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Tensile and Compressive Behaviour of Hollow Glass Microspheres Reinforced LM13 Aluminum Alloy Based Syntactic Foam

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Abstract: Aluminium compound materials saw to be the best choice with its exceptional utmost of sketching out the material to give required properties. Aluminium alloy composites are expanding broad affirmation for aeronautics application in perspective on their high strength combined with low density. In the present work, an endeavour is made to prepare and focus the tensile and compressive behaviour of Hollow Glass Microspheres (HGM) reinforced Aluminium alloy LM13 based syntactic foam. Stir casting method was used to manufacture the aluminium alloy LM13 based syntactic foam with hollow glass microspheres (HGM) as space holders in 10 v%, 15 v% and 20 v% of concentration. Based on ASTM benchmarks, the composite samples were prepared. Results indicate that there is notable improvement in compressive strength while the tensile strength is on the lower side when observed in reference to the unreinforced LM13 alloy.

Keywords : Hollow Glass Microspheres, Tensile Strength, Compressive Strength, Stir Casting, LM13 Syntactic Foam.

I. INTRODUCTION

Syntactic foams are being used since 1960s and at that time, these foams were used for deep sea applications as buoyancy aid materials [1]. Syntactic foams are also one of the composite materials, synthesized by dispersing the particles of hollow geometry known as micro-bubbles, micro-balloons, or microspheres into a ceramic, polymer or metal matrix. Presence of these hollow particles results into a composite with higher strength to weight ratio because of low density and lower coefficient of thermal expansion. Such foams exhibit excellent combination of mechanical and physical properties which may be of great importance for various specific and tailored applications [1]. Such as core in sandwich structures, for packaging / fire proof, crash safety, damping panels and under-water buoyant structures [1–5]. One of the most remarkable property of syntactic foam is their high damage tolerance because of their high energy absorbing potential. As compared to other foams syntactic foams shows high specific stiffness, improved strength and high acoustic and mechanical damping capacities as well [2,3].

In the view to achieve improved and desired mechanical properties, syntactic foams are primarily developed by two techniques. In the first method the volume fraction of the dispersed particles that is micro-balloon in the syntactic foam structure is changed whereas in the second technique, micro-balloons of different size or wall thicknesses are used to fill the syntactic foam structure. Syntactic foams compressive properties mainly depend on the properties of micro-balloons while the tensile properties depend on the properties of material for matrix that holds the micro-balloons together. It has been observed in the literature that the syntactic foams filled with ceramic particles and the volume fraction of this ceramic phase is comparatively high in the matrix, shows excellent thermal insulation and the coefficient of thermal expansion is also observed to be low [6–8].

By far the literature of aluminium alloy syntactic foams are concerned, the quasi-static compression behaviour with a focus on energy absorption capability of these foams, has attracted few researchers in the past to carry out the study [2–6,9–11]. Ramachandra and Radhakrishna reported that by adding the micro-bubbles, density of composites reduces and the mechanical properties enhances as they synthesized aluminum based metal matrix syntactic foams (MMSFs) by dispersing micro-bubbles by stir casting method [12].

In the present research work, an endeavour has been made to synthesize Aluminium LM13-HGM syntactic foam as no research has been observed during the literature review about the development and characterization of syntactic foam having matrix of LM13 aluminium alloy with space holder as the hollow 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 novel syntactic foam developed by dispersing hollow glass microspheres with varying volume concentrations in the LM13 Aluminium alloy matrix, resulting in syntactic foams with three different densities. These composites behave like solid foams in general and their behaviour under compression changes along with composite density.

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II. MATERIALS AND METHODS

A. Matrix Material

LM13 alloy was found suitable and chosen to be the matrix material because of industrial viability, and its chemical composition is given 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. It possesses good fluidity due to which it can be cast into comparatively thin sections. LM13 approximately melts in the range of 525-560 ºC whereas its typical pouring temperature is 700 ºC 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. Micro Balloon Material

Hollow Glass Microspheres, also called bubbles, microbubbles or microballoons, and are typically made out of soda lime - borosilicate glass blend formulation which provides low density with other useful benefits such as high heat and chemical resistance. These hollow glass microspheres, typically possesses rigid walls with thickness of about 10% of the diameter of the sphere. Generally the thickness of wall of these hollow glass spheres determines the crush strength and, as expected, the higher the density of the sphere, the higher the crush strength. Some other impressive properties offered by these light weight soda lime borosilicate hollow glass microspheres are that they are chemically stable, non-combustible, nonporous, and have excellent water resistance.

