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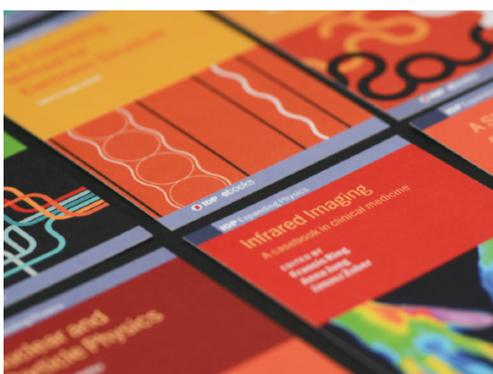
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Abaqus Simulation on Basalt Fibre Reinforced Polymer Epoxy Tube Subjected to Axial Compression for Energy Absorption

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Abstract. In practical application, fibre reinforced polymer (FRP) technology is implemented as the outer jackets in structural elements such as column, beam and in automobile engineering as light weight components in the head liners of car, brake pads and energy. In civil engineering FRP is mainly used in the retrofitting technique against corrosion, in columns, piles and poles. The research aims to provide a recyclable, natural, low-cost energy absorption material capable of increasing the load bearing capacity of the structure by increasing the fabric layer. The study focuses on the finite element analysis (FEM) of the energy absorption characteristics of basalt fibre reinforced polymer epoxy tube (BFRPE) subjected to axial compression with varying BFRPE layers. The results also discuss the failure modes of the specimens using abaqus. Parameters such as the energy absorption, crush force efficiency (CFE) are discussed. Energy absorption is defined as the area under the load displacement and CFE is defined as the ratio of the mean load to that of the initial peak force. The test results indicate that as the number of layers increases the ultimate load and CFE of the tube also increases. Compared to flax fibre reinforced polymer the thickness of the basalt fibre is very less with better energy absorption.

1. Introduction

Fibre reinforced polymer (FRP) composite is extensively used in the building refurbishment for the structural elements to improve the structural efficiency of the building components. It is also used in the underwater piles to improve the durability and act as an additional corrosion reinforcement layer [1]. FRP has extended its application in automobile and aircraft industries focusing on energy absorbers using different FRP materials. Developing an energy-absorbing devices using composite natural material has attracted many researchers [2-6]. One of the main factor to improve the energy absorption is the crush force efficiency (CFE) which is the ratio between the average peak load and maximum peak load and it is directly related with the deceleration experienced by the vehicle occupants in the occurrence of a collision. Maintaining the CFE closer to one in the range of 0.7-0.9 aids in providing better energy absorption and facilitate crush protection. Studies reveal that larger the diameter of the tube better the energy absorption [2,3,7].



The study of the crashworthiness of a material is important in-vehicle manufacturing. It is defined as the resistance offered by the vehicle to protect its occupants [2,8]. Most vehicle manufacturers have started to utilize FRP in vehicles replacing conventional materials such as steel and aluminium. Having light-weight FRP materials reduces the vehicle body by 50% resulting to reduce the fuel consumption of the vehicle [9]. Applying “green” materials or natural materials as composite structures helps to meet the environment requirements and ensure the natural recycling of the material. The advantage of using FRP is it can be modified to any desired shape and size. There are various types of FRP used such as glass, carbon, flax fibres. Basalt being a low-cost mineral fibre are obtained from basalt rocks has high thermal insulation and durable to chemical attack. Basalt having equivalent tensile strength and better alkaline resistance [10-13]. On analysing the various failure modes of the FRP composite, the tube behaves with almost uniform collapse such as petal wrinkling, buckling of the FRP and shows brittle failure producing a loud noise due to a sudden collapse of the FRP [14-17]. The FRP possesses two major failure modes on axial crushing, 1) progressive crushing failure, and the 2) catastrophic crushing failure. The failure mechanism depends on parameters such as the type of loading, geometrical size of the specimen, type of fibre-reinforced polymer, the thickness of the tube, number of FRP layers, type of resin, and type of fillers inside the FRP tube [2,5,15]. Tran et.al [18], has studied theoretical and numerical behaviour of the crashworthiness of multi-cell triangular tubes and validated the efficiency of the tube design method. There are very few investigations in bi-directional basalt fabric subjected to axial load.

2. Experimental work

2.1 Casting of BFRPE tubes

Basalt fibre reinforced fabric is commercially available bidirectional woven fabric obtained from Haining Anjie Composite material Co, China. The fabric is 5.48 threads/ cm in wrap and 5.41 threads/ cm in weft direction. The basalt fibre was impregnated by the epoxy SP high modulus prime 20 resin and hardener with the mix ratio of 100:28 by mass. Layer by layer method was adopted. After 24 hours at room temperature the hardened basalt tube was removed from the mould.

