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Evaluation of Mechanical Characteristics of Magnesium Foam by Varying the Percentages of Foaming Agent

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Abstract: ***Magnesium metal foams have the ability to withstand the structural material impact for the lightweight applications. However, the main disadvantages of using magnesium are due to high reactivity and consequently the mechanical characteristics. The present study aims at evaluating the effect of porosity on the mechanical characteristics. The magnesium metal foams are fabricated by powder metallurgy technique using the crucible made of silica gel for holding the particles. The magnesium powder of 350 microns of mesh size was used as raw material. The mechanical behaviors were evaluated by the universal testing machine. Foams with 36%-43% porosity have the compression strength of 17.134MPa - 85.032 MPa.***

I. INTRODUCTION

The concepts of foam are the encouraging trend in research as it serves as structural and functional improvement in a lightweight, high impact strength, and high energy absorption. Several methods are followed to fabricate the metal foam, they are basically melt forming[2], molding and powder metallurgy process [1]. Apart from open cell and closed cell, the development of the sandwich panel is also researched and followed in different means[3]. In particular previous decades, the aluminum and aluminum alloy foams are progressed for good strength, high specific strength with low density for good absorbing strength for the application of both automobile and aerospace[4]. [1] Foams were fabricated with various amounts of porosity from magnesium alloy by powder metallurgy method, using Ammonium Hydrogen Carbonate salt as space holding particles to control the porosity. The results clearly explained about the porosity range of 14-19% and an increase in porosity lead to an increase in the corrosion rate.[2] The closed metal foam of magnesium alloy AZ31 was manufactured by melt forming method by using calcium carbonate ($CaCO_3$) as the blowing agent. The experiment was detailed about the effect of porosity with the yield strength and energy absorption. The result stated that the increase in the porosity leads to a decrease in the yield strength of 20.55MPa to 2.26MPa, and energy absorption. [4] The cellular Mg foam was fabricated by melt- foaming process. The foaming agent used was $CaCO_3$.

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The experiments were conducted at a different porosity of 71.1-53%. It was proved that the yield strength was increased from 8.69MPa to 27.11MPa, the capacity of absorbing energy was proved to be 4.21MJ/m^3 to 12.72 MJ/m^3 and the specific strength was reached to 33.2 MPa/(gcm^{-3}),

Which was proved to be more than aluminum foam for the yield strength and compared to be equal to Al foam for the energy absorbing capacity. [5] The closed cell magnesium alloy foam were made with a different percentage of hollow ceramic microsphere by melt - forming process. The results were observed that the foam porosity was increased initially and decreased as the percentage of the composite matrix was increased. The percentage increase in composite matrix changed the compression fracture mode from brittleness to ductility of the foam. [6] The open cell magnesium alloy composites were fabricated by using electric resistance furnace. The results were observed that the compressive strength of the composites was 4.9 times higher than the aluminum foam. The compressive strength of Al-foam was 6.9 MPa, the composite foam was 33.9MPa. [7] In this study, the open cell magnesium foam was made by casting process and passing argon gas to avoid flammability. [13] The coating of Ni-P was done on open cell foam by an electroless plating process. The results were proved in the improvement of compressive strength, specific strength, and energy absorption capacity. The foam was proved by SEM and EDAX report. [8] The Titanium foam was fabricated by powder metallurgy technique and acicular urea particles as a space holder. The result of compressive strength was analyzed as 275 MPa and energy absorption was 55 MJ/m^3.

II. LITERATURE SURVEY

[1]A powder metallurgy (PM) approach was developed to fabricate Mg-(15– 50%) closed cell foam, the foaming agent $CaCO_3$ is selected. The successful formation of the closed cell foam is due to the addition of Al and the concerned over sintering treatment, which regulates the intermetallics compounds formation during the gas release of $CaCO_3$ in the process of foaming. The compressive stress–strain curves of Mg-Al alloy foams are serrated during the plateau region due to the intermetallics in the cell walls, and the less Al addition, the less intermetallics formed in the cell walls, the higher yield strength of the Mg-Al alloy foams.