Some important physical properties of soda lime – borosilicate, hollow glass microspheres used as space holder material for developing the concerned syntactic foam as per the data of supplier 3M^{TM} is given in Table 2.

Table 2: Properties of Hollow Glass Microspheres

Appearance	White Powder
True Density	0.6 g/cc
Softening Point	600 Degree Celsius
Crush Strength	27,000 MPa
Size	18 microns

C. Composite Fabrication

The studied HGM reinforced LM13 alloy syntactic foam is developed using permanent mold 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 hollow 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 and superheated to 700 ºC. Commercially available Hexachloroethane tablets (C_2Cl_6) were used to degas, the molten metal in order to reduce the defects of casting namely porosity, blow holes and voids. Before adding the HGM particles to the melt the temperature of the melt was reduced and maintained at 650ºC. In order to remove loose scales, residues and moisture, the reinforcing HGM particles of size 18 microns were preheated to 200 º 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 HGM particles are discharged to the molten metal whirlpool at a rate of 15 - 20 g/minute through a funnel. In the view to avoid contamination, the chromium steel blades mechanical stirrer with zirconium coating was used. The stirring was maintained at a low rate of 300 rpm for about 15 min to obtain adequate dispersion of HGM particles. On completion of stirring process the molten mix of metal and reinforcing particles was at last poured into a preheated mold of cast iron, at a pouring temperature of 650 ºC and then allowed to cool and solidify at ambient temperature. Three dissimilar composites with different percentages of HGM namely, HG10 (10 v% HGM), HG15 (15 v% HGM) and HG20 (20 v% HGM) were fabricated to study the effect of HGM reinforcement on the tensile 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 and process details is given in Fig. 1 and Table 3 respectively.

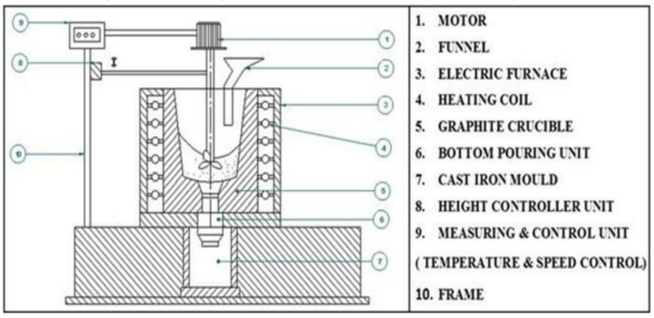

Fig. 1. Schematic of Stir Casting Setup [24]

Table 3: 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 crucible	~15 min	550 - 600 rpm	650 ºC

D. Tensile Strength Testing

A computer controlled BISS Universal testing machine test system as shown in Fig. 2 was engaged for performing the tests. 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 tests. The strain data was collected with the help of an extensometer having gauge length of 25 mm. The tensile strength and also the modulus of elasticity for these specimens were calculated on the basis of the data of load-strain collected by these tests.

The surface finish was enhanced by minimizing the effects of surface irregularities, by removing the machine marks and all the circumferential scratches, and for this purpose 800 grit emery paper was used for grounding the gauge sections. Minimum of five samples for every type of syntactic foam 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.

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

E. Compressive Strength Testing

Fig. 3. BiSS Slow Strain Rate Test System

Quasi-static compression test was performed on the developed syntactic foam at ambient temperature using BiSS Slow Strain Rate Test System as shown in Fig. 3. These tests were performed in accordance with ASTM-E9-95 at Advanced Centre for Material Science at IIT, Kanpur (U.P), India. Strain rate for these tests was set at 0.1/s. Samples prepared for this test are cylindrical in shape with length of 15 mm and diameter of 10 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 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. Set of five samples were tested for each density set of syntactic foam.

