautics application in perspective on their high strength combined with low density or light weight. In the present concerned work, an endeavour is put to prepare and focus the tensile and compressive behaviour of Aluminium alloy LM13 and Solid Glass Microspheres (SGM) particulates Composite with perspective to get better properties with light weight. Stir casting method was used to manufacture these aluminium alloy LM13 and SGM particulate composite with 10 v%, 15 v% and 20 v% of reinforcement. Based on ASTM benchmarks, the composite samples were prepared and tested, and the results obtained were then analysed. A notable improvement was perceived in the strength of tensile and compressive capacities of the developed metal matrix composites (MMC).

Keywords : Solid Glass Microspheres, Tensile Strength, Compressive Strength, Stir Casting, Aluminium Alloy Metal Matrix Composites.

I. INTRODUCTION

In the previous couple of decades, ton of research work has been observed, committed to the advancement of lightweight and low cost metal matrix composites. In this respect, for multiple purposes in the manufacturing, aviation and building sectors, alloys of aluminium with low-density were utilized as material for matrix components with particulates of several types such as ceramic and carbon [1-5]. The manufacturing method utilized to make most of the parts is casting, and the subsequent microstructure of this as-cast casting determines physical as well as mechanical characteristics of the developed component. Ceramic and carbon based strengthening are mostly used to further enhance aluminium alloy's mechanical, tribological and physical characteristics. The fortifications like fibers of graphite (P-55) [6], carbon fiber packs (K139) [7] and SiC particles [8,9] of various dimensions were utilized to strengthen different aluminium alloys. Metal Matrix Composites (MMC) with aluminium or its alloy as the matrix are gaining broad prevalence in numerous categories owing to their enhanced mechanical characteristics along with lower density, particularly when endurance and weight are of primary significance. In many implementations, aluminium-based MMC's are used as a product, such as engine cylinders, engine pistons, and several others [10]. Particle reinforced MMC's have found outstanding intrigue due to their specific performance and firmness [11]. By far, the assessment work finished on aluminium and its alloy based composite materials, incorporates silicon carbide, $Al2O3$, beryl, red mud and so forth [12]. Metal matrix composites also have excellent resistance aga inst wear and are good energy absorbers as metallic foams or sponges.

In this concerned work, endeavour has been put to synthesize an Aluminium LM13-SGM Composite as no research has been observed during the literature review about the development and characterization of composite material having matrix of LM13 aluminium alloy with the structural component as the solid glass microspheres. Hence, it was thought to be an interesting project to study their behaviour under tension and compression so as to understand its worthiness for such applications. This work imbibes the tensile and compressive behaviour of a novel composite developed by dispersing solid glass microspheres with varying volume concentrations in the LM13 Aluminium alloy matrix, resulting in composite with three different densities. These composites behave like solid foams in general and their behaviour under compression changes along with composite density.

II. MATERIALS AND METHODS

A. Matrix Material

LM13 alloy was found suitable and chosen to be the matrix material because of industrial viability, and the chemical composition of LM13 alloy is given for reference in Table 1. Owing to its good resistance against wear, low coefficient of thermal expansion along with good bearing properties, various uses and applications of LM13 alloy are not limited to pulleys (sheaves), pistons for diesel and petrol engines, and other automotive engine parts operating at elevated temperatures. Another impressive characteristic of LM13 alloy is its high resistance to corrosion under atmospheric conditions.

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It possesses good fluidity due to which it can be cast into comparatively thin sections. LM13 approximately melts in the range of 525-560 °C whereas its typical pouring temperature is 700 °C but depending on the mould configuration the temperatures may range between 670-780 °C.

Table 1: Elements in LM13 Aluminium alloy

Elements	Si	Mg	Cu	Fe	Ti	Cr	Ni	Mn	Al
Wt.%	12.1	1.2	0.8	0.8	0.02	0.07	0.9	0.2	Bal.

B. Structural Material

Solid Glass Microspheres, also known as glass beads, grants several benefits like low oil absorption and excellent thermal stability as it has good heat and chemical resistance which in turn results in enhanced processing. Owing to these characteristics it has found applications in electrical, automotive, paint, packaging, and construction industry. It is also used in domestic appliances and adhesives. Since these glass beads are made up of glass, hence they are extremely stable, non-toxic, and recyclable as well. Suitability of these solid glass spheres for applications involving high stress or processes where these microspheres will be subjected to high stress is because of its high crush strength.

Soda Lime Glass is one of the several formulations of glass that is known by soda lime silicate glass also, and is used to manufacture these solid glass microspheres. Based on supplier's data, that is, M/s India Glass Beads, some of the important physical properties of this soda lime solid glass microspheres is given in Table 2 and its chemical composition is given in Table 3. These solid glass microspheres are used as reinforcement material for developing the concerned metal matrix composite.

Table 2: Properties of Solid Glass Microspheres

Appearance	Grains
Specific Gravity	2.5
Softening Point	750 Degree Celsius
Hardness	6 Mohs
Size	50 microns

Table 3: Chemical Composition of Solid Glass Microspheres.

