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Compressive Behaviour of Aluminium Foam Prepared By Melts Route Method by Different Addition of Nickel Particles

Arun Negi[1],Virendra Singh Rana[2], Dashrath Singh Kathait[3], Himanshu Painuly[4]

[1,2,3] Department of Mechanical Engineering, H. N. B. Garhwal Central University, Srinagar, Pauri Garhwal, India
[4]G.B.P.E.C Pauri Garhwal Uttarakhand

Abstract: **Aluminium foam due to its low specific weight and high stiffness to bending ratio is an adequate structural material however its compressive strength is low in comparison to its counter parts. Hence in this research work an attempt was made to enhance the compressive strength of aluminium foam which was prepared by melt route method by different addition of nickel particles. The objective of this paper is to deliver a better quality of foam, made of aluminium with low relative density and higher strength against compression. This material can be applicable where energy absorption and light weight property is heavily required such as automotive industries. Different compositions are used to find out the best conditions of producing better quality aluminium metal foam. Nickel particles were added directly to molten aluminium and different samples of 30x30x30 mm size with different percentage of nickel particles by weight were prepared. Compressive strength testing of different of these samples was performed on universal testing machine with maximum load of 400KN and pace rate of .001KN/sec. The result of compression test was compared with pure aluminium foam samples and thus the effect of percentage of nickel particles on compressive strength of aluminium foam was examined. Energy absorption of different samples of aluminium foam was also determined from stress strain diagrams generated during compression test.**

Keywords: **Aluminium foam, Compressive strength.**

I. INTRODUCTION

Metal foam is defined as a by solid material surrounded by a three dimensional network of voids. Metallic foams have combinations of properties that cannot be obtained with dense polymers, metals and ceramics foams. For example, the mechanical strength, stiffness and energy absorption of metallic foams are much higher than those of polymer foams. They are thermally and electrically conductive and they maintain their mechanical properties at much higher temperatures than polymers. Besides, they are generally more stable in harsh environments than polymer foams **[1]**.

The high stiffness to weight ratio possessed by aluminium foam makes it an ideal material for use in a number of different applications, especially structural engineering. In order to use foams efficiently in any situation it is essential to understand their behaviour and properties in scenarios relevant to potential uses **[2]**. The level of accountability that exists in structural engineering projects and catastrophic repercussions of insufficient designs make this especially true **[3]**. Foam properties are directly related to the relative density, whether the cells are open or closed, the degree of anisotropy of the foam, as well as the material properties of the ligaments **[4]**. Aluminium foam possess high sound absorption capacity hence it can be used as a structural material for construction of seminars auditoriums where better communication is required however its low compression strength prevents its use in such area so in this research work an effort has been made to increase the compressive strength of aluminium foam **[5]**.

***GENERAL PROPERTIES OF METAL FOAM [6]*:**

General properties of aluminium metal foams are given below:

1. The defining characteristic of metal foams is a very high porosity: typically 75–95% of the volume consists of void spaces.

2. The strength of foamed metal possesses a power law relationship to its density; i.e., 20% dense material is more than twice as strong as 10% dense material.
3. Metallic foams typically retain some physical properties of their base material. Such as, Foam made from non-flammable metal will remain non-flammable; Coefficient of thermal expansion will also remain similar as the base material while thermal conductivity will likely to be reduced than solid of same volume.
4. They are light (typically 10–25% of the density of an identical non-porous alloy; commonly those of aluminium) and stiff, and are frequently proposed as a light weight structural material.
5. After maximum compression it acts like a solid made of same material. Foam properties get disappeared.
6. Normally the closed cell foams are fire resistant.

MECHANICAL PROPERTIES OF ALUMINIUM METAL FOAM:

TABLE I: MECHANICAL PROPERTIES OF ALUMINUM FOAM [7]

Property	**Value**
Density	0.11 to 0.27 g/cm^3
Maximum service temperature	450°C
Melting point	660°C
Compression Strength	2.53 MPa
Tensile Strength	1.24 MPa
Shear Strength	1.31 MPa
Modulus of Elasticity (Compression)	103.08 MPa
Modulus of Elasticity (Tension)	101.84 MPa
Shear Modulus	199.95 MPa
Specific Heat	0.895 J/g-C

USE AND APPLICATION OF ALUMINIUM METAL FOAM [7]:

Aluminium metal foam is popular in several sectors. In near future, application of metal foam is going to be increased rapidly. But it is still limited in laboratory & research phase. Some applications are given below:

(1) Orthopedic uses.