[2]In the present study, an endeavour has been made to investigate the mechanical properties of hollow glass microspheres reinforced die cast magnesium alloy under vacuum die casting process.

The particle size, mass fraction, stirring speed has been considered as input process parameters to analyze the mechanical properties such as hardness, compressive strength, porosity and density of the syntactic foams. Taguchi-Grey relational based multi response optimization has been 15 utilized to compute the optimal process parameters and find the influence of those parameters on performance measures of casting process. From the experimental investigation, the optimal process parameters have been found as particle size (45 microns), mass fraction (20%) and stirring speed (600 rpm) among the chosen process parameters. The determination of mechanical properties has a high influence in the particle size, which also determines the porosity. It has been also observed that the density of syntactic foam decreases with increases in the mass percentage of hollow glass microspheres.

[3]Open-cell pure Mg foams were produced by replication casting process. The spherical particles of NaCl are used as the perform to manufacture the foam with the size varying (A) 1 mm to (D) 2 mm. It was observed that the relative density decreases with increase in pore size. The energy absorption and mechanical properties were examined by means of compression testing procedure The mechanical properties obtained and the large plateau region could be favourable for scaffold and energy absorbing applications.

III. METHODOLOGY

3.1 Raw materials and Foamable pellets preparation.

The pure magnesium and aluminum (all purities >99.5 wt %, particle size -325µm, 99.5% pure supplied by Sigma Aldrich, Bangalore) were used as the starting metal powders. Titanium Hydride (TiH_2 - purity>99.0 wt%, particle size -325 µm, Alfa Aesar, UK) is chosen as the blowing agent. The table.1 illustrates about the different percentage of the foaming agent, which is added to the samples and 10 minutes of foaming timing is allotted.

Table1 Powder mixture compositions for making foamable pellets of 50% of Mg and 50% of Al, TiH_2 are used at a different percentage.

Particulars	Percentage of Foaming Agent
Sample 1	5
Sample 2	10
Sample 3	15
Sample 4	20
Sample 5	25
Sample 6	30
Sample 7	50

The production of foamable pellets comprises of the following steps as mentioned below:

1) Mixing: Mg, Al powders of 50:50 weight ratio with the different percentage of blowing agent was blended by using the ball milling apparatus for 8 hrs.

2) Compacting: The average of 10.2 g powder mixture was uniaxially compacted at the room temperature with the pressure of 9 tonnes to form cylindrical pellets.

3) Sintering: The pellets are sintered at 475^0C under the constant supply of inert gas (Argon) and maintaining the vacuum pressure around 10^{-3}m in a tubular furnace

3.2 Mg-Al foaming procedure

The pictorial view of the fabricating apparatus for preparing cellular Mg-Al, which consists of the tubular furnace of Chemical Vapor Deposition system (CVD-100 of Precision Quazar Tech Pvt. Ltd.) as shown in Figure.1. The vacuum apparatus is set at the top and connected to the tube to create the vacuum during the sintering process, in addition, the inert (Argon) gas supply is also let in the full process of the sintering to avoid the flammability due to the property of Magnesium. The specifications of the fabricated apparatus are listed in the table.2

Table.2 Represent the specification of Chemical Vapor Deposition System(CVD)-1000

Furnace	Parameter	Geometry	Max. Temp.		
	Value	Tubular	1100^0C		
Temp. Controller	Parameter	Max. Temp.	Sensor	Operation	
	Value	1100^0 C	K-Type Thermocouple	Isothermal and ramp mode with PID control	
Vacuum system	Parameter	Pump type	Ultimate pressure	Chamber Isolation	Vacuum Sensor
	Value	Double stage rotary	10^{-3} m Bar	Butterfly Valve	Pirani gauge
Gas Flow	Parameter	Channels	Controller	Max. Flow	
	Value	4	Rotameter Type	1liter/min per channel.	

