

# Investigation on energy absorption properties of Al-foam, foam filled and empty MS tube under 3-point loading condition at room temperature

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**Abstract.** This paper aims to investigate the comparison of energy absorption of metal foam (AlSi10Mg), foam filled mild steel tube and empty mild steel tube under dynamic loading condition experimentally. The metal foam used is aluminum-silicon alloy foam and the material of steel tube is mild steel. The applications and properties of metal foam were studied. The area, volume and density of all three specimens was studied. Al-Si foam has novel properties like light weight, high energy absorption, vibration dampening and it has prevalent use in applications such as ship building, automobile industries, aeronautical industries, etc. The energy absorption capacity and deformation behavior of metal foam, foam filled mild steel tube and empty mild steel tube was studied under 3 point bending test at room temperature. The graph results showed that Al-Si foam filled mild steel tube absorbed more energy than the foam and empty mild steel tube.

## 1. Introduction

In passenger cars, light duty vehicles and heavy-duty vehicles the bumper beams are used at the front and back. The bumper beam is the first component in vehicle which fails after the impact. The function of a bumper beam is to absorb the impact load and save the vehicle and passengers from shock. But in most of the cases it begs to differ. Generally hollow aluminum bumper beams are used in light duty vehicles and hollow mild steel beams are used in heavy duty vehicles [1-6]. These hollow beams have low absorption capacity and immediately fail after the impact thus penetrating shock to the passengers which is fatal [7-14]. In recent times, aluminum foam has shown some novel properties like light weight due to porous structure, high energy absorption, vibration dampening, lower draught and hence it has prevalent use in applications such as automotive industries, aviation, ship building, etc. [14-15]. So, hollow bumper beams can be filled with metal foam and can be tested for endurance.

In present work, the mild steel tubes are cut as per 3-point bending test requirement. The aluminum-silicon foam is cut to exact dimensions as the tubes by electrical discharge machining. The foam is then filled in the tube. Three specimens are made viz. empty mild steel tube, Al-Si foam filled mild steel tube and Al-Si foam. These samples are tested on 3 point bending test setup. The results have shown that Al-Si foam filled MS tube absorbed more energy than other two samples. This indicates that foam filled tubes have more energy absorption capacity and can be used as bumper beams in light duty and heavy duty vehicles. The loads versus displacement graphs of the test are studied and the conclusion is drawn. Hollow bumper beams have low density and low energy



absorption capacity and they fail early, solid bumper beams have very high density and they absorb very less amount of shock so there is threat of bounce back of chassis after the impact, which is more dangerous. So, it is desirable to use foam filled bumper beams having density greater than hollow beams but lower than solid beams which makes it optimum for use.

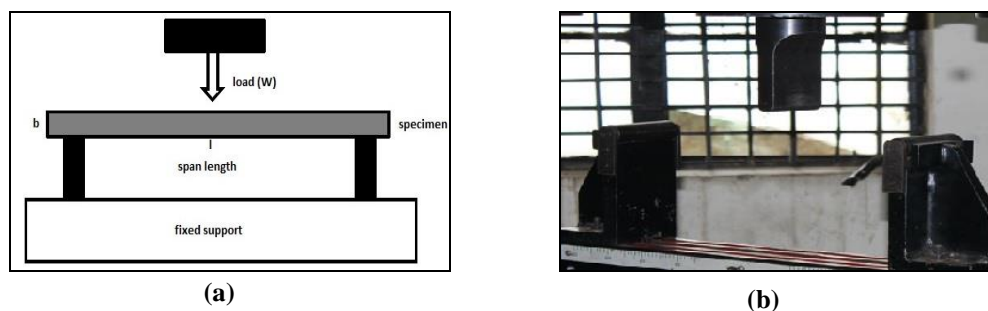
## 2. Experimentation

### 2.1. Sample preparation

In this paper, three specimens are considered and tested. A hollow section of mild steel 400mm x 25mm x 75.5mm of 1.5mm thickness was cut to be prepared as first sample. Another same section of same material was cut for foam to be filled inside it as second sample. The specimen after cutting was machined to remove its burr smoothly. The same was done for the second specimen. Now for the third specimen two sections of Al-Si foam 400mm x 21mm x 71.5mm was cut by electrical discharge machining (EDM) without damaging the pores of the foam, for fine and smooth cutting of the foam. A chemical adhesive aero light was applied to another cut section of the foam and inserted in the mild steel tube. Adhesive adheres to the foam so well and helps to keep the foam inside hollow mild steel tube well enact.