(2) Clinical studies on mammals.

(3) Orthopedic use in humans.

(4) Energy absorption uses.

II. EXPERIMENTAL INVESTIGATION

MATERIAL CHARACTERIZATION:

The raw materials to be used in the present experiment are as follows:

***Pure aluminium ingots*:** Commercially pure aluminium with 99.5% purity will be used as foaming material.

***Calcium powder*:** Pure calcium powder was used as thickening or viscosity enhancing agent.

***Calcium carbonate*:** Commercially pure $CaCO_3$ is used as foaming or blowing agent.

***Nickel Particles*:** Commercially pure nickel particles with 100 meshes were used as strength enhancing agent.

Preparation of Metal Foam

For the preparation of metal foam the set up required and process are explained below

Experimental setup:

Experimental setup consists of the following main components:

***Crucible*:** A standard 12 inch graphite crucible was used for melting aluminium. Graphite crucible was used as it suited the temperature range also it has self-lubricating properties which facilitate easy removal of metal once it has foamed and cooled down.

Crucible pit furnace: The pit crucible furnace which is cylindrical in shape consists of grate inside on which coal and wood was placed for firing the furnace. Inside of the furnace was lined with fire bricks. A blower is attached to the furnace for providing draft. A removal lid was placed on the furnace having a hole in the centre of diameter 8 cm.

Stirrer*:* Stirrer was indigenously built having two mild steel blades with 1.5 cm thickness. The length of the impeller shaft of 60 cm and was attached to a 3 phase electric motor. To vary the speed of the motor a regulator was used.

Fig.1. Assembled Setup for foam manufacturing

PREPARATION PROCEDURE:

The preparation procedure that was followed for foam manufacturing is as follows:

[1].Firing the pit crucible furnace.

[2].Placing the crucible over the furnace and placing solid pure aluminium (1.5 kg) in the crucible and then waiting for it to melt.

[3].Once aluminium melted the blower was switched off as too much high temperature makes the melt less viscous and thus hinders the foaming process

[4].Calcium which act as viscosity enhancing agent was then added (2wt.%of aluminium).The calcium was added in powder form.

[5].Then stirring was initiated at around 200 rpm for about 2 minutes so that calcium gets mixed with molten aluminium and makes the melt viscous.

[6].After calcium nickel was added to molten aluminium in different weight percent for every sample (0,0.5,1and1.5wt %)

[7].Then stirrer was placed on the furnace and stirring was initiated. The stirring speed was 200 rpm and was done for 5 minutes.

[8].After that calcium carbonate was added (1wt.%) and again stirring was done with the speed of 200 rpm for 2 minutes.

[9].The stirrer was removed and the holding time of about 10 sec was provided which resulted in foaming of aluminium inside the crucible.

[10].Then crucible was removed from the furnace and was kept in the air so that the foamed molten metal may cool down.

[11].After the removal of the foam from the crucible sample of specified size was cut from it for desired testing.

Fig.2. Aluminium foam sample

COMPRESSION TEST:

A compression test determines behaviour of materials under crushing loads. The specimen is compressed and deformation at various loads. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength and, compressive strength. For compression testing specimen of size 3x3x3 mm were prepared. Compression test were performed on an electronic universal testing machine whose details are mentioned below in the table:

TABLE II: COMPRESSION TESTING MACHINE DETAILS

S.No.	Machine Type	Main Units	Capacity	Ram Stroke	Make
1	Electronic Universal Testing machine	1. Loading Frame 2. Hydraulic Pumping System 3. Electronic Control Panel	400KN	200 mm	Heico

The specimen was kept at the bed of the machine and the ram was allowed to apply load on the specimen. Once the specimen started to get deformed the graph between deformations of the specimen with the applied incremental load was plotted on the computer attached to the machine. The load applied was in KN while the displacement was kept in millimetres. Stress strain curves were then derived from load displacement data and thus the yield strength of every foamed sample was calculated. The maximum circuit pressure of the machine was around 200 bars.