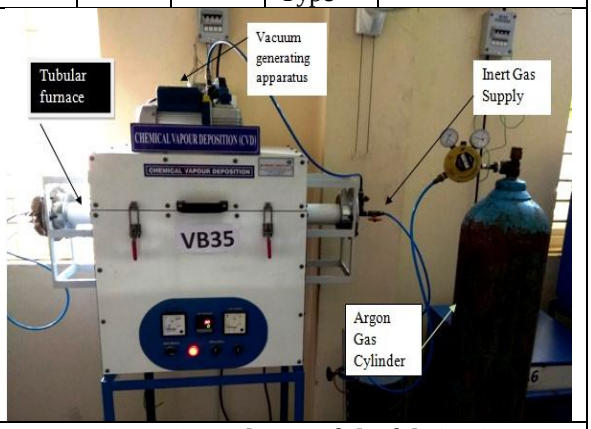


Fig. 1 Pictorial view of the fabricating apparatus for preparing the cellular Mg-Al

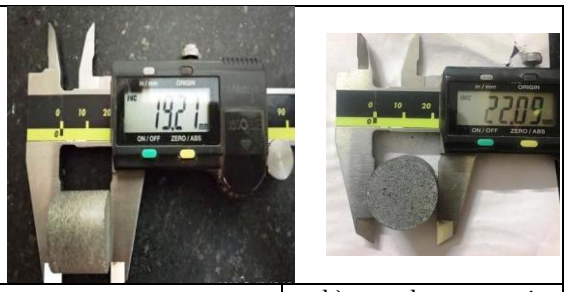
The pictorial view of the crucible and the position at which it is placed inside the furnace as shown in figure. 2. The crucible is made up of silica to withstand the temperature up to 1200^0C and the dimensions are about 24mm diameter and 50mm height.

The pellets are placed in the crucible and directly subjected to heat at the temperature of 475^{0}C and maintained at the same temperature of about 600s. The foamed pellets are allowed to cool at room temperature.

a) Crucible placed inside the furnace | b) Crucible made up of Silica

Fig. 2 Pictorial View of the crucible placed inside the furnace

To subside the flammability property of magnesium, the vacuum is created of about 300mmHg and constant passage of inert (argon) gas throughout the sintering process.

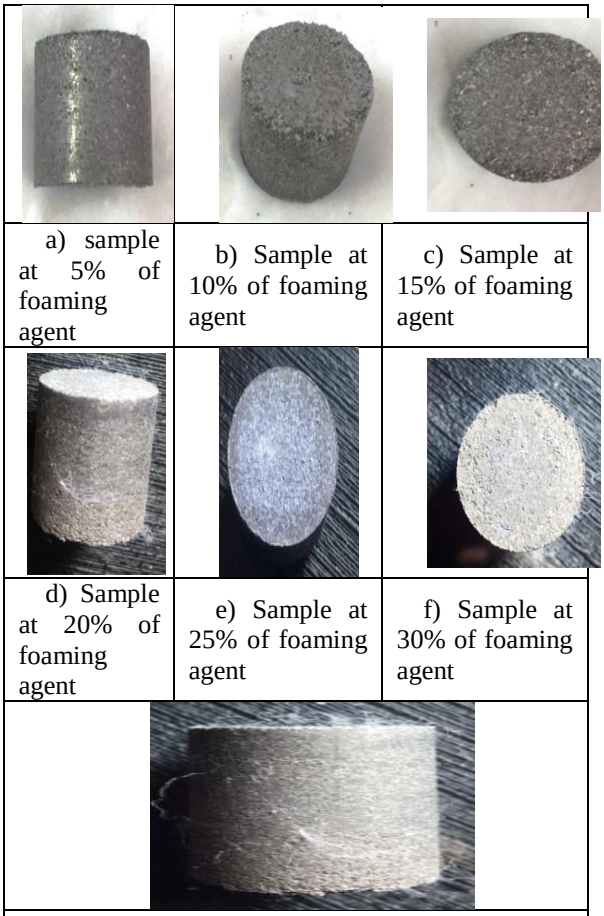


a) change in thickness from 16mm to 19.21mm after sintering | b) change in diameter from 20mm to 22.09mm after sintering

c) Change in diameter from 20mm to 21.35mm after sintering

Fig. 3 Represents the details of the samples after sintering, which illustrates the change in dimension for both diameter and thickness after sintering

