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Reinforcement Of Elastomeric Rubber Using Carbon Fiber Laminates

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Abstract: The Elastomeric rubber is a good energy absorbing device with spring back effect. The effectiveness of any form of rubber depends on its strength and stiffness which cannot be varied beyond a certain limit by using chemical additives alone. So, the elastomeric rubber has to be reinforced by adding a material that is normally stronger and stiffer than rubber. In this paper, the usual problem of vulcanization of rubber was overcome by selecting carbon fibers as the filler material. The unidirectional property of carbon fibers gives it the ability to be oriented in any desired direction, thus imparting required properties. The material was modeled as a composite beam structure initially using the ANSYS software and dynamic analysis was performed to find out the fundamental mode of vibration. A Test specimen was then fabricated according to ASTM standards and experimental investigations were carried out. Mechanical properties of the material such as tensile strength, compression strength, flexure strength and impact strength were obtained from the experimental investigation. The test results of the carbon fiber laminated elastomeric rubber were then compared with ordinary elastomeric rubber with usual additives and it was found to be superior in all aspects.

Keywords: Elastomeric rubber laminates, Unidirectional Carbon fiber composites, Fabrication of Carbon fiber laminates, Modes of vibration of rubber composite, Mechanical properties of rubber composite.

I. INTRODUCTION

Rubber is an engineering material that finds use in most of the products that we use every day. To name a few, rubber is profoundly used as door and window profiles, hoses, belts, matting, flooring and dampeners (anti-vibration mounts) in the automotive industry and as structural material in buildings and bridges. Natural rubber consists of suitable polymers of the organic compound isoprene with minor impurities of other organic compounds plus water. Synthetic rubber, invariably a polymer, is any type of artificial elastomer mainly synthesized from petroleum by-products. An elastomer is a material with the mechanical (or material) property that it can undergo much more elastic deformation under stress than most materials and still returns to its original shape without permanent deformation.

The rubber pads which are commonly used as vibration isolators is subjected to static and dynamic loads during its lifecycle. As a result, the mechanical properties of rubber pads are severely affected during its service which eventually leads to the failure of the material apart from casual wear and tear. In case of the elastomeric bearing pads, some commonly encountered problems in using the steel as the reinforcement material are that, when the rubber is loaded beyond a particular limit, the steel plates or rods laminated with the rubber pads delaminates and a gap is formed as a result, the moisture present in air occupies the gap. Also, the steel is subjected to rust when it is in contact with air resulting in weaker steel with degraded mechanical properties. These problems can be overcome by using composite materials.

As the usual reinforcement technique results in corrosion and delamination in the long run, a non-metal is to be chosen in the place of steel. In this paper, carbon fiber, a non-metal is chosen in the place of steel. The unidirectional property gives the carbon fibers the ability to be oriented in any desired direction. The test specimen is modeled using the ANSYS software and a dynamic analysis was performed to find out the fundamental mode of vibration. Experimental investigation was conducted on the specimen to determine the mechanical properties namely, tensile strength, compressive strength, flexural strength and impact strength. The test results of the carbon fiber laminated elastomeric rubber were then compared with ordinary elastomeric rubber and it was found to be superior in all aspects

II. DIRECTIONAL PROPERTIES OF COMPOSITES

A given material can have three kinds of behaviors with regard to the relationships among its strength, stiffness properties and the direction of load applications. These behaviors are called isotropic, anisotropic and orthotropic.

Isotropic behavior means that the elastic response of the material is the same regardless of the direction of the applied load. Rubber is an isotropic material. Orthotropic behavior means that the material properties are different in three mutually perpendicular directions. This is the behavior that is most often assumed for composite material. Carbon fiber falls under this category.

Parameters used in selection of composite materials

Two parameters that are used to compare materials are specific strength and specific modulus. Specific strength is defined as the ratio of the tensile strength of a material to its specific weight. Specific modulus is the ratio of the modulus of elasticity of a material to its specific weight.

III. DESIGN OF THE COMPOSITE MATERIAL

The manner in which layers are oriented relative to one another affects the final properties of the completed structure.