Fig.3. Electronic Universal Testing Machine

Fig.4. Specimen being compressed in Universal Testing Machine

III. RESULT AND DISCUSSION

Result obtained from compression test are tabulated and given in the table below:

TABLE III: YIELD STRENGTH OF ALUMINIUM FOAM SAMPLES

Matrix	Ni %	Specimen Size (mm)	Density (g/cm^3)	Foaming Efficiency (%)	Yield Strength (MPa)
Al 99% pure	0	30x30x30	0.519	80	9.63
	0.5	30x30x30	0.527	80	14.36
	1	30x30x30	0.531	79	22.44

Stress strain curve for various aluminium foam samples are shown below:

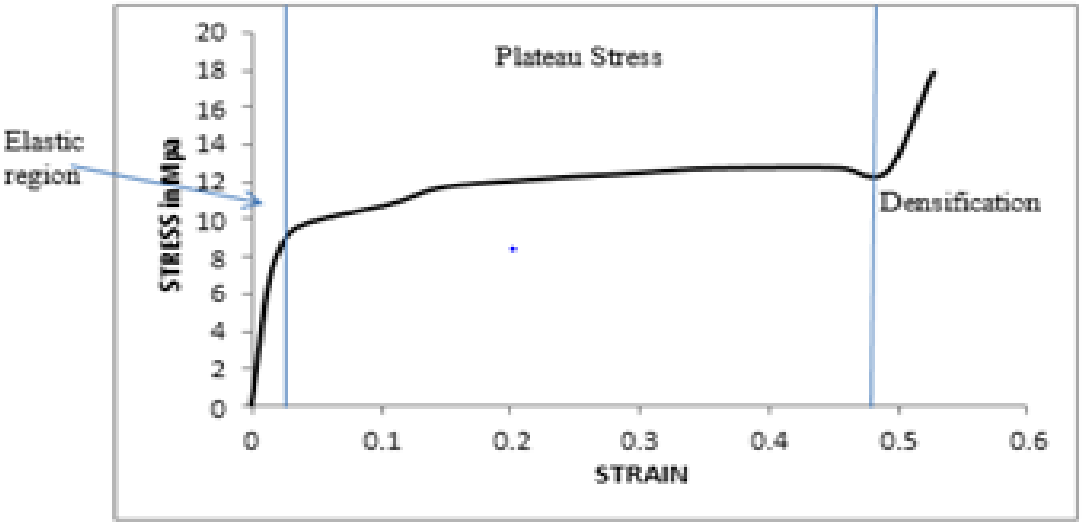

Fig.4. Stress strain curve for pure Aluminium foam

The compressive stress–strain curves of aluminium foams with different Ni contents. similar to other closed cell aluminium alloy foams three distinct regions: First a linear deformation region when strain is low; then a plateau deformation region where stress is almost constant or changed slightly with the strain increasing and at last a densification region where stress rises sharply as the strain changes little. It should be noted that due to the addition of Ni elements the compressive stresses of the foams were increased.

The figures below shows the compressive stress stain curve for aluminium foam prepared by different addition of nickel particles.