The details of the change in dimension both in diameter and thickness after sintering as referred in figure.3. The specimen specification of the sample is 16mm thickness and 20mm diameter, but after sintering the sample dimensions are changed in both diameter and thickness. The figure.4 represents the pictorial view of the samples at different foaming agent after sintering, the samples are 5%, 10%, 15%, 20%, 25%, 30%, and 50% respectively.



a) sample at 5% of foaming agent | b) Sample at 10% of foaming agent | c) Sample at 15% of foaming agent

d) Sample at 20% of foaming agent | e) Sample at 25% of foaming agent | f) Sample at 30% of foaming agent

e) Sample at 50% of foaming agent

Fig. 4 Represents the pictorial view of the samples at different foaming agent after sintering

3.3 Compression Test

The uniaxial compression tests were carried out at room temperature on the universal testing machine (HTP-1000) with a constant head speed of 0.01mm/sec. The load and displacement values were recorded by using the computer. The stress and strain curves were plotted.

IV. RESULT AND DISCUSSION

4.1 Temperature and time on the foaming process

As per the concept, while the pellet starts to sinter, the reaction between Mg, TiH_2 and Ca, which is used as the binder, will begin and the corresponding foaming process will start immediately. The sintering temperature is set for 475^{0}C because the flame temperature of the magnesium is same. Meanwhile, the foaming time can influence the foam structure also, theoretically longer the foaming time, lager the pore size can be obtained. Hence the foaming time is set for 10 minutes.

4.2 Compression behavior of Mg-Al foam

The compression stress-strain curves of Mg-Al foams has shown in figure.5. The values are predicted to be more strength for the fabricated Mg foam by powder metallurgy method than the melting foaming method [9, 10].

The compressive stress for the different percentage of foaming agent 5%, 10%, 15%, 20%, 25%, 30%, 50% are 17.134MPa, 21.146 MPa, 43.312 MPa, 54.045 MPa, 50.382 MPa, 32.452 MPa, 85.032 MPa respectively . It is observed that 50% of 85.03MPa, 20% of 54.045MPa and 25% of 50.38MPa performed better compressive stress when compared with another percentage of foaming agent. [9]The same composition but fabricated by melt- forming process, was observed to be 5MPa.

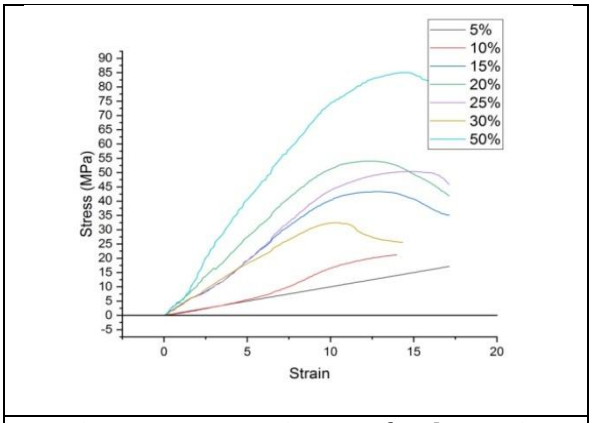


Fig.5 Stress vs. strain curve for the varying percentage of foaming agent

The energy absorption with respect to load are illustrated as shown in figure.6. It is observed that the energy absorbed for the different percentage of foaming agent are for 5%- 38.709KJ, 10% - 49.269KJ, 15% - 137.464KJ, 20% - 175.479KJ, 25% - 161.443KJ, 30%- 111.682KJ, 50% - 145.533KJ. The more energy absorption was identified in 20%, 25% and 50% of foaming agent. It is because the porosity place a main role in which the dimension difference in the thickness makes to absorb more energy. It is observed that the dimension differs about 6.5mm after sintering for the samples of 20% and 25% of foaming agent, whereas for the 50% of foaming agent the dimension after sintering does not change much, it is the difference of about 1mm. Hence the energy absorption is observed to be less.

