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Numerical Simulation On Lateral Collapse of Bamboo Foam Composite in Hollow Cylindrical Tube Subjected to Quasi Static Loading

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Abstract: Bamboo or its scientific name Bambusoideae, Bamboos are a complex genus of evergreen perennial flowering plants that belong to the Poaceae grass family's Bambusoideae subfamily. It could be the country's next industrial crop based on research findings on the technical and commercial potentials of the plant in Malaysia. These raw materials can be processed into pulp and paper, bio-composites for automotive door trimmings and interior shelving's, as well as building material. Its specialty is having good mechanical properties and makes it desirable fibres in various industries. However, the application of bamboo as energy absorption by being the filler inside hollow cylindrical tube structure has not been much explored. In this study, quasi-static simulation study using finite element program, ABAQUS has been carried out on empty and bamboo foam composite filled in hollow cylindrical tube with three different of wall thickness and four different percentages of bamboo particle. Wall thickness that has been used are 2.5mm, 3.2mm and 4.0mm, while densities of 5%, 10%, 15% and 20% bamboo particle is used to develop the model of material. The result shows that energy absorption capability is proportional to the wall thickness. When the wall thickness is increased, energy absorption also increased.

Keywords: Foam Filled Tube Energy Absorption, Lateral Collapse, Quasi-Static Loading

1. Introduction

Nowadays, many studies have been done by using of accessible natural capital. Bamboo is an example of natural resources that have the ability to replace reinforced concrete with steel reinforcement. Bamboo is commonly regarded as a giant grass rising steadily in tropical and subtropical areas. Its weight is greater than wood and its tensile strength is about half that of steel producing it. Suitable for the substitution of steel reinforcement bar in concrete [1]. In comparison, bamboo is lightweight relative to steel. As a result, the use of bamboo as a support would minimize building costs.

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This would be advantageous if high building strength could be accomplished at a cheaper cost. In short, bamboo has the ability to substitute steel as reinforcement in reinforced concrete due to its characteristic of being inexpensive, readily available and, most significantly, high in tension and compression.

Malaysia usually consists of 70 bamboo species, including 50 in Peninsular Malaysia, 30 in Sabah and 20 in Sarawak [2]. The land has so far been raised to 329 000, and a few researchers have argued that bamboo as a natural resource in Malaysia has been listed as the second largest non-timber source next to rattan. It has been merged with Malaysia's conventional rural lifestyle for a long time, but it has never been. Commercialize extensively as emphasis is concentrated only on handicrafts, wood and furniture industries or is often used as additional building materials. Bamboo resources in Malaysia are currently left as an unmanaged wild species [3].

This paper explores the quasi-static simulation using finite element program, ABAQUS for bamboo foam composite filled in hollow cylindrical tube.

2. Materials and Methods

Most material models that describe mechanical behaviour are available for the static stress analysis. The following material properties were not active during static a static stress analysis: acoustic properties, thermal properties (except for thermal expansion), mass diffusion properties, electrical conductivity properties and pore fluid flow properties.

2.1 Materials

The density and Young Modulus of different percentages of bamboo and different thickness of the hollow cylindrical tube that had been used to build the model of material. These values were according to the previous experimental result. The density of bio-foam will increase as increasing the bamboo percentages. It was initially with 100% PU foam with density below 0.1 g/cm^3. For the different thickness of tube, 2.5mm, 3.2mm and 4.0mm the density was ranging between 7 to 8g/cm^3

2.2 Methods

Tubes were applied lateral forces resultant more plastics hinge were formed during the collapse occurred. The tube was constrained by applied the penalty friction formulation for the interaction between the tube and two rigid bodies, top and bottom of the tube. These rigid bodies were analytical rigid type and extruded shell was the base feature. The top rigid body was acted as a loading plate. This rigid body was assigned a reference point and was applied boundary conditions in order to fix in *x*and *z*-directional but not for *y*-directional. Velocity (cross-head speed) of 8mm/min, U_2 was applied using instantaneous amplitude to allow the movement of the loading plate downward (*y*- directional) in order to subject the tube to lateral impact. For the lower rigid body which was acted as the base of the tube were applied boundary condition type symmetry/antisymmetric /encastre. This type of boundary condition was fixed the rigid body in all directional e.g *x*, *y* and *z*-directional. Tangential behaviour was chosen for the contact property option in order to apply theinteraction between bamboo foam composite and tubes. In this case, rough friction formulation was used to ensure there was no slip occurs once point was in contact. The tube and bamboo foam were assigned hundreds of seed edge in the meshing section and used ‘tri’ for the element shape. Thistype of element shape can give the better result for this analysis compared to the other type

2.3 Equations

Energy absorption is one of the important aspects that should be considered in designing a structure that experiencing collapse. In study the mechanical energy absorption, the other aspect that should be considered are the collapse load, collapse efficiency, specific energy and unbalancing. The final objective is designing a structure that can minimize the material damage and any injuries.

