International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Manufacture of Aluminum Foam Using Water Beads

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Abstract: ***This paper significantly aims at producing aluminum metal foam by providing a simple production technology using water beads to acquire the desired product and at the same time cost effective. The team has pioneered in achieving uniform porosity thereby reducing the weight of the metal foam considerably, resulting in a new method of production of aluminum metal foam. The material used in the experiment is LM6 aluminum alloy. A Cope and Drag similar to the conventional Gravity Casting was used and a cavity was carved in the moulding sand which was then entirely filled up with water beads. After having prepared the experimental setup, molten aluminum metal was poured into the casting through a riser. The molten metal occupied the entire cavity except the space occupied by the water beads. The water beads created hollow cavities throughout in the foam. Upon cooling, the aluminum metal solidified and the foam was examined after removing the water beads and it was found that a uniform porosity was maintained throughout the metal foam eventually achieving considerable weight reduction. The aluminum foam underwent several tests to ensure that the dynamic properties of the aluminum metal were closer to the desired values. The dynamic behavior of aluminum metal foam under compressive and impact load is of great interest in fundamental research and engineering applications as well. This paper presents a detailed compression testing of the aluminum metal foam under various loading conditions and the results were recorded. Thus, this project has been successful in accomplishing a cost effective, simple technology in producing aluminum metal foam with significant weight reduction.***

1. Introduction

Metal foams are cellular structures defined by porosity acquired through various manufacturing processes. The high stiffness along with low density accounts for the widespread usage and high demand of aluminum foams. Owing to the difference in porosity, the metal foams are categorized into two; closed cell metal foams and open celled metal foams which are also known as metal sponge. The closed cell metal foams are structures that have sealed pores i.e. no porosity on the superficial layers whereas the pores of the open cell metal foams are interconnected. Metal Foams are used in vibration damping and sound absorption due to high absorption characteristics, used in load bearing structures and in impact absorbing structures owing to its reduced weight and thus increasing performance. They are also used in heat exchangers.

2. Objective

Although the properties of metal foams enhance the demand of their usage in market, the current manufacturing process of metal foams are quite complex and highly expensive. Thus the prime objective of this study to is to simplify the manufacturing process and to be made available at a comparatively low price.

This paper significantly aims at producing aluminum metal foam by providing a simple production technology using water beads to acquire the desired porosity and other mechanical properties; thereby reducing the weight of the metal foam considerably, resulting in a new method of production of aluminum metal foam. A comparison of compression test results of the manufactured metal foam and the parent specimen was done to study the behavior of the metal foam under loading.

3. Literature Review

Various Research papers have been published in this area and a lot of research work also has been done on production of aluminum metal foams and their testing are as follows:
Bernd Friedrich, Katherina Jessen, George Rombach, in their Research Paper, ‘Aluminum Foam - Production, properties and recycling possibilities’ published on August 22nd, 2003, have discussed the various methods of manufacturing metal foams and have compared the properties of the metal foams acquired through different methods and have also studied the recycling possibilities of metal foams. [1]

Ahmet Güner *, Mustafa Merih Arıkan and Mehmet Nebioglu, in their Research Paper, ‘New Approaches to Aluminum Integral Foam Production with Casting Methods’ published on 28th August 2015 have discussed manufacturing of metal foams by direct gas injection and continuous casting methods and compared the properties of metal foams obtained by both the methods. [2]

Xinzhu Wang and Guangtao Zhou, in their Research Paper, ‘The Static Compressive Behavior Of Aluminum Foam’ published on October 17th, 2011, investigated uniaxial compression and indentation of closed cell aluminum metal foam experimentally under Quasi Static Loading conditions. [3]

K.Y.G. Mccullough, N.A. Fleck and M.F. Ashby, in their Research Paper, 'Uniaxial Stress - Strain Behavior Of Aluminum Alloy Foams' published on April 20th, 1999, have studied the tensile and stress-strain behavior of closed cell aluminum metal foam using a different alloy called 'Alulight'. [4]

O.B. Olurin, N.A. Fleck *, M.F. Ashby, in their Research Paper, 'Deformation and Fracture of Aluminum Foams' published on April 17th, 2000 have studied deformation under loading and fracture resistance of two aluminum alloys foams. [5]