A. Laminated Composite Construction

Each layer is made from a set of parallel strands of the reinforcing filler material embedded in a rubber matrix. To produce the maximum strength and stiffness in a particular direction, several layers or plies could be laid on the top of one another with all the fibers aligned in the direction of the expected tensile load. This is called unidirectional laminate. After curing, the laminate would have high strength and stiffness when loaded in the direction of the strands, called longitudinal direction. However, the resulting product will have lower strength in the perpendicular direction called lateral direction. The material specification is shown in Table I

TABLE I
MATERIAL SPECIFICATION

Sl. No.	**Dimension of the material as per ASTM specification**		
	Length, l (mm)	Breadth, b (mm)	Thickness, t (mm)
1.	304.8	304.8	25.4

The primary criteria of (l/t) ratio < 16:1 was satisfied (i.e.) (304.8/25.4) =12. A little math to arrive at the number of layers required to build up the composite material is shown as a flow chart in Fig 1.

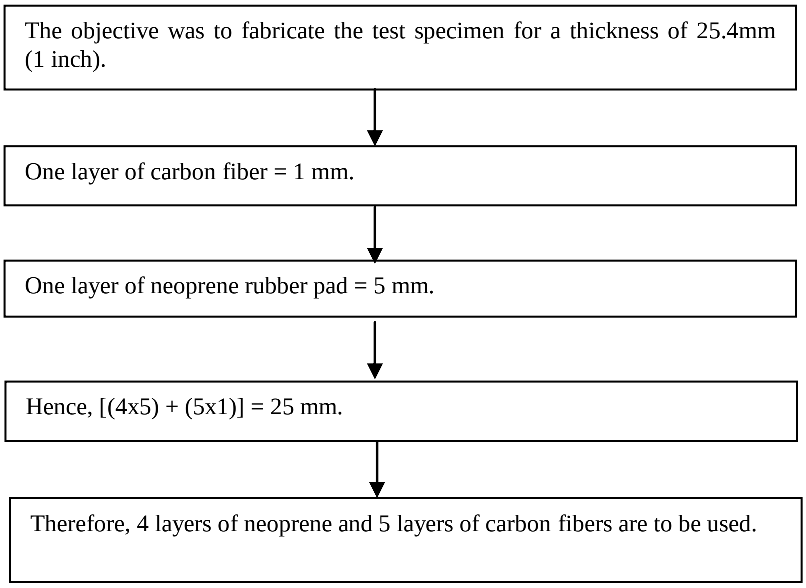

Fig. 1 Flowchart for the calculation of the number of layers to be used.

B. Orientation of Layers

The orientation of layers can be made unidirectional or quasi-isotropic. The term quasi-isotropic means symmetry and balance of the layering technique which result in uniform properties in two directions. So a combination of layers with different orientation was tried out in ANSYS and the best combination with quasi-isotropic property is selected. Modeling of the carbon fiber reinforced polymer (CFRP) in ANSYS to find out the first mode of vibration is shown in Fig 2. The Fig. 2 shows a quasi-isotropic orientation of the carbon fibers (material #1) and rubber (material #2). Naming the longitudinal direction of the surface layer the 0^o ply, this structure is referred as 90^o-0^o-45^o-0^o-90^o-0^o-45^o-90^o. The different possible orientation of layers is designed using permutation and combination and the fundamental frequency of vibration was calculated in each case. The design with the highest first mode of frequency is then selected for further tests.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

Fig. 2 Modeling of the CFRP in ANSYS

Table II shows the fundamental frequency and highest frequency on different orientation of layers. From the table III it was found that the orientation Sl.No.3 & 4 gives the highest fundamental frequency of vibration. For the sake of fabrication and to remove complexity in design, the orientation in row 4 is selected.

TABLE III
THE FREQUENCIES FOR DIFFERENT ORIENTATION OF CARBON FIBERS AND RUBBER.