### 2.2. Test Rig

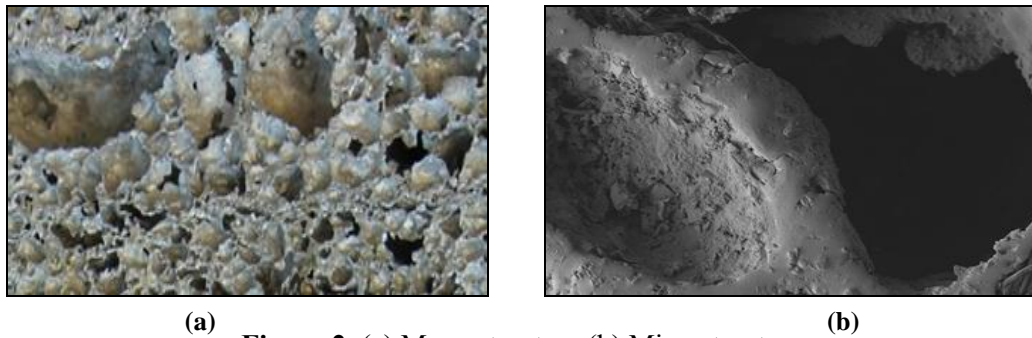
The 3-point bending test was carried out on all three specimens. The test setup consists of the two supports at the bottom separated by the span length, third support which acts as the load. Fig 1 (a) shows the line diagram of 3-point bending test rig. The test is carried out on Universal Testing Machine (UTM). The span length between two supports is adjusted according to the length of the specimen. For the test of above mentioned three specimens the span length was adjusted to just less than 400mm so that the specimens of length 400mm rest properly on the supports. Then, the specimen is placed on the supports and the third support is brought near to the specimen. It then starts applying load gradually and the connected computer shows the load versus displacement graph. A point of maximum deflection occurs depending on the load which a material can sustain, and the test stops. Then, the third support is brought upwards and the specimen undergoing deformation is then finally removed. Fig 1 (b) shows the 3-Point bending test setup.



**Figure 1.** (a) 3-Point Bending Test Rig (b) 3-Point Bending Test Setup

### 2.3. Macrostructure and Microstructure

Macrostructure is the large scale overall structure of the material. Fig 2(a) shows the macrostructure of metal foam. Microstructure is the very small-scale structure of a prepared surface of al foam sample. Microstructure of metallic materials can influence properties like strength, toughness, ductility, hardness, corrosion resistance, temperature behavior, wear resistance, etc. Fig 2(b) shows the microstructure of metal foam. By using field emission scanning electron microscope test (FESEM), microstructure of a material can be well studied up to 100X. Also, by FESEM test high resolution imaging can be performed with very low accelerating voltage. FESEM machine uses a fine electron beam which is to be shot on the surface whose microstructural properties to be determined.