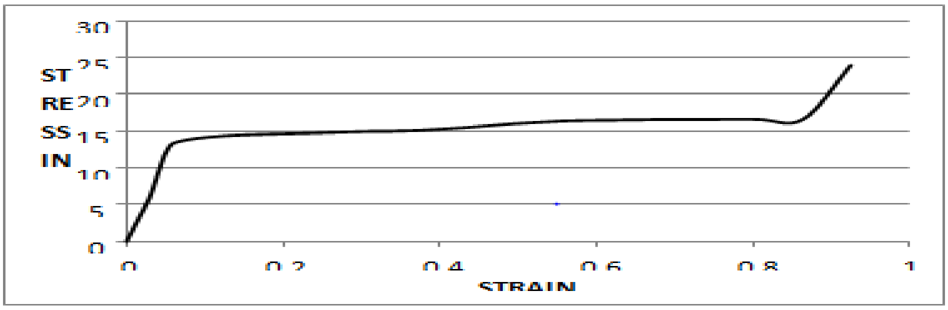

Fig.5. Stress strain curve for 0.5wt% Aluminium foam

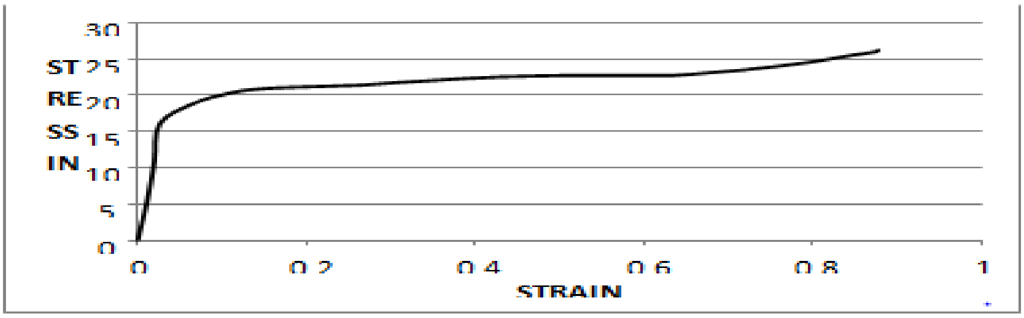

Fig.6. Stress strain curve for 1.5% nickel containing Al foam

For metallic foam, the first peak stress on the stress–strain curve was defined as yield strength. From above compressive stress strain diagrams it is inferred that the yield strength of aluminium foam produced by addition of 1 wt. % nickel particles is about 1.5 times that of pure aluminium foam. The highest yield strength is of 1.5 wt. % nickel containing aluminium foam however density is also considered 1 wt. % nickel containing aluminium foam is surely better as its density is less and yield strength is almost comparable to 1.5 wt. % nickel containing foam. Nickel addition above 2 wt. % in aluminium foam manufacture is not advised as it its higher percentage also makes the foam brittle and hence its compression strength gets affected. The plateau region is smoothest for 0.5 wt. % nickel aluminium foam. All nickel containing foam samples exhibits a higher compressive strength than pure aluminium foam however the density of foam samples have increased by addition of nickel particles which is obvious as nickel possesses a density of around 8.8 g/cm^3 which is much higher in comparison with aluminium (2.74g/cm^3).

ENERGY ABSORPTION:

In most cases, metal foams are used in energy absorption fields. Energy absorption capacity per unit volume is an important aspect to evaluate the properties of metal foams. It is defined as the area under the stress-strain curve up to plateau stress region.

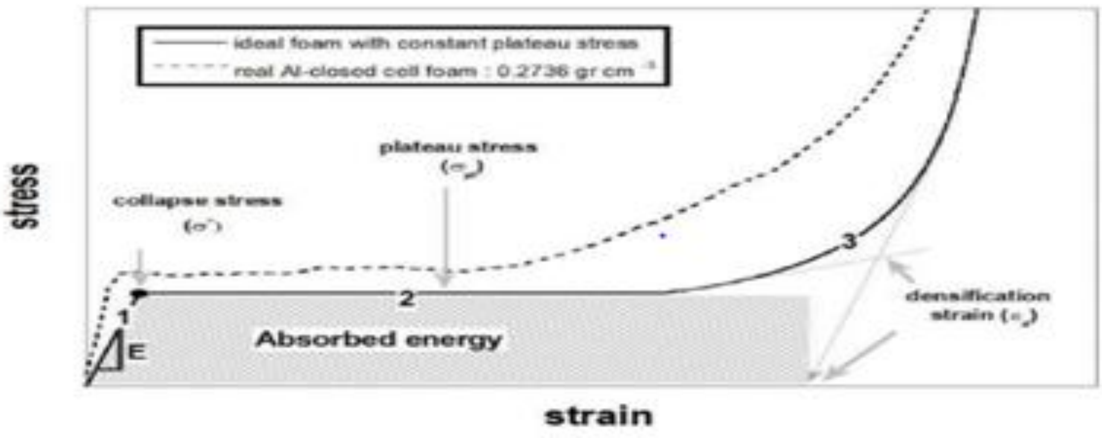

Fig.7. Stress strain curve area showing energy absorption

The calculated values of energy absorbed for different foam samples are tabulated below:

TABLE IV: ENERGY ABSORBED BY VARIOUS FOAM SAMPLES

Matrix	Ni %	Specimen Size (mm)	Density (g/cm^3)	Foaming Efficiency (%)	Energy Absorbed (MJ/m^3)
Al 99% pure	0	30x30x30	0.519	80	5.24
	0.5	30x30x30	0.527	80	10.94
	1	30x30x30	0.531	79	16.23
	1.5	30x30x30	0.614	79	18.83

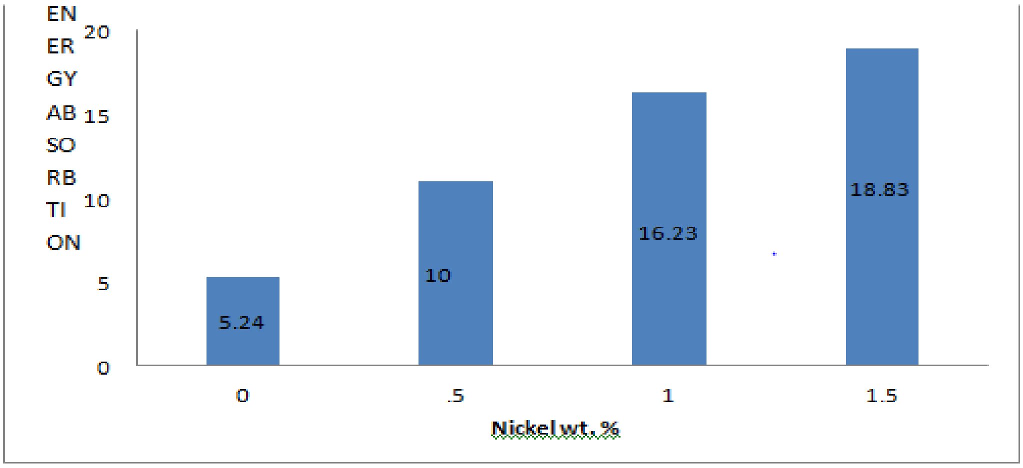

Fig.8. Variation in absorbed energy by varying nickel content

The area under the stress in curve was calculated using graph pad prism software. It is clear from the above values that for pure aluminium foam the value of energy absorbed is quite less the reason is clear as it has a low yield and compression strength but as the nickel addition increases the slope of the line increase up to 1 % after which the graph nearly becomes stable which means that the value of energy absorbed rapidly increases up to 1 wt. % but at 1.5 wt. % we see that increase in energy absorption becomes quite less compared to 1 wt. % nickel foam. The reason behind this low energy difference relies on the fact that addition of higher quantity of nickel makes the metal foam brittle and thus hinders its mechanical properties.

IV. CONCLUSION

The effects of Ni elements on the compressive properties of Al foams were studied and the results were summarized as follows:

The average pore size was found to be around 0.16 mm which is very fine. The distribution of Ni elements was uniform in the cell walls. The cross-section of the foamed metal showed that expect for one or two cells all other cells were homogeneous. The cells formed were of closed nature.

The compressive strength test showed that the yield strength of pure aluminium foam was quite less but with the addition of nickel particles the there was a marked increase in its value. It was noted that the yield strength first increased rapidly but then as the quantity of nickel increased the growth rate decreased which showed that addition of higher percentage of nickel particles was making the foam brittle. The addition of Ni elements prominently improved the plateau region compressive strength and yield stress of the foams but in order to guarantee the ductile deformation the content of Ni elements should be limited.

Energy absorption of various metal foam samples was calculated by finding out the area under the stress stain curve up to the plateau region. The Ni-containing aluminium foams possessed higher energy absorption capacity than those commercially pure aluminium foams. Results showed the same variation as in case of yield strength. The increase in energy absorbed value with addition of nickel particles was rapid during early stages but with further increase in nickel content the growth rate declined. Here also 1 wt. % nickel added aluminium foam sample was proven the best as its energy absorption was greatest relative to density.

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