Sl. No.	Orientation of layers	Fundamental Frequency	Highest Frequency
1	0-0-0-0-0-0-0-0-0	20.624	89.123
2	90-0-90-0-90-0-90-0-90	20.324	89.123
3	0-0-90-0-90-0-90-0-0	30.514	124.83
4	90-0-0-0-0-0-0-0-90	30.514	124.83
5	90-0-0-0-90-0-0-0-90	30.508	124.81
6	0-0-0-0-90-0-0-0-0	20.647	89.27
7	0-0-45-0-45-0-45-0-0	26.322	112.36
8	90-0-45-0-0-0-45-0-90	26.335	112.39
9	90-0-45-0-45-0-45-0-90	26.322	112.36
10	0-0-45-0-45-0-45-0-0	26.322	112.36

C. Fabrication of the specimen

The Orientation of layers which gives the highest fundamental frequency was selected for fabrication. The orientation 90^o-0^o-0^o-0^o-0^o-0^o-0^o-0^o-90^o was chosen to remove complexity in design. The pictorial representation of the steps involved in fabrication is depicted clearly in the Fig. 3. A mould was designed to accommodate the rubber pad and carbon fibers which were cut as per dimensions (a) & (b). The rubber pad was scratched and carbon fibers were oriented according to specifications (c) & (d). The carbon fibers were coated with epoxy resin and made to dry in the hot sun (e) & (f).

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Vol. 2, Issue 7, July 2013

Fig. 3 Steps followed in fabrication of the material for test specimen (a) Cut Specimen (b) Perpendicularity Check (c) Scratch of the Specimen (d) Orientation of Fibers (e) Epoxy Resin Coating (f) Sun Dried Specimen.

IV. EXPERIMENTAL INVESTIGATIONS AND FINDINGS

Experimental investigation was conducted on the specimen to determine the mechanical properties namely, tensile strength, compressive strength, flexural strength and impact strength.

A.Tension Test

A tensile test was conducted on the flat test specimen which was cut as per ASTM specification (ASTM D 638).The dimensions of the specimen was thickness 25.00 mm, width 13.60 mm and Area 340.00 mm^2. The stress strain plot of the test specimen under tension is shown in Fig. 4. From the graph (Fig. 4), it was observed that the material has undergone maximum extension in its length and it seemed to possess enough toughness. The stress gradually increased with the application of force, yielded and attained the ultimate stress of 32.5 N/mm^2 and eventually it has collapsed at a stress value of about 4 N/mm^2.

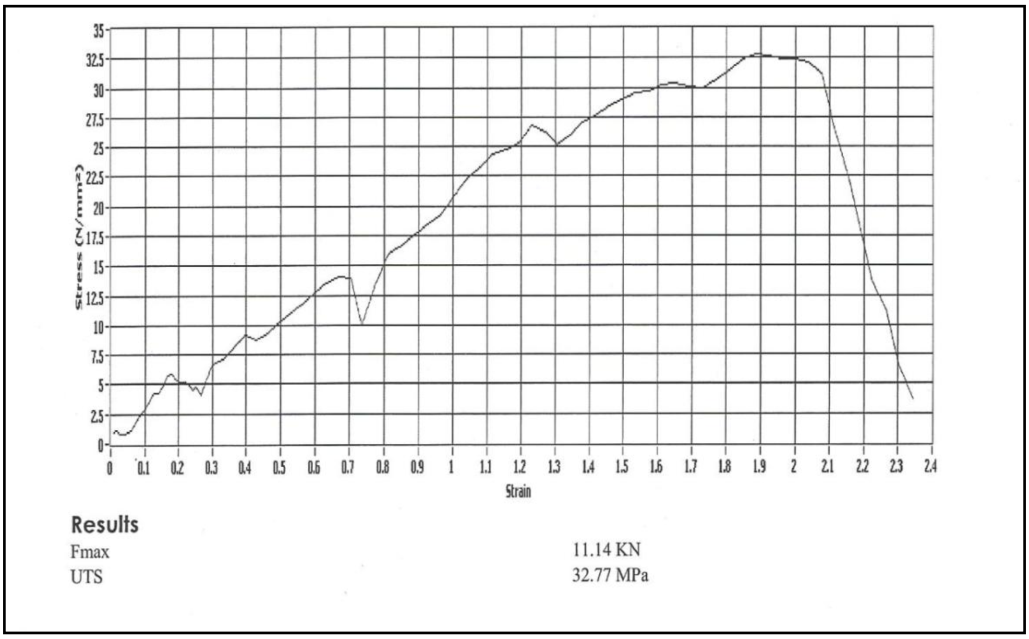

Fig. 4 Stress-Strain plot of the composite material under tension test.