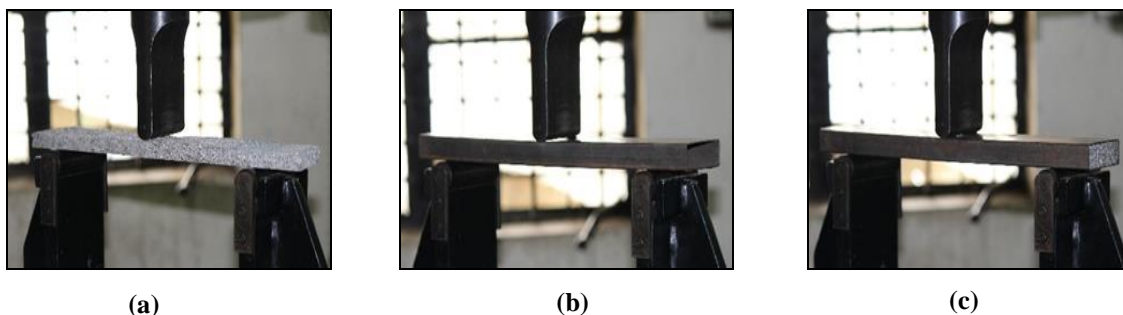
**Figure 2.** (a) Macrostructure (b) Microstructure

#### 2.4. Analytical and Mathematical Modeling of Samples

**Table 1.** Characteristics Of Prepared Samples

Sr. No.	Sample	Height (mm)	Width (mm)	Length (mm)	Thickness (mm)	Mass (g)	Cross-Sectional area (mm <sup>2</sup> )	Volume (mm <sup>3</sup> )	Density (g/cm <sup>3</sup> )
1	Foam Beam	25	75	400	-	190	1875	750000	0.253
2		25	75	400	-	230	1875	750000	0.306
3		25	75	400	-	240	1875	750000	0.320
4	Hollow MS Beam	25	75	400	1.5	610	291	116400	5.240
5		25	75	400	1.5	590	291	116400	5.068
6		25	75	400	1.5	650	291	116400	5.584
7	Foam Filled MS Beam	25	75	400	-	810	1875	750000	1.080
8		25	75	400	-	803	1875	750000	1.070
9		25	75	400	-	790	1875	750000	1.053

The density is by far the most important parameter as low density would absorb more energy which is seen in porous metal foam as shown in table 1. Higher the density lesser is the energy absorbed which is seen in hollow MS beam. When such beam is used as bumper beam for vehicles, it creates the threat of bounce back. Foam filled beam shows the most optimum results of density absorbing more energy. Fig 3(a) signifies hollow MS tube. Fig 3(b) signifies Al-Si foam and Fig 3(c) signifies foam filled tube.

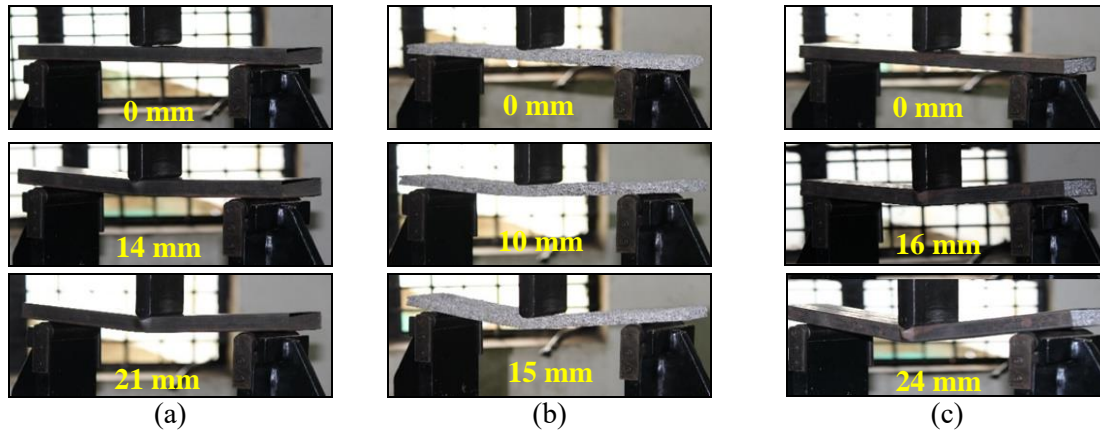


**Figure 3.** Specimen for 3 point bending (a): Hollow Beam, (b): Foam Beam, (c): Foam Filled Beam

#### 2.5. 3-Point Bending Test

In this paper, three specimens in each set were tested and comparison between them is studied. The 3-point bending test was carried on three specimen viz. 1. AlSi10Mg foam filled MS tube 2. Empty MS tube 3. AlSi10Mg foam beam. The tests were conducted one by one on UTM. The span length between two supports was reduced to just less than 400mm since the length of all three specimen is 400mm. The first specimen was put forward for the test and the load was brought to the specimen.