4. Material Selections

LM6 alloy of aluminum exhibits remarkable casting characteristics that enable it to produce intricate castings of different thickness. This alloy is also preferred since it has high corrosion resistance. Its chemical composition is as follows:

Table 1: Chemical composition

Metal	*Percentage*
Copper	0.1% max
Magnesium	0.10% max
Silicon	10.0-13.0% max
Iron	0.6% max
Manganese	0.5% max
Nickel	0.1% max
Zinc	0.1% max
Lead	0.1% max
Tin	0.05% max
Titanium	0.2% max
Aluminum	85.2%

5. Methodology

5.1 Casting procedure

1) The LM6 aluminum alloy ingot is taken in a crucible and placed inside a furnace and is melted at 670 degree Celsius.
2) Preparation of Sand Mould - Green sand is taken in a Cope and Drag that is clean and free of any debris. This sand that is placed in the Cope and Drag is then packed tightly by ramming it on all sides.
3) After tight packing of the green sand is ensured, a desired shape of the mould cavity is cut in the center of the Drag.
4) Water beads were soaked in water overnight. The mould cavity is then entirely filled with soaked beads.
5) Gates are cut for runner and risers carefully to ensure smooth flow of molten metal into the mould cavity. Holes are made in the mould to facilitate easy escape of flue gases.
6) Molten aluminum metal is poured gently into the runner and checked that it reaches the mould cavity and fills it entirely. It is then allowed to solidify. The molten metal occupies the entire mould cavity except the space occupied by the water beads. This experimental set up is left still for some time for the metal foam to be formed.

Figure 1: Water beads

7) After a sometime, the Cope is carefully taken apart from the Drag and the solidified metal foam is taken out from the mould cavity and is quenched in cold water until it gets thoroughly cooled.

Figure 2: Casted Specimen

8) During the process, the water beads shrink in size and are still stuck into the pores that were formed due to the presence of the water beads. Upon formation of the metal foam, the water beads that are reduced in size are carefully removed using a pair of tongs. After the removal of the water beads, the foam that is obtained shows uniform porosity when observed.
9) The obtained aluminum foam is machine to acquire the desired shape and size.

6. Failure Analysis

Failure analysis is the process that determines the root cause of the failure. Each failure should be verified and then analyzed to the extent to identify the cause of the failure and any contributing factors. The methods used can range from a simple investigation of the circumstances surrounding the failure to a sophisticated laboratory analysis of all failed parts.

6.1 Trial 1

Problem Title: Desuetude of Cope and Moulding sand.
Cause: The first trial of aluminum metal foam casting was done using an open hemispherical container without Cope and moulding sand. Once the molten Aluminum metal was poured into the container containing the water beads, the liquid Aluminum spread at the bottom of the container and since there was no escape of Flue gases, the water beads jumped up to the surface and eventually creating porosity only on the superficial area of the metal foam.

Figure 3: Molten Aluminum being poured

6.2 Trial 2

Problem Title: Usage of Aluminium strings
Cause: During the second attempt of Aluminium metal foam casting, Aluminium strings were used to align the water beads uniformly in the mould cavity. Water beads were inserted through the Aluminium strings and placed uniformly across the mould cavity. Liquid Aluminium was then poured into the mould cavity. Upon solidification, the Aluminium strings could not be retrieved from the metal foam.

Figure 4: Aluminum strings in cast

6.3 Trial 3*:*

Problem Title: Usage of Thermocol Beads and Water Beads
Cause: During the third attempt, thermocol beads and water beads were mixed in the ratio of 5: 1 respectively inside the cavity and molten Aluminum was poured into the mould cavity. Since the thermocol beads were more in number, the desired porosity could not be obtained throughout the foam except in the superficial layer where water beads occupied in the mould container.

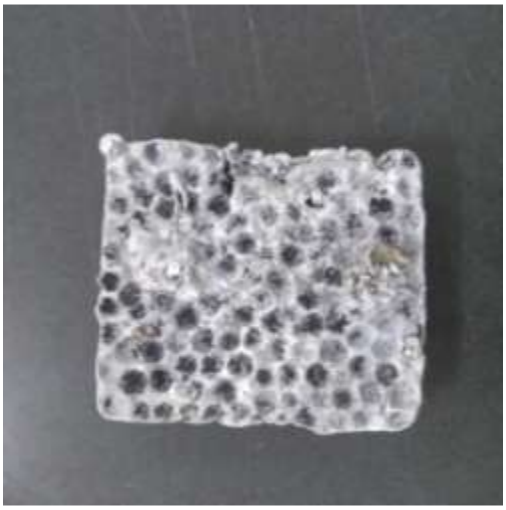

Figure 5: Thermocol bead cast

7. Characteristics of metal foams

- Low weight
- High porosity
- High compression strength
- Excellent absorption characteristics