Though it is a pure ductile material cup and cone formation was not observed but delamination had occurred in certain portions along the length of the specimen. The crack started at one or two spots on the inside surface of the tip, then it propagates across the thickness of the specimen to form a full initial crack before it propagates along the width of the specimen. The collapse occurred near the clamping portion and the laminated layers had torn apart in that portion. This is due the occurrence of overstressing or stress concentration in the clamped section. There was shifting of strain values observed at various stress application and material seemed to behave nonlinearly. From the literature review and the experimental data, the findings of the tension test is tabulated in Table III.

TABLE III
COMPARISON OF THE LOAD AND STRESS VALUES FOR NEOPRENE AND COMPOSITE RUBBER

NEOPRENE RUBBER	S_{ut}= 8.2 MPa	F_{max} =10 kN
COMPOSITE RUBBER	S_{ut}= 32.77 MPa	F_{max} =11.14 kN

B. Compression Test

A compression test specimen was cut as per ASTM specification(ASTM D 790). The test specimen has thickness 25mm, width 31mm and area 775mm^2. The specimen subjected to compression loading is shown in the Fig.5

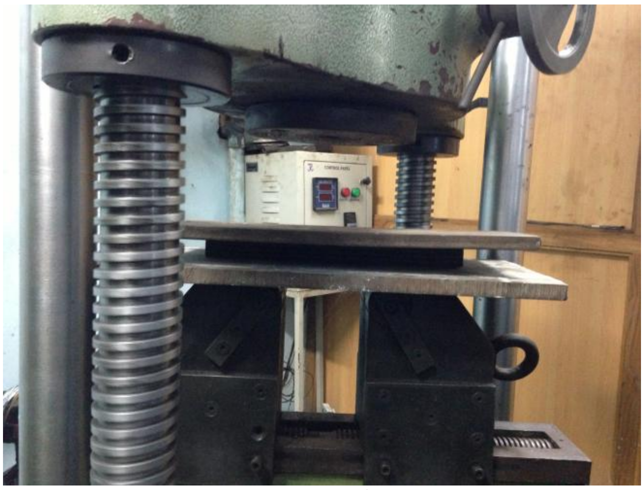

Fig. 5a Loading of the Test Specimen

ISSN: 2319-8753
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Vol. 2, Issue 7, July 2013

On visual examination, it was found that the material got bulged up. Also, the material got cracked along its edges at 45^0 to the horizontal on the top and bottom surfaces which proves that the material has undergone shear on the application of the compressive load (Fig.6). This causes the movement of the material in lateral direction which results in propagation of cracks and bulging of the specimen.

Fig. 6 Failed Edges of the Specimen.

A force versus stroke plot of the specimen under compression test is shown in Fig.7. From the graph, it was observed that the material obeys Hooke's law. After attaining the yield point at a force value of approximately around 4200 N, there was strain hardening region observed, i.e., with the small application of force from 4500 N to7000 N the material had undergone larger strain with changes in crystal structure.