Gradually the load is applied and the graph is made on the data acquisition system. The specimen may break or deflect as per the material. Then the load was brought upward and the specimen was removed. Fig 4(a) signifies the bending evolution of hollow MS beam. Fig 4(b) signifies the bending evolution of AlSi10Mg foam. Fig 4(c) signifies the bending evolution foam filled beam. As the load goes on increasing the displacement from the zero position goes on increasing.

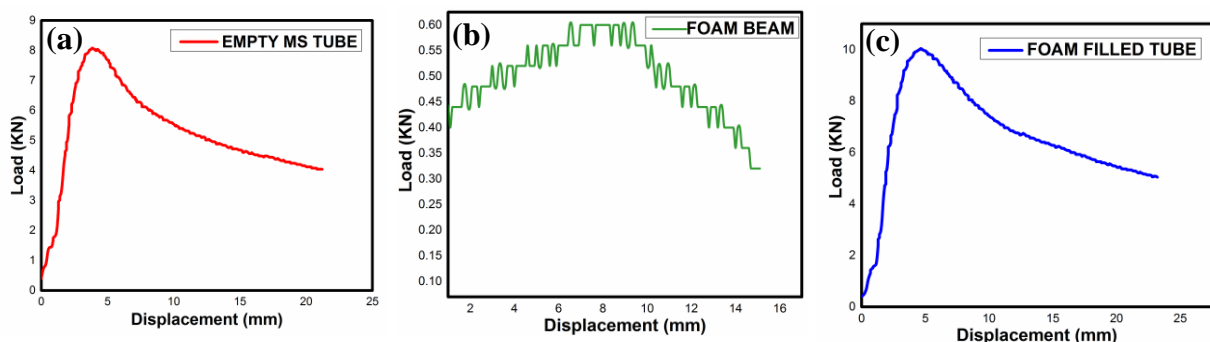


**Figure 4.** Crack Propagation in the specimens (a): Hollow Beam, (b): Foam Beam, (c): Foam Filled Beam

### 3. Result And Discussion

#### 3.1. Point Bending Test Result

The results of the 3-point bending test showed that hollow MS tube sustained 8.08 KN load which is depicted in Fig 5(a), Al-Si foam sustained 0.60 KN load which is depicted in Fig 5(b), where Al-Si foam filled MS tube sustained 10.04 KN load which is shown in Fig 5(c). This shows that foam filled tube had greater load absorption capacity, greater strength, and higher density than that of hollow MS tube [13-15]. The deflection from the initial position in the hollow MS tube is 21 mm, the deflection in the foam is 15 mm and the deflection in the foam filled MS tube was observed to be 24 mm. This shows foam filled MS tube absorbed more load and is beneficial to be used as the bumper beam.



**Figure 5.** (a) Empty MS tube (b) Foam beam (c) Foam filled MS tube

### 4. Conclusion

The results and graphs of all three specimens show that only Al-Si foam has least load absorbing capacity among the three specimens, hollow MS tube has moderate load absorbing capacity and the foam filled tube has the highest load absorbing capacity. This indicates that if foam filled tubes are used as bumper beams, the safety of the passengers increases with the high energy absorption of the foam filled beam. The foam filled beam will safeguard the passengers and vehicle as well.

- Al-Si foam has comparatively least absorbing capacity 0.60 KN
- Hollow MS tube has moderate absorbing capacity 8.08 KN
- Foam filled tube has the highest energy absorption capacity 10.04 KN

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