2.2 Tensile strength of BFRPE slats

Tensile coupon test was carried out for three different types of layers, 2-4-and 6-layer basalt fibre reinforced polymer epoxy (BFRPE) slats. Five specimens were tested under each case. Extensometer was attached to the BFRPE slats to measure the extension during the tensile load. The tensile modulus of 2-4-and 6-layer basalt fibre reinforced polymer after impregnation of epoxy resin was found to be 9.5 GPa, 12.5 GPa and 12.66 GPa respectively. Figure 1 (a and b) shows the coupon test of BFRPE slats, figure (c) shows the SEM photograph of basalt fibre before epoxy. Figure 2 (a, b and c) shows the basalt fibre before preparation without epoxy, basalt fibre after epoxy preparation and completed BFRPE tube. Figure 3 shows the stress strain profile of basalt fibre of 2-4-and 6-layer.

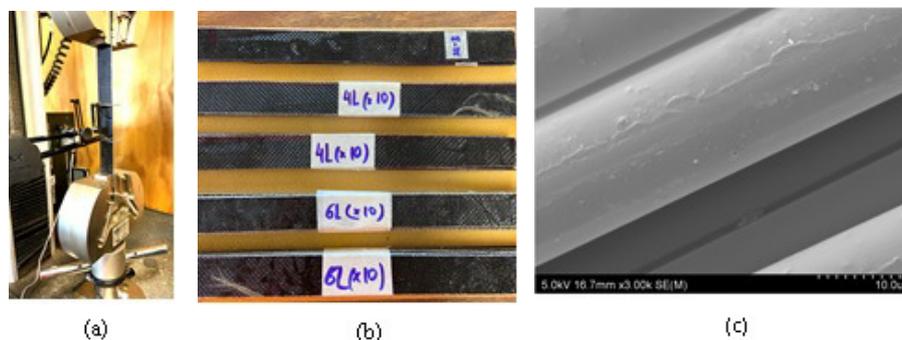


Figure 1. a) BFRPE in Instron 50 b) BFRPE slats c) Specimens before testing.

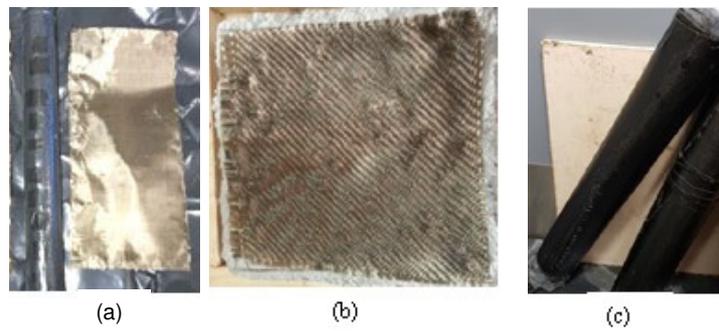


Figure 2. a) Basalt fibre without epoxy b) basalt fibre with epoxy c) Specimens after casting.

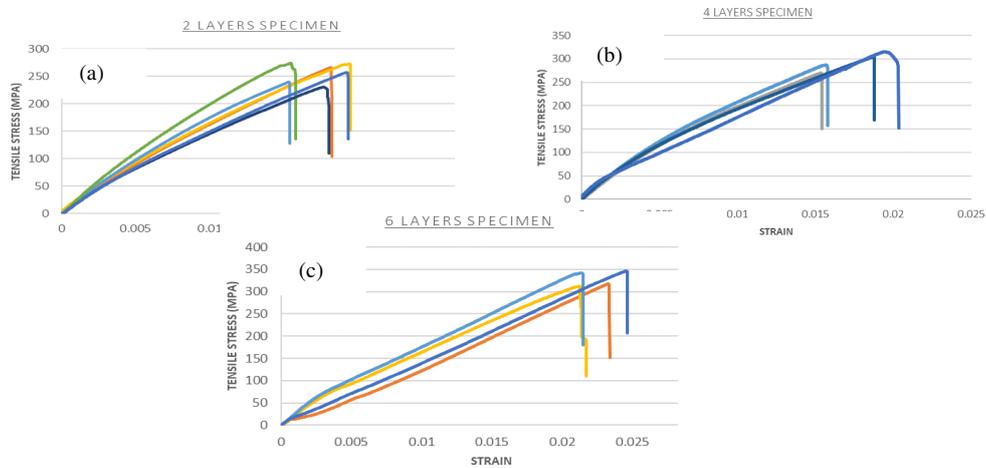


Figure 3. Stress – Strain profile of a) 2-layer b) 4-layer c) 6 – layer.