In the metal foam, the specific strength is accepted as the peak stress of Mg5Al5 with porosity of 36%, 36%, 37%, 41%, 43%, 39%, 43% are 10.93MPa, 13.49MPa, 27.04MPa, 32.11MPa, 28.73MPa, 19.85MPa, 48.67MPa respectively, which is illustrated in Figure.7.

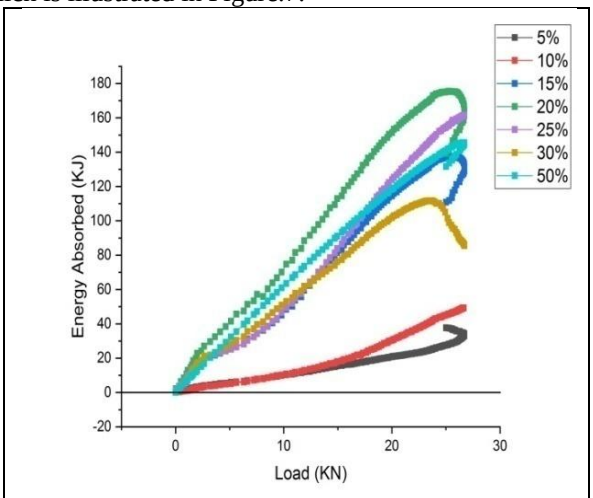


Fig. 6 Energy Absorbed in KJ vs. Load in KN for the varying foaming agent

It is observed that 20% and 50% of foaming agent yields the result of 41% and 43% of porosity respectively and 32.11MPa and 48.67MPa respectively. The porosity range between the 30-40% of porosity does not give the optimum result because the particle space is not sufficient to absorb the energy to withstand the strength.

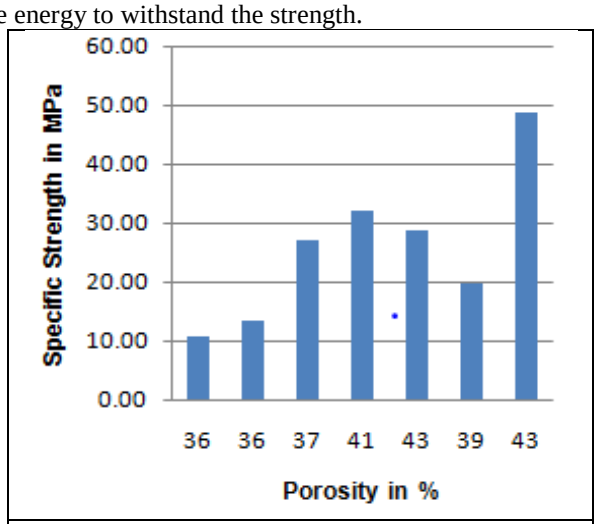


Fig.7 Specific strength in MPa vs. Porosity in % for the different compositions of foaming agent.

The details of porosity for the different compositions of the foaming agent are illustrated in the graph as shown in figure.8. It is observed that the porosity, 36%, 36%, 37%, 40%, 42%, 38% and 42% for the respective percentage of foaming agent are as follows 5%, 10%, 15%, 20%, 25%, 30%,and 50% respectively. The graph illustrates the energy absorption and the compressive strength of the samples as shown in the fiugure.9, by varying the percentage of foaming agent. It is observed that 50% of foaming agent exhibits more compressive strength of 85.032MPa and the energy absorbed to be around 145.533KJ.

