# Compressive Properties and Imaging Analysis of A new Metal Foam-Natural Rubber Hybrid Structure

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## Abstract

In this study an attempt has been made to create a new hybrid structure. The hybrid structure has been made by hierarchically combining closed cell Aluminum foam and natural rubber. The hybrid structure, when subjected to compressive loading, displayed improved energy absorption characteristics compared to its parent monoliths. It also displayed significant strain recovery post deformation. High resolution imaging was also carried out to compare the internal structure of hybrid samples before and after compression. Critical discussion of the experimental results has been made.

**Keywords :** Aluminum foam, hybrid, energy absorption, compressive, strain recovery, natural rubber

## Introduction

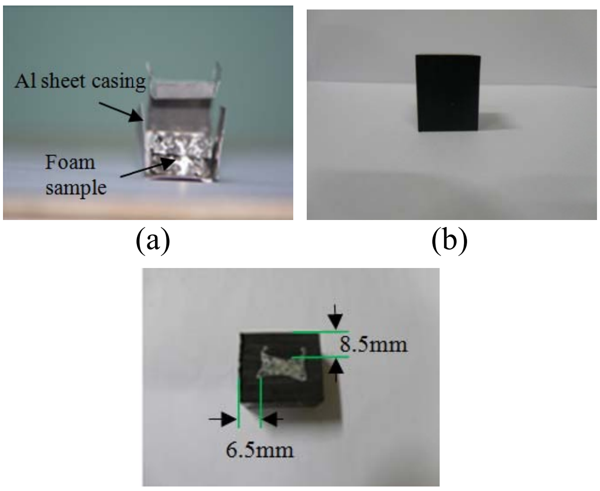
With the advancement of technology come challenges that are sometimes difficult to meet by a standalone material. One such growing area of research interest is energy absorption involving situations such as transportation, heavy machinery vibration etc. wherein contrasting requirements of energy absorption by plastic deformation need to occur alongside elastic recovery processes to regain the original shape and size as a functional need. Besides, the design at times also calls for high specific strength, high stiffness and light weight structure as add-ons among other things. Such demanding applications can however be fulfilled by a proper selection of two or more materials and their suitable hybridization.[1] Hybrid materials result from a combination of two or more monolithic materials such that its properties are a combination of the properties of its parent materials.

As regards energy absorption by plastic deformation characteristics metallic foams clearly emerge as a potential candidate.[2] On the other hand, certain polymers possess good elasticity. They are also lightweight and good energy absorbers.[3] These two materials can therefore be combined to achieve the functional goal. Several researchers have investigated the mechanical behavior of metal foam-polymer hybrid composites.[4-8] Some studies have reported improvement in energy absorption aspects of the hybrid when compared with their parent monoliths.[3, 9] However, most of the investigations involved either infiltrating the foam cells with a thermosetting/ thermoplastic polymer[3, 9-10] or joining spherical hollow metal balls using polymer adhesives .[11] This study marks a departure from earlier studies inasmuch as a Duocel® make closed cell Aluminum foam and natural rubber have been combined hierarchically to generate a novel functional hybrid structure.[12] Compressive testing was carried out to evaluate the mechanical properties of the hybrid structure vis-a-vis the parent monoliths. Post compression, high resolution imaging of the cut section of tested sample has been carried out and compared with the untested sample. The results of the experimental work have been analyzed and discussed in this paper.

## Materials and Experimental Procedures

### *Preparation of specimen*

The Aluminum metal foam used in this study is commercially available Duocel® closed cell type with a density of 0.1～0.35 g/cm3, Pore size 2-11mm and Porosity between 60%-90%. The foam was available as 5mm thick sheet of 100mmx100mm dimensions. The natural rubber formulation was supplied my M/s Indian Rubber Manufacturers Research Association, Thane, India. The natural rubber formulation used had a Tensile strength of 138Kg/cm$^2$, Tear strength of 41Kg/cm, Elongation at break of 320% and a Shore A hardness value of 70. To prepare the samples, ~17mmX17mm samples of Al foam were neatly cut out and 2 such samples were joined using ARALDITE®. Such epoxy based adhesives are widely reported in literature to have excellent mechanical properties with high levels of shear and peel strength upon curing. The completely cured foam samples were encased in Aluminum casings made from 0.25 mm thin Aluminum sheet and the casings were welded at the edges. This was done to ensure that foam samples do not spoil during the molding process. Subsequently, the Aluminum casing surfaces were thoroughly solvent degreased and a brush coat of adhesive Chemlok® 607 was applied to bond the unvulcanized natural rubber to the metal substrate. The Aluminum casings post welding measured ≈16.5mmX16.5mmX10.5mm. The average natural rubber thicknesses were 8.5mm and 6.5mm in the two directions as shown in Figure.1(c). This amounted to a volumetric ratio of 85::15 between natural rubber and Aluminum foam.(1) The finished dimensions of the hybrid samples after molding turned out to be ≈32mmX28mmX24mm. Two pieces of hybrid specimen were prepared for study. The details of specimen preparation are depicted in Figure 1.