2.3 Material Preparation of BFRPE slats

A flat thin slat of material is mounted on Instron 50. The specimen surface were prepared and is mounted and gripped. Friction tabs are provided at the edges of the slats. The slat is monotonically loaded in tension with constant rate of 2mm/min, extensometer is placed on the slat to measure the change is length of the slat. Loading and displacement are measured, based on which stress-strain response and tensile modulus of elasticity are obtained. The length of the slat is 250mm and 25mm width.

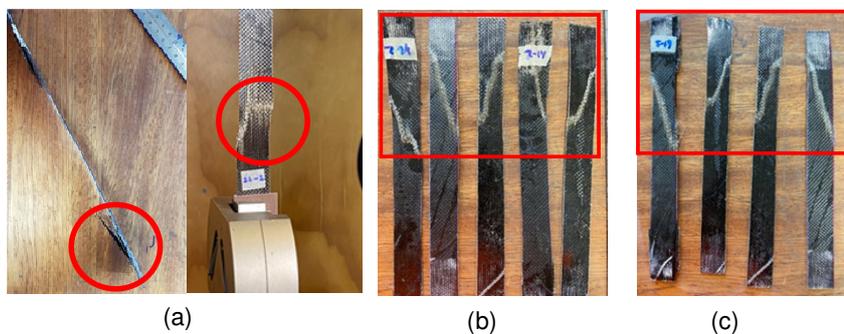


Figure 4. Failure modes of a) 2-layer b) 4-layer c) 6 – layer BFRPE slats

2.4 Failure modes of tensile test BFRPE slats

Figure 4. Shows the failure pattern of BFRPE slats of different layers. On tensile pulling of fibres, the failure pattern follows SGM code and DGM code of ASTM standard D 3039/D [19]. This SGM code means long splitting, gauge or tab, multi-mode failure in (x, y and z) directions. DGM code is the edge delamination along the gauge in multi-mode failure. The basalt fibre is a bi-directional fabric, therefore the delaminates propagate along all sides of the slats. Generally, FRP results in a ductile failure and the FRP with epoxy by brittle failure. If the amount of epoxy used is increased the failure of the FRP will be with a sudden noise with brittle failure. The figure 4 (a) shows delamination along with the rupture at the centre of the slat and figure 4 (b) and (c) shows a shear failure of the FRP. Thus, weakening the overall structure. The failure and ultimate load purely depend on the size of the slats. If the gauge length of the specimen is increased then the ultimate load of the specimen also increases. But higher the length more the epoxy used resulting to brittle failure.

3. Abaqus simulation of BFRPE tubes

The abaqus modelling of basalt fibre reinforced polymer tube has been modelled and analysed using finite element analysis. For the basalt fabric wraps shell elements were used to simplify the FEM model to save time. The model was created as shown in figure 5 (a, b and c). Two loading plates were bonded to the top and bottom of the column to transfer the axial compressive loading to the full section of the composite column. Boundary condition and axial compressive force were applied to the loading plate with respect to the reference points on the model. The given boundary conditions are the displacement and rotation and the bottom loading plate were fixed while the top plate were free and the displacement were given along the Z axis.

The plate and the composite tube were considered to be welded using 'tie' option and surface-surface interaction was given to the entire model. Based on the previous studies the friction factor was taken as 0.3. The interaction between BFRPE tube and the plate were identified as 'tie' function.

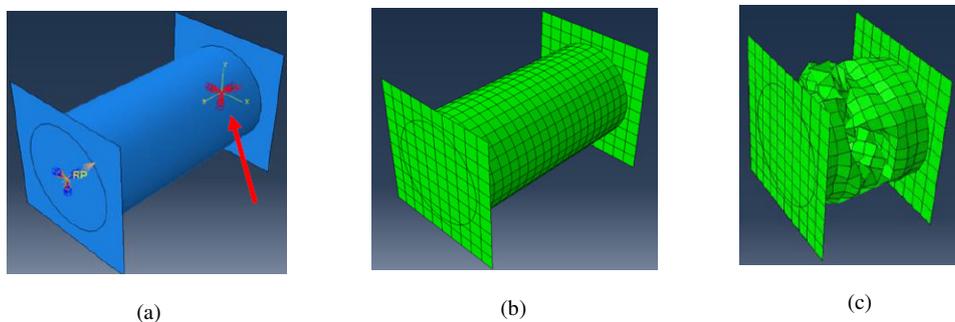


Figure 5. a) FEM model b) FEM model with meshing c) model after application of load