The area under the force-displacement curves gives the energy absorption for the component for a particular loading direction.

$$E_s = \int_0^{d_{max}} F.dx$$

Where the energy absorbed, E (kJ) has been calculated up to the maximum crush distance, d_{max}(mm), and F is the crushing force (kN). [5]

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3. Results and Discussion

The results and discussion section present data and analysis of the study. The result obtained were discussed accordingly.

3.1 Deformation

In this numerical analysis, the wall thickness was varied from 2.5 mm, 3.2 mm to 4.0 mm and densities was 5%, 10%, 15% and 20% of bamboo particle. When the load was applied, the model was started to deform to oval shape mode and at the same time the bamboo foam elements also compressed to deformation form. A 'figure of eight' was formed during the final stage of failure and the simulation progress status shows the 'complete' message. . Figure 1 show the deformation form of the empty cylindrical tube when subjected to lateral loading. From the observation, the model of empty cylindrical tube had smallest time to deform and have longest deformation compared to the foam-filled tube

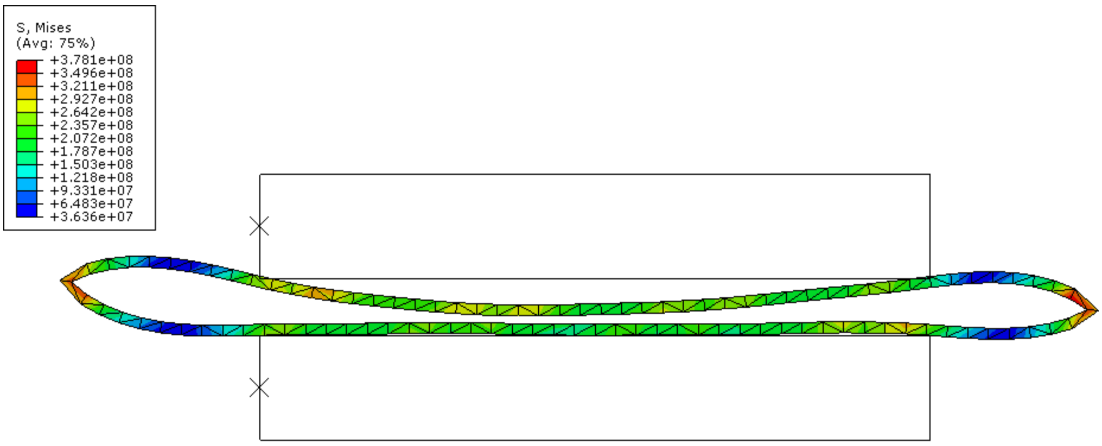
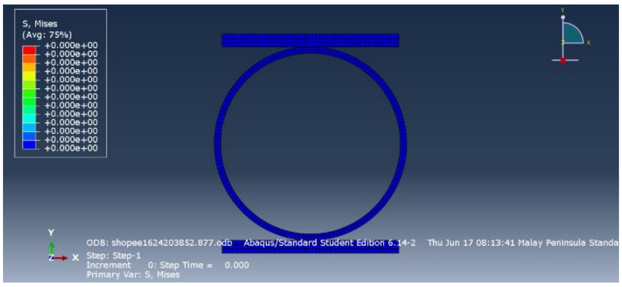
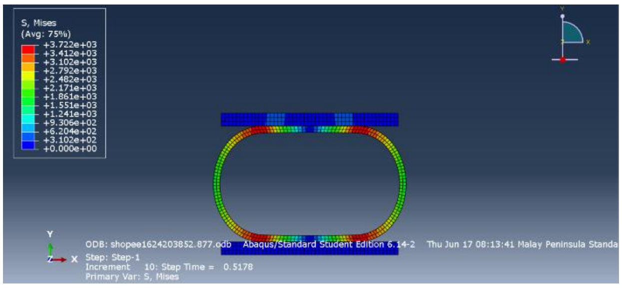
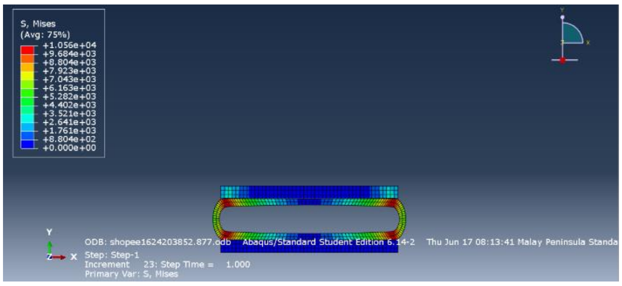