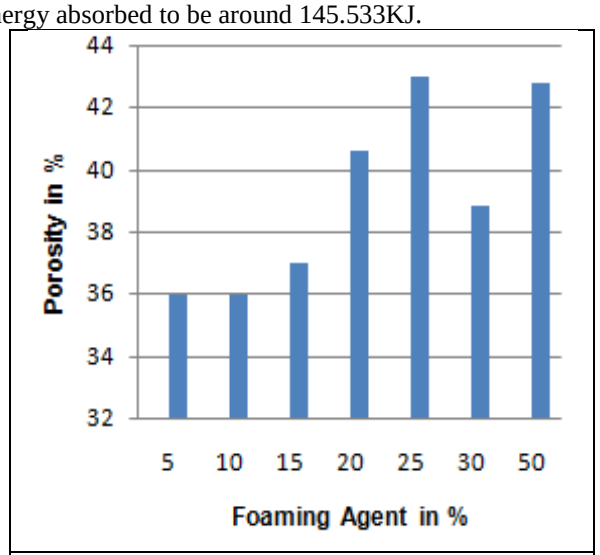


Fig.8 Details of porosity for the different percentage of the foaming agent.

For the 20% of foaming agent the energy absorbed to be the most when compared with other samples of about 175.479 KJ, but the compressive strength is only 54.045 MPa. The same result sustains for 25% of the foaming agent is the compressive strength is observed to be 50.382 MPa and the energy absorbed is to be 161.433 KJ. Hence the composition of 50% is said to be both tough and brittle

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material to withstand more compressive strength.

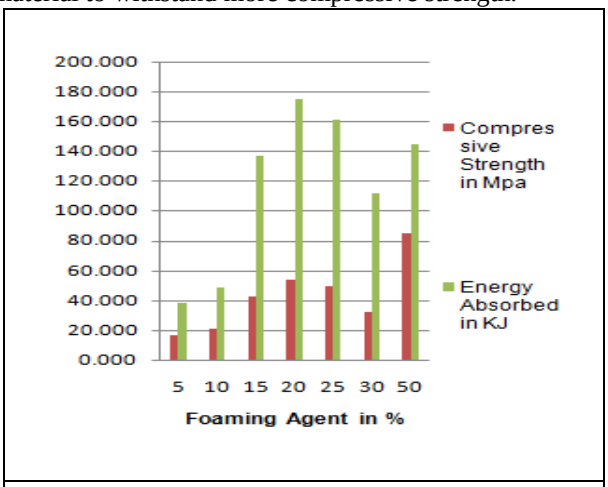

Fig.9 Details of Energy absorbed in KJ and Compressive strength in MPa for the different composition of foaming agent.

It was observed as shown in figure.10, that the density of the samples at varying foaming agents are less and equal to the parent material, which is said to be magnesium of 1.74g/cm^3. The sample of 50% foaming agent is observed to be 1.75g/CC of density, compressive strength is said to be 85.032MPa, the energy absorbed to be 145.533 KJ and the specific strength is said to be 48.590 MPa. Though the density is equal to the parent material, the sample proved to be tougher, stronger and brittle when compared to other compositions.

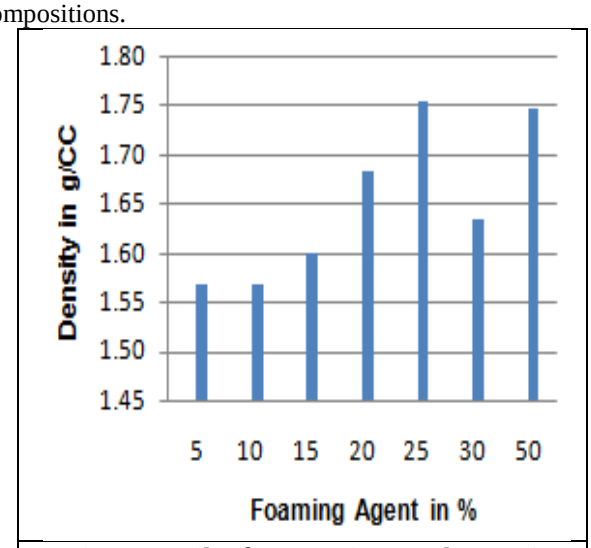

Fig.10 Details of Density in g/CC by varying the foaming agent.