8. Testing and Analysis

8.1 Compression testing procedure

The aim of a compression test is to determine the behavior of a material as it experiences a compressive load by measuring fundamental variables, such as, strain, stress, and deformation. By testing a material in compression the compressive strength, yield strength, ultimate strength, elastic limit, and the elastic modulus among other parameters may all be determined. With the understanding of these different parameters and the values associated with a specific material it may be determined whether or not the material is suited for specific applications or if it will fail under the specified stresses.

8.2 Machine specifications

Universal Testing Machine model: TUE-C –400 has 40 T capacity for ascertaining the strength and deformation of all kinds of materials, such as steel and other materials in the form of rods, sheets, wires, tubes, chains, and so on. It is a Computer control operating system, which enhances the performance of the machine, uniform and accurate control of the testing, on line display of load Vs. deformation or stress Vs. strain, customized test reports, storage and retrieval of test data, rotary encoder detects yield point based on 0.2% proof stress This machine is comply with Grade A of BS

1610 – 1964 and Grade 1 of IS 1828-1991 with an accuracy of +/- 1% of capacity of the machine.

Figure 6: Universal testing machine

6.3 Test Specimen

The specimen for testing was cut to size following the ASTM D695 standards. As per the ASTM standards, the specimens can either be blocks or cylinders. Typical block sizes are 12.7 mm x 12.7 mm x 25.4 m

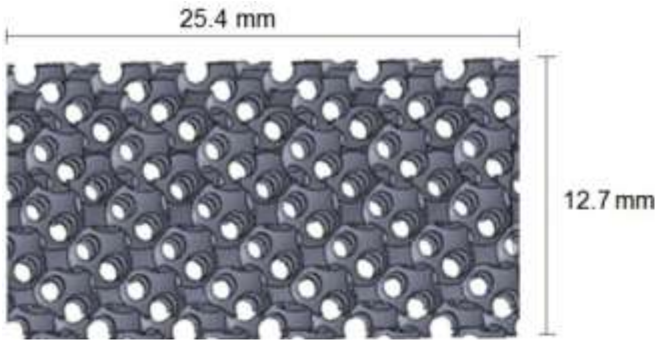

Figure 7: Specimen size

9. Calculations and Results

Area = 0.0127m x 0.0254m = 3.22 x 10^{-4} m^2

Trial 1

Stress σ = Force (KN) / Area (m2)

= 62.9 KN / 0.322

= 195.34 N/mm^2

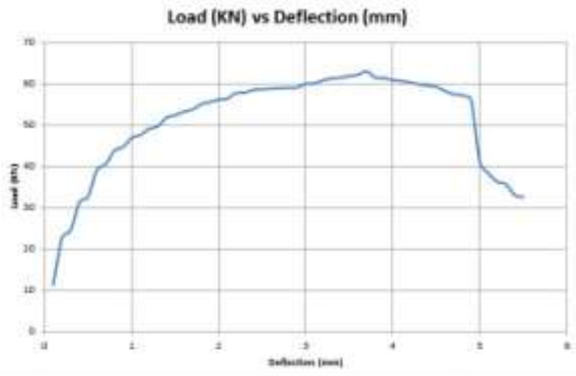

Figure 8: Load vs Deflection – Trial 1

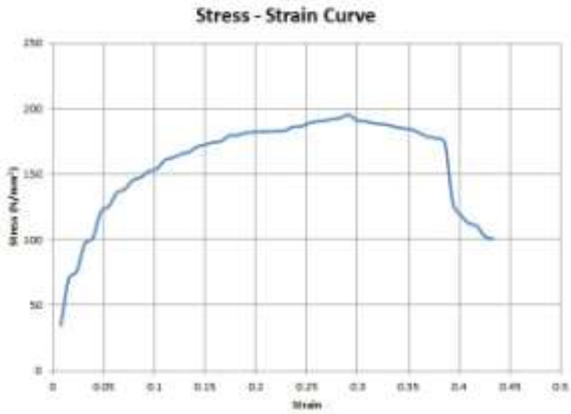

Figure 9: Stress vs Strain – Trial 1

Trial 2

Stress σ = Force (KN) / Area (m2)