Compounds	Quantity
SiO_2	70-71%
Na_2O	11-14%
CaO	7-9%
MgO	4-6%
K_2O	3-5%
Al_2O_3	1%

C. Composite Fabrication

The studied SGM reinforced LM13 alloy MMC was developed using permanent mould die casting assisted with melt-stirring technique. An innovative two-step blending method, preheating of particles, rationally chosen stirrer velocity, and melt degassing using hexachloroethane tablets (C2Cl6) have assisted to achieve steady dispersion of solid glass microspheres [13-18]. The ingot-shaped LM13 alloy was previously split into smaller parts and then kept inside a resistance furnace of 2 kW Power working at 230 V, in a graphite crucible. It was then heated to 800° C in order to melt this LM13 alloy. Commercially available Hexachloroethane tablets (C_2Cl_6) were used to degas, the molten metal in order to decrease the defects of casting namely porosity, blowholes and voids. Before adding the SGM particles to the melt the temperature of the molten metal was reduced and retained at 730° C. In order to remove loose scales, residues and moisture, the reinforcing SGM particles of size 50 microns were preheated to 200° C for 2 hours. Stirring of molten metal was carried out by a motorized stirrer operated at speed of 550 - 600 rpm in order to generate a whirlpool. The particles of SGM are discharged into the whirlpool of molten metal at 15 - 20 g/minute of speed, through a system of funnel. In view to avoid contamination, the chromium steel blades mechanical stirrer with zirconium coating was used. The stirring speed was maintained at a low rate of 300 rpm for about 15 minutes to obtain adequate dispersion of SGM particles. On the completion of stirring process, the molten mix of metal and reinforcing particles was at last poured into a preheated mold of cast iron, at 700° C of pouring temperature and was cooled at ambient temperature to solidify. Three different types of composites with varying SGM volume percentages namely, SG10 (10 v% SGM), SG15 (15 v% SGM) and SG20 (20 v% SGM) were fabricated to study the reinforcement effect on tensile behaviour and compressive behaviour of these combinations of matrix and reinforcement. Unreinforced LM13 alloy was also cast for comparison purpose. The stir casting experimental set up is given in Fig. 1 and the details of process is given in Table 4 for reference.

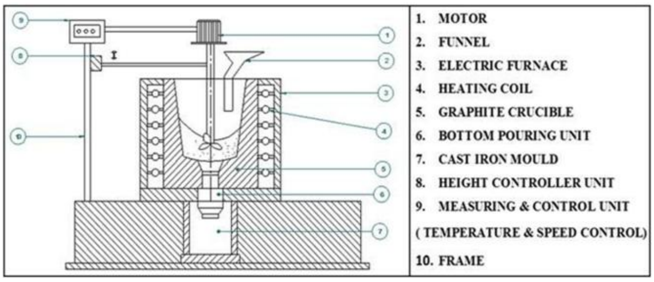

Fig. 1. Schematic of Stir Casting Setup [24]

Table 4: Stir Casting Process Parameters

Impeller Type	Placement of Stirrer	Span of Stirring	Speed of Stirring	Metal Pouring Temperature
3 blades fan type made from chromium steel and coated with Zirconium	Depth of ~2/3 calculated from the bottom of the crucible	~15 min	550 - 600 rpm	700 °C

D. Tensile Strength Testing

Tensile strength is a measure of the material's ability to withstand the loads tending to elongate the structure or material. It is tested by placing the sample between a pair of jaws in a Universal testing machine and then the sample is stretched and the data is recorded. A computer controlled, BISS Universal testing machine test system as shown in Fig.2 was engaged for performing the tests. These tests were conducted at Advanced Centre for Material Science at IIT, Kanpur (U.P), India. Before carrying out the tests, initially the grip alignment of the machine is checked. Speed of 0.5 mm/min for crosshead displacement was set in the test system for carrying out the tensile test. Strain data for these tensile tests was collected by using an extensometer of 25 mm gauge length. The specimen's tensile strength capacity and also the elastic modulus were calculated on the basis of the data of load-strain collected by these tests. Minimum of five samples for every combination of the composite was tested and average values of them are reported. These tests were performed in a well-mannered way at room temperature as per ASTM-E8-95.

Some of the samples may exhibit premature failure because of the matrix porosity. Such samples, when compared with other specimens, shows fall in the strength values, minimum by 30%. The results for such specimens were discarded when the presence of matrix porosity was established after inspecting the fracture surface and were not included in any type of comparison and analysis.