4. Result and discussion

Figure 6 (a, b and c) shows the load-displacement profile of 2-layer, 4-layer and 6-layer. The area covered under the load-displacement profile is the energy absorbed by the material. The energy absorption of 2-layer, 4-layer and 6-layer is found to be 70 J, 252 J and 1604 J. Several studies reveals that with the increase in number of plies or layers the energy absorption capability of the FRP tube also increases. Maximum load of 2-layer, 4-layer and 6-layer is found to be 4.5 kN, 15.6 kN and 32kN. Figure 7 represent the energy absorption of BFRPE tube with different layers. The crush force efficiency of the composite tube is found to be 0.5 for 2-layers, 0.3 for 4-layers and 0.67 for 6-layers. As the area under the 4-layer is comparatively smaller than 2-layers the crush force efficiency has been reduced. This can be improved by adopting better FEM elements.

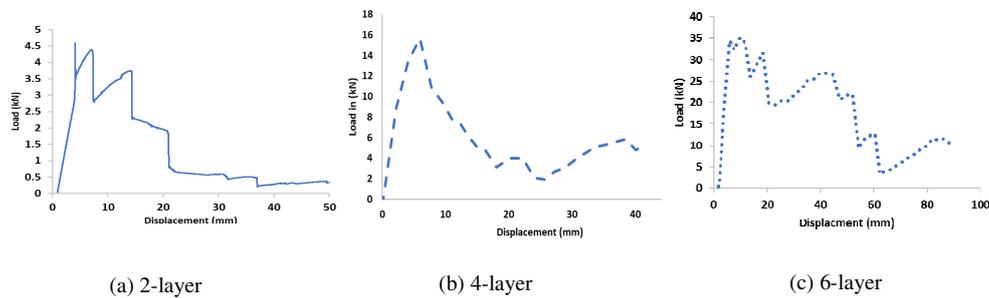


Figure 6. Load- displacement profile of different layers of BFRPE

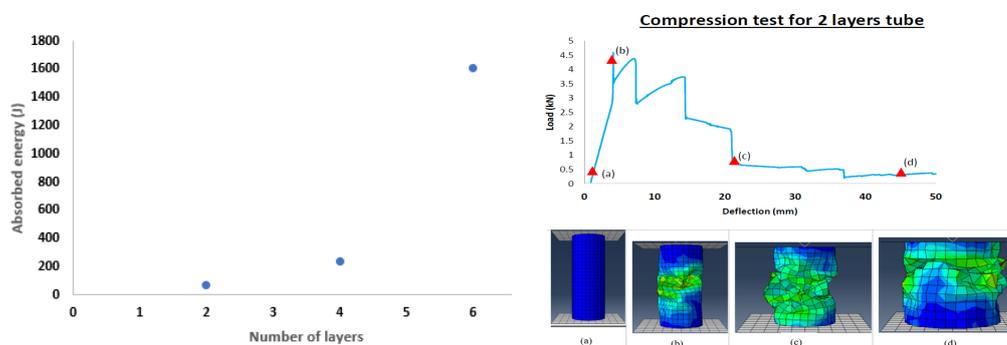


Figure 7. Energy absorption of different layers

Figure 8. Failure mode of 2-layer BFRPE

4.1 Failure mode of FEM model

Failure mode of the structure is an important parameter to evaluate the crashworthiness of a composite energy absorber. According to the test validation, failure pattern of the 6-layer BFRPE tube failed in progressive rather than a catastrophic failure. Whereas the 2- and 4-layers failed in rupture. The tubes were subjected to inward buckling followed by the delamination of basalt fabric. Thinner the size of the tube more is the inward buckling. Fig.8. represents the behaviour of the tube with respect to load-displacement of 2-layer. Catastrophic failure resulted in the partition of the tube along the circumferential direction of the BFRPE tube. The failure pattern can be improved by filling the tube with natural material fillers. The experimental set up was conducted with BFRPE tube filled with natural fillers. As the modelling of the natural fillers is complex, the present study focused on the empty BFRPE tube.

5. Conclusion

The used basalt fibre is a bi-directional fabric. Very limited research has been undertaken using bi-directional basalt fabric. The results of the FEM analysis show that the energy absorption of the polymer fabric increases with the increase of fabric thickness. The crush force efficiency (CFE) also increases with the increase in layer thickness. The 4-layer basalt fabric shows reduced results of CFE this is due to the insufficient elemental analysis which can be further improved.

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