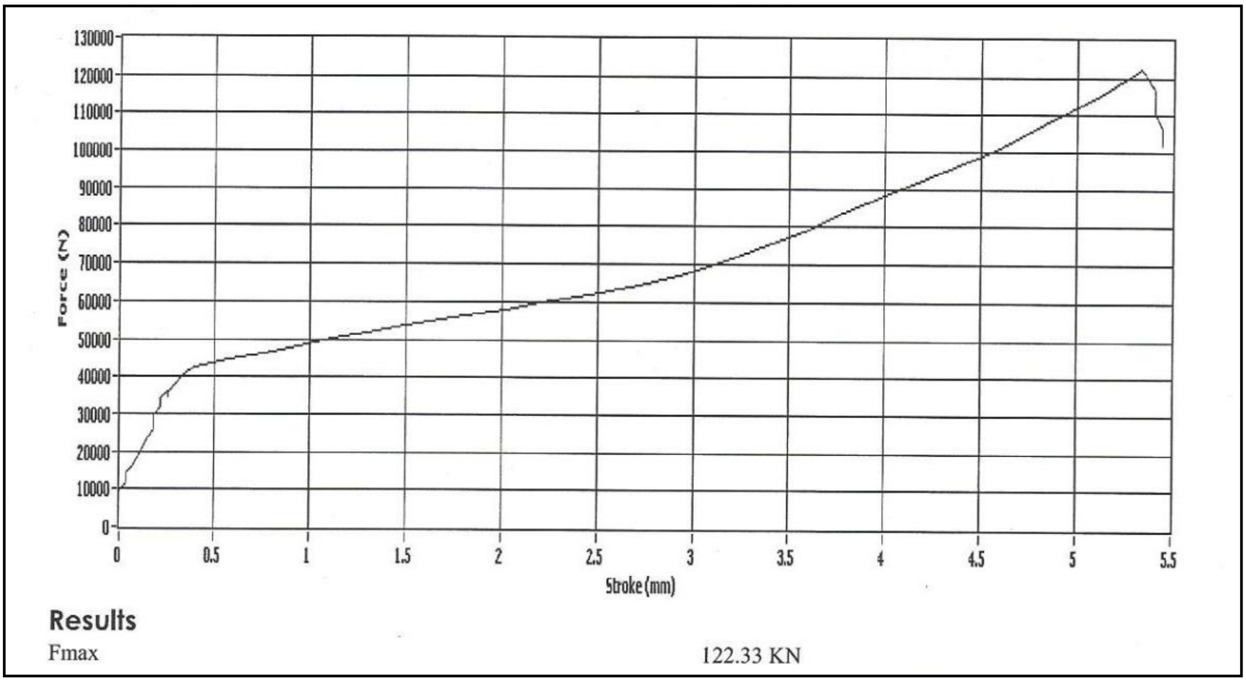

Fig. 7 Force versus displacement diagram to find compression strength

C.Flexure Test

The test specimen for three point bending was cut as per ASTM specification (ASTM D 256) with the following dimensions, thickness 25.5 mm and width 29.4 mm. The loading of the specimen under bending and final failure due to delamination is pictorially depicted in Fig. 8.

From Fig. 9, it is found that the force versus displacement curve is a sloping straight line upto the maximum load 1630N. The curve increases linearly upto a deflection value of 30mm after which there is a fluctuation in both load and deflection values. The above observation gives rise to an inference that the material can withstand a deflection of 30mm under the maximum loading condition. When bending of material initiated, the epoxy resin layers got weakened, which resulted in delamination of the specimen layers. Since the top fibers underwent

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International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 7, July 2013

compression and bottom fibers experienced elongation, fine cracks appeared at the bottom edges and propogated in a direction perpendicular to the specimen.