Fig. 2. BiSS Universal testing machine (100kN)

E. Compressive Strength Testing

Compressive strength is the measure of the materials ability to withstand the loads tending to decrease the size of the sample. It is tested by placing the sample under the compression testing fixtures in a Universal testing machine where a moving plunger compresses the sample. Developed metal matrix composite was tested for compressive strength as per ASTM-E9-95 at a strain rate of 1/s on BISS Universal testing machines at Advanced Centre for Material Science at IIT, Kanpur (U.P), India. Samples prepared for this test are of cylindrical shape with diameter of 10 mm and length 15 mm. Prior to testing, the friction between the compression test plates and the specimen surface was reduced by mechanically polishing the specimens surfaces and coating them with a thin layer of molybdenum sulphide for lubrication. During the testing, data was recorded for load-displacement and then standard methodology was used to convert it to stress-strain graph.

III. RESULTS AND DISCUSSION

A. Tensile Strength

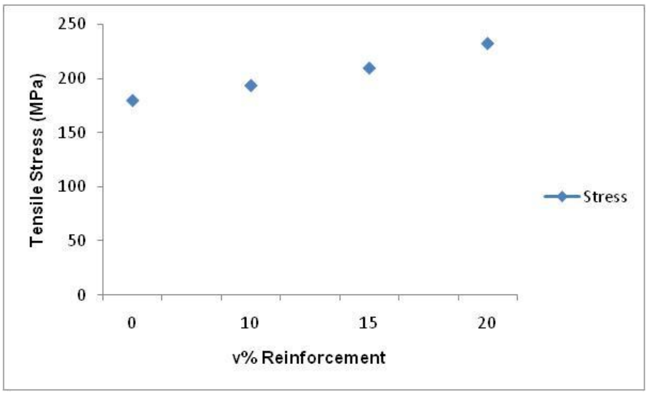

Fig. 3 Change in Tensile Strength with reinforcement

The variation in the capacity of tensile strength for the developed MMCs with the change in the percentage of reinforcement is visualized in Fig. 3. During evaluation and analysis it was found that the tensile strength capacity of the resulting MMCs increases with the increase in the reinforcement quantity in the LM13 matrix material. Tensile strength improvement for the developed MMCs was observed to rise from 180Mpa for unreinforced LM13 alloy to 232Mpa for 20 v% of reinforcement. It was also observed that there is a decrease in the amount of ductility possessed by the developed composite as the unreinforced LM13 had percentage elongation of 0.5, that then reduced to about 0.3 for 20 v% of reinforcement. This may be attributed to the phenomenon that the higher number of dislocations in the matrix material resulting from the reinforcement, also increases the restrictions in the dislocation movements. Furthermore it has been also observed that the higher number of dislocations in the MMCs may result from the higher dissimilarity between the coefficient of thermal expansion of reinforcement and matrix that in turn yields in the higher interruption concentration in the MMCs. Rise in the applied stress also leads to surge in the amount of grain boundaries which inhibits the movement of dislocations and results in the pile up of dislocations at the grain boundary region [19-22]. Hence, the tensile strength enhancement of the MMC was observed.

B. Compressive Strength

Deviation in compressive strength of the developed composite has been demonstrated in Fig. 4 which also depicts the correlation between v% of SGM particulates and compressive strength. Increase in the quantity of SGM particulates from 10 v% to 20 v% builds up the compressive strength of the resulting composites.

As observed, there is an increase in the compressive strength capacity of the developed composite, and is due to the bonding at the interface, that makes possible the compressive loads to be conveyed viably to the consistently connected and very much fortified reinforcement. Comparative outcomes of compressive strength of various composite materials were shown in different investigations [23].

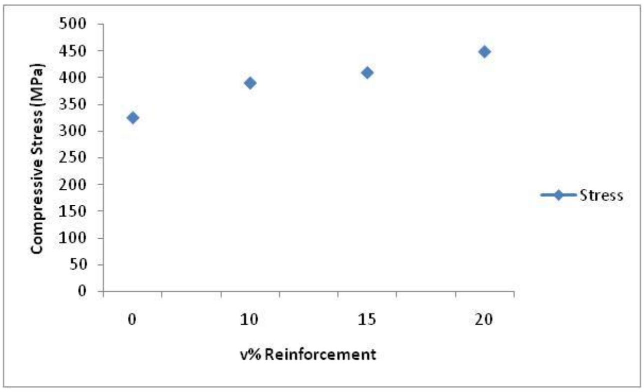

Fig.4 Change in Compressive Strength with reinforcement

IV. CONCLUSION

- Metal matrix composite with up to 20 v% solid glass microspheres was synthesized successfully by using the permanent mould die casting assisted with melt-stirring technique.
- The density of the developed MMC was decreased with the increase in the content of solid glass microspheres providing weight reduction per unit volume.
- The Ultimate tensile strength of the developed composite was observed to increase with the increase in the solid glass microspheres content whereas the ductility has decreased with increase in solid glass microspheres content.
- The compressive strength of the developed composite also improved with rise in the solid glass microspheres content.
- Incorporation of solid glass microspheres in the matrix of aluminium alloy may lead to the production of low cost aluminium alloy metal matrix composites with superior mechanical properties like tensile and compressive strength. Such composites can find applications where lightweight materials are needed with good stiffness and strength.

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