(a) (b)

(c)

**Figure 1**. (a) Foam sample in Aluminum casing (b) Hybrid sample containing foam inside (c) cut section of the hybrid sample

*Compression testing*

An MTS make table top UTM Model 858 with load cell capacity of 25KN was utilized for compressive testing. The mode of operation was displacement control. Samples of hybrid composite as well as natural rubber and foam samples were tested in compression mode at the rate of 1mm/min. The compression testing was carried out at room temperature. Timed load-displacement data was recorded in electronic form. All dimensional measurements were carried out before and after testing.

*Imaging*

For the purposes of high resolution imaging analysis, samples of tested as well as untested specimen were cut mid way using a mechanized saw. The split parts were subsequently placed on Rapid-I Vision measuring model V 2015 J LX (5X-335X) (Figure.2) having high resolution optical systems and analyzed.

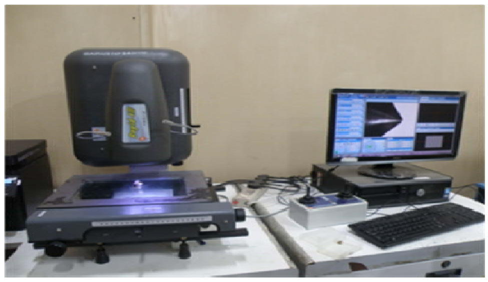


**Figure 2.** Rapid I vision measuring system

## Results and Discussion

The stress-strain graph of the compression test of Aluminum foam-natural rubber hybrid samples is presented in Figure 3.

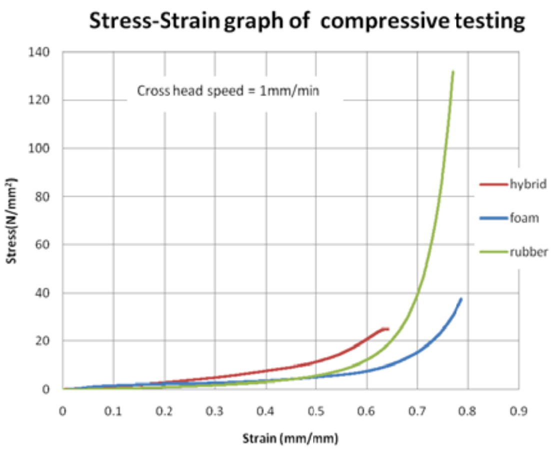



**Figure 3.** Stress-strain graph of hybrid, Al foam & natural rubber

Stress-strain curves of Aluminum foam and natural rubber samples are also superimposed in the same graph for the purposes of comparison. In this context, it may be noted that the contribution from Aluminum casing encapsulating the Aluminum foam (Figure1.(a)) is neglected here since it is very thin and the bulk of deformation happens in the Aluminum foam.

By looking at Figure 3, it is clear that the Aluminum foam core serves as reinforcement in natural rubber matrix. For ε~0.2 and beyond, the hybrid displays superior load carrying capacity compared to foam and rubber. Also, the hybrid performs better in terms of both energy absoprtion capacity (defined as the area under the stress-strain curve) vis-à-vis its parent monoliths. The energy absorption capacity, E, is defined mathematically as

$$E=\int_{0}^{\varepsilon} \sigma(\varepsilon)\,d\varepsilon \qquad (1)$$

Where ε is defined as strain and σ is the compressive stress as a function of strain ε. The energy absorption capacity was evaluated up to ε=0.4. The respective values for natural rubber, Aluminum foam and hybrid composite are 0.46MJ/$m^3$, 0.85MJ/$m^3$ and 1.26MJ/$m^3$. Hence, the energy absorption capacity of hybrid composite is considerably higher than that of its parent monoliths. This higher energy absorption capacity of hybrid sample could be attributed to complex rubber-foam interactions among other things. Figure 4. compares the % increase in 'E' corresponding to ~40% strain of our study with respect to previous researches. Cheng et al.[1] and Yu L et al.[9] reported an increase of 8% and 80% with open cell Aluminum foam-silicate rubber and open cell Aluminum foam-polypropylene combination respectively whereas the present study showed an increase of ~50% with closed cell Aluminum foam-natural rubber combination. Moreover, they fabricated the hybrid by infiltrating polymer into the foam. It is extremely important here to remind the readers that type of foam and polymer, volumetric foam as well as polymeric content and the type of structure of hybrid have a great bearing on such experimental results.