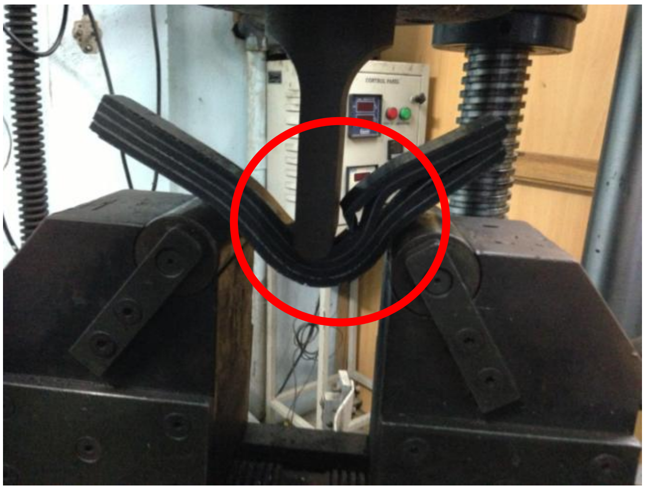

Fig. 8 Flexure Loaded Test Specimen

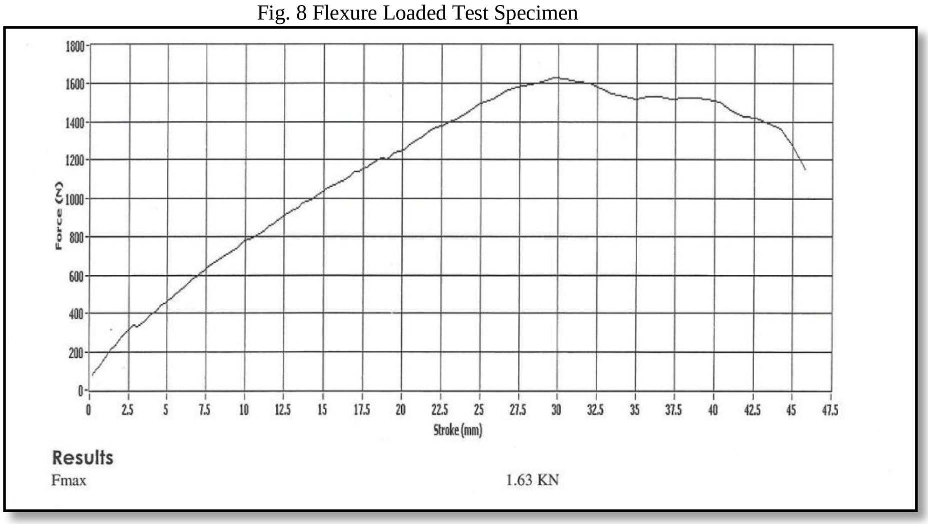

Fig. 9 Force versus displacement diagram to find out flexure strength

D.Charpy Impact Test

The Charpy impact test specimen was cut to the ASTM dimensions (56 x 10.5 x 10.5 mm). The Charpy impact test was conducted to find the maximum energy the material can absorb. The photometric view of the energy readings after impact testing measured in Charpy test setup is shown in the Fig. 10.

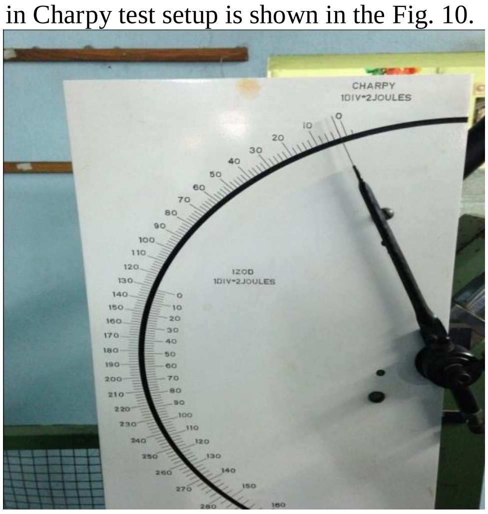

Fig. 10 Energy Reading after impact testing (2 J)

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Vol. 2, Issue 7, July 2013

The absorbed energy is calculated by taking the average of three readings. Here, the energy absorbed is 300-2=298 J in all three cases.Impact Energy absorbed = (298+298+298)/3= 298 J.

V. RESULTS AND COMPARISONS

The values obtained as a result of design modification and subsequent mechanical testing are as follows:

Design Modification

The fundamental frequency of vibration of the chosen material was found to have improved from 1.77 Hz to 30.5 Hz after reinforcing with carbon fibers.The fundamental frequency has gone up nearly 17 times.

Tension Test

The tension test under a Universal Testing Machine (UTM) gave rise to a larger value of ultimate strength of 32.77 MPa.

The Ultimate strength of the test specimen was nearly four times the original value which suggests that the material could withstand tension in addition to compression.

Compression Test

The Compression test of the specimen was found to be 12.93 MPa. The specimen was able to withstand a maximum compressive load of 122.33 kN.

Flexure Test

The 3-point bending or flexure test yielded a bending strength value of 19.18 MPa. The maximum deflection that the specimen underwent for a maximum bending load of 1630N was 30 mm.

Impact Test

The Charpy test revealed that the test specimen was able to absorb as much as 298 J of the available energy on a scale of 300 J.

VI. CONCLUSION

The Dynamic analysis indicated that the fundamental frequency of vibration of the chosen material had improved after reinforcing with carbon fibers. The orientation of the carbon fibers had also influenced the mode shapes. The fabrication of the material done at the ambient temperature has not affected the mechanical properties in anyway. The testing of material in Universal tension testing machine revealed that the material behaviour is superior in tension, compression and bending than the elastomeric rubber. The compression test revealed that the specimen is as strong in compression as in tension. The flexure test showed that the specimen bends elastically upto the maximum load value after which the formation of cracks started on the outer edges. The crack propagation in the lateral direction lead to delamination and final failure of the material. The impact test suggested that the material was able to absorb nearly 99.33% of the kinetic energy due to the impact. Though it is a bit expensive, these superior mechanical properties makes it a viable replacement as a energy absorber. In addition to synthetic carbon fibers, natural fibers from coconut and banyan trees can also be used as a supplement to bring down the cost of the final product.

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