III. RESULTS AND DISCUSSION

A. Tensile Strength

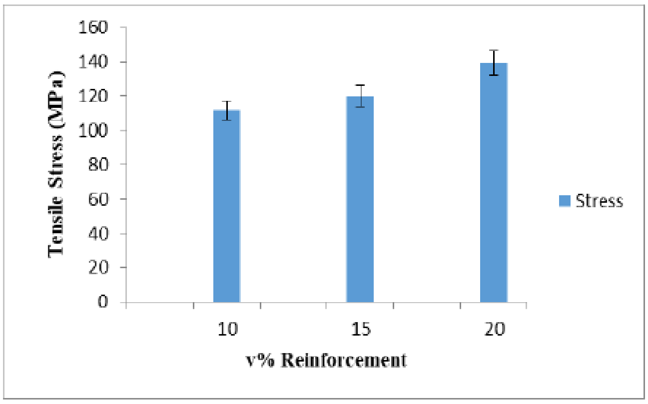

Fig. 4 Change in Tensile Strength with reinforcement

The variation of tensile strength of the developed syntactic foam with the change in reinforcement percentage is graphically analyzed in Fig. 4. It can be seen that adding the HGMs into LM13 matrix increases the tensile strength of the syntactic foam when the reinforcement increases from 10 v% to 20 v%. The tensile strength of developed syntactic foam is enhanced from 111 MPa for 10 v% of reinforcement to 139 MPa for 20 v% of reinforcement. It was also observed that the ductility of the composite shows no significant change as the percentage elongation remains about 0.3 for all sets of density of the developed syntactic foams. Since the developed composite is foam, therefore its tensile strength is comparatively less than the base metal alloy due to the induced porosity. But, if the comparison is within the syntactic foam of different densities then, as mentioned above, the results showed some increase in the tensile strength with the increase in the reinforcement. This may be attributed to the phenomenon that higher number of dislocations restricts the dislocation movement, so, in the matrix, there are no dislocation movements by the addition of reinforcement. More the dissimilarity between the coefficient of thermal expansion of reinforcement and matrix has the propensity in the direction of higher number of dislocations in the syntactic foam.

This difference in coefficient of thermal expansion also results in high interruption concentration in the syntactic foam. Rise in the applied stress also leads to surge in the amount of grain boundaries which inhibits the movement of dislocation and ends up with pile-up of dislocation at the grain boundary region [19-22]. Hence, the tensile strength enhancement of the syntactic foam is observed.

B. Compressive Strength

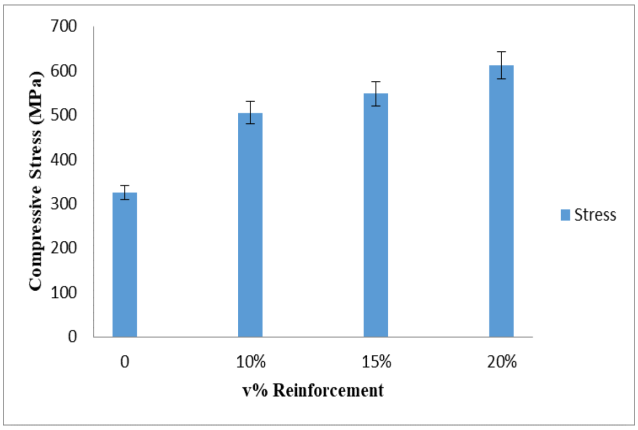

Fig.5 Change in Compressive Strength with reinforcement

Deviation in compressive strength of the developed composite has been demonstrated in Figure 5 which also depicts the correlation between v% of HGM particulates and compressive strength. Increase in the quantity of HGM particulates from 10 v% to 20 v% builds up the compressive strength of the resulting composites. As viewed, this surge in the compressive strength of the developed composite is due to the bonding at the interface, resulting in the viable exchange of the compressive load conveyed to the consistently connected and very much fortified reinforcement. Comparative results of compressive strength of various composite materials were shown in different investigations [23].

IV. CONCLUSION

- Syntactic foam with up to 20 v% hollow glass microspheres was synthesized successfully by using the permanent mould die casting assisted with melt-stirring technique.
- Syntactic foam's density has decreased with rise in the content of hollow glass microspheres resulting in per unit weight reduction.
- Ultimate tensile strength improved with rise in hollow glass microspheres quantity while ductility was found to be constant for all sets of reinforcement of hollow glass microspheres content.
- Compressive strength of the developed syntactic foam was observed to improve significantly with increase in the hollow glass microspheres content.
- Incorporation of hollow glass microspheres in aluminium alloy matrix may lead to the development and production of low cost aluminium alloy syntactic foam with superior compressive strength. These foams can find applications where lightweight materials are needed with good stiffness and strength.

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