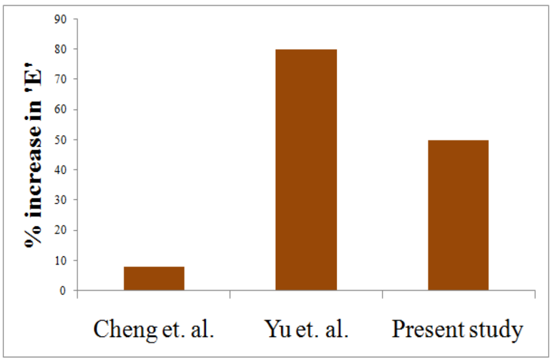



**Figure 4.** Comparison of % increase in 'E'

Post compression dimensional measurements revealed overall height of hybrid specimen to be 22.9 mm which was originally 24.6 mm in the direction of loading. The total loss in height was therefore ≈7% which is not significant and points to considerable strain recovery in the specimen. This effect is attributed to the presence of natural rubber component in the hybrid specimen. However, the specimen does not fully regain its original shape and barreling is observed as shown in Figure 5. One possible cause of such barreling could be an uneven state of stress prevailing across the foam cross-section during loading due to a highly non-uniform porous geometrical structure.

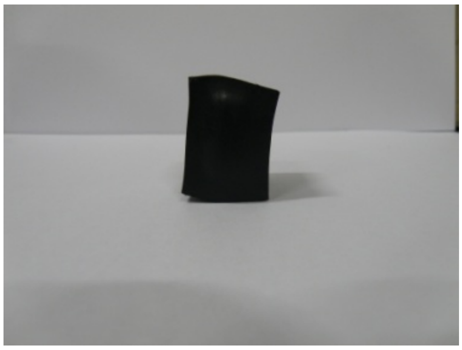
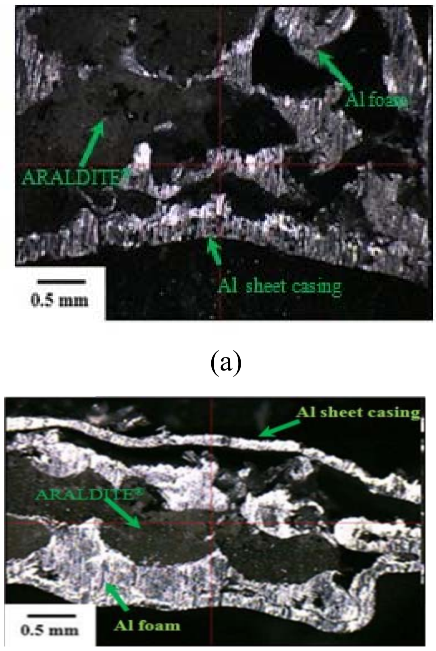


**Figure 5.** Post compression photograph of hybrid sample showing barreling

Results of the high resolution imaging analysis are presented in Figure 6.




(a)

(b)

**Figure 6.** High resolution image of (a) untested (b) tested sample sample

From Figure 6(b), it is clear that the foam part has completely densified during compressive loading. The non-linear behaviour of hybrid specimen is seen in Fig.3 to follow the two parent monoliths which become non-linear in quick succession. The slight load dropping observed in the hybrid specimen at the end of the testing could come from the subsequent squeezing and compression of ARALDITE® which comes into picture once the Aluminum foam has densified as the adhesive is much softer and less dense than the densified foam material.

## Conclusions

A new hybrid structure has been generated by combining closed cell Aluminum foam and natural rubber. The hybrid structure displayed superior load carrying as well as energy absorption capacities vis-à-vis the parent monoliths during compressive testing. The hybrid structure also displayed considerable strain recovery characteristics. The Aluminum foam part largely absorbs the energy during deformation while natural rubber helps in strain recovery. Such hybrid composites offer solutions to the complex industrial need of structures capable of energy absorption and strain recovery mechanisms combined in a single material.

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