= 75.5 KN / 0.322

= 234 N/mm^2

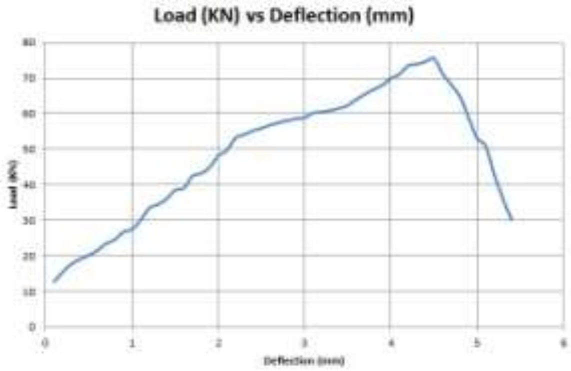

Figure 10: Load vs Deflection – Trial 2

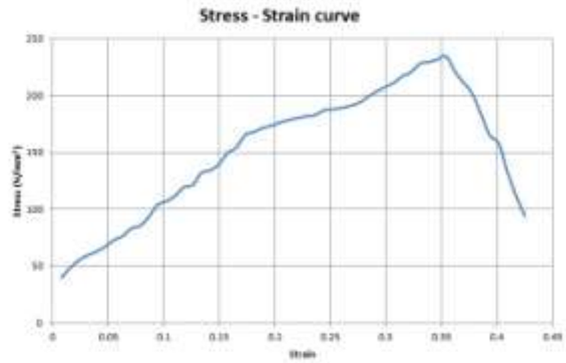

Figure 11: Stress vs Strain – Trial 2

Trial 3

Stress σ = Force (KN) / Area (m2)

= 51.2 KN / 0.322

= 159.00 N/mm^2

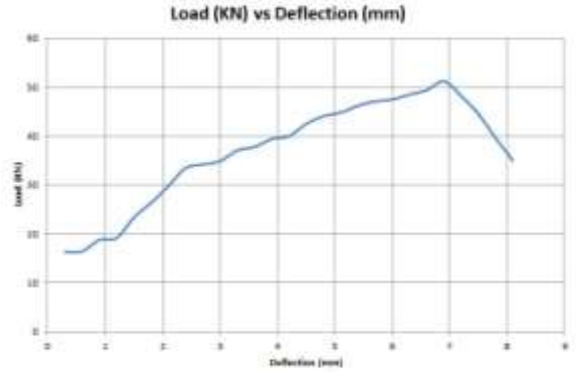

Figure 12: Load vs Deflection – Trial 3

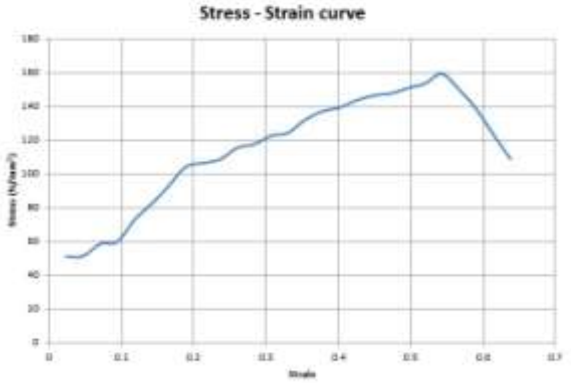

Figure 13: Stress vs Strain – Trial 3

Table 2: Results

Trial	Load (KN)	Ultimate Strength (N/mm^2)
1	62.9	195.34
2	75.5	234.47
3	51.2	159.00

Figure 8: Tested specimen

10. Conclusions

1) The result of the study has been successful in attempting at a simplified procedure of manufacturing aluminum foam.
2) The process has been effective in achieving reduced weight of the metal foam with a very low density of 0.98 gm/cm3 with 63% porosity.
3) Compression test result of the newly acquired metal foam shows an ultimate strength of 234 MPa compared to 280MPa of solid LM6 aluminum.
4) A 4"x4"x0.5" sized metal foam in the commercial market costs Rs.1750/- whereas the cost of manufacturing the same sized metal foam using water beads costs only Rs.150/-

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