The graph illustrates, as shown in figure.11, the variation of compressive strength in MPa, Energy absorbed in KJ, Specific Strength in MPa, density in g/CC and porosity in %. It was observed that the optimum results are obtained for two samples that are 20% and 50%. In the sample of 20% of foaming agent, the compressive strength is 54.045MPa, Energy absorbed is 175.479KJ, specific strength is 32.169 MPa, density is 1.68 g/CC and porosity is 41%. In the sample of 50% of foaming agent, the compressive strength is 85.032 MPa, Energy absorbed is 145.533 KJ, specific strength is 48.590MPa, density is 1.75g/CC and porosity is 43%. It is observed that even though the energy absorbed is less when compared to 20% of foaming agent, the compressive strength is more for 50% of the foaming agent.

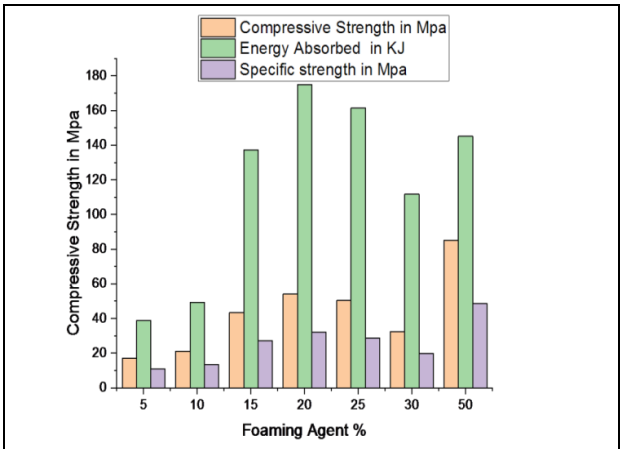

Fig.11 Details of compressive strength in MPa, Energy Absorbed in KJ, Specific strength in MPa, Density in g/CC and porosity in % for varying foaming agent.

V. CONCLUSION

This paper explains about the process of fabricating the sample of Mg and Al of 50:50 weight ratio by powder metallurgy method. The foaming agent is TiH_2 which is added at different percentage. The mechanical characteristics are concluded as below.

- The compressive stress for the different percentage of foaming agent is observed that the maximum stress for 50% of foaming agent is 85.03MPa and the minimum stress for 5% of foaming agent is 17.134MPa.
- The energy absorption with respect to load for the different percentage of foaming agent is observed that the maximum energy absorbed for 20% of foaming agent is 175.479KJ and the minimum energy absorbed for the 5% of foaming agent is 38.709KJ.
- The specific strength with respect to porosity is observed for the different percentage of foaming agent. The maximum porosity of 43% was obtained for the samples of 50% and 25% of foaming agent, but the maximum specific strength was observed for the 50% of foaming agent as 48.67MPa. The minimum porosity of 36% for the 5% of foaming agent as 10.93Mpa.
- The density of the samples are observed to be within the parent material, which is magnesium of 1.75g/CC.
- The yield result is observed for the 50% and 20% of foaming agent for which the compressive strength is observed to be 85.03MPa and 54.045MPa respectively, the energy absorption is observed to be 145.533KJ and 175.479KJ respectively apart for the two samples the 25% of foaming agent yields better result of energy absorption of 161.443KJ, the porosity is observed to be 43% and 41% respectively and the specific strength is observed to be 48.67MPa and 32.11MPa respectively.
- The relationship between the specific strength and porosity for the various compositions of magnesium and aluminum and stress and strain for varying porosity[9].It was observed that the composition of Aluminium, copper, silicon, and magnesium of about the porosity 75% gives the specific strength of 25MPa[10].

It was observed the magnesium and aluminum foam of 50:50 weight ratio, the stress is observed to be 5Mpa and by varying the composition of the magnesium and aluminum, the maximum stress to be predicted is up to 25Mpa and the porosity lies between 55 to 75%[9]. This paperwork of 50:50 weight ratio of magnesium and aluminum foam by powder metallurgy method using TiH_2 as the foaming agent yield to give the maximum stress of 85.032MPa for the porosity within 32-44 % of porosity. It is proved to be less the porosity more the strength.

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