Figure 1: Deformation of empty tube at thickness (2.5mm)

The deformation was decreased and became slowly by increasing bamboo percentages for each thickness. This was due to the crystalline cellulose content of bamboo fibres that act as fibre reinforce. It can vary between 44% and 57% in the natural fibre [6]. Thus, for 10% bamboo foam, the crystalline cellulose content is highest compared to the other percentage of bamboo particles. The crystalline cellulose is plasticized to allow molecular chain mobility. Thus, to have optimum energy absorption structure, it is not inconceivable to have highly filled bamboo composites. The reinforcing element is far below the limits when used of high filled bamboo composite percentage [6]. Besides, wall thicknesses of tubes also influence the deformation movement and time period. Table 1 shows the example of deformation sequences of bamboo foam filled tube which is first mode, continues mode and collapsed mode for each thickness.

Table 1: Example of deformation sequences of foam filled tube for first mode, continues mode and collapsed mode.

Conditions (2.5mm)	
First mode	
Continues mode	
Collapsed mode	

3.2 Energy Absorption

The specific energy absorption clearly increased as the thickness was increased, as shown in the Figure 2. This is because the number of layers is proportional to the amount of composite used. The stiffness of the materials is changed as the composite content increases, yet the materials become brittle. It was observed that lower density of bamboo foam filled in hollow cylindrical tube was almost ineffective in increasing the energy absorption. The empty tube, 15% and 20% foam filled tube have similar behaviour, and it was showed that the foam did not give much influence on the structure deformation. However, the 10% bamboo percentage gave the large effect of force-displacement curves and is the best energy absorption performance due to it high fibre reinforce property. This situation was met the agreement with the experimental study and it was illustrated in the Figure 3. The curve of force-displacement is also well agreed with the experimental study. Result from previous researcher, showed the agreement with this result which stated that the average crushing load of foam-filled tube is higher than empty tube [8]. The energy absorption due to the foam-filled increase depends on the cross-sectional area and the foam strength, which is by increasing the bamboo percentages in the bio-foam. However, foam-filled tube will increase the mass compared to the empty ones.

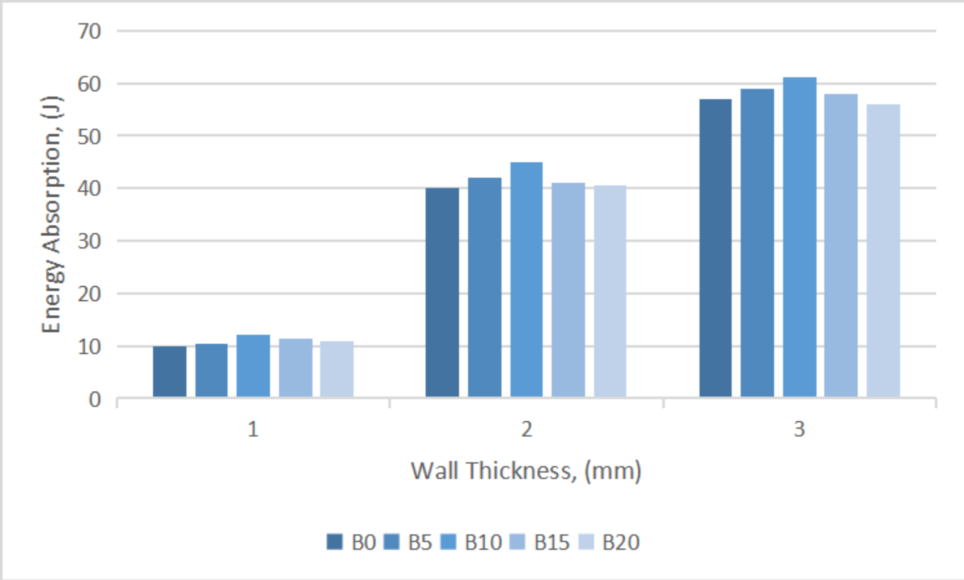


Figure 2: Energy absorption for all thickness on various percentage of bamboo foam-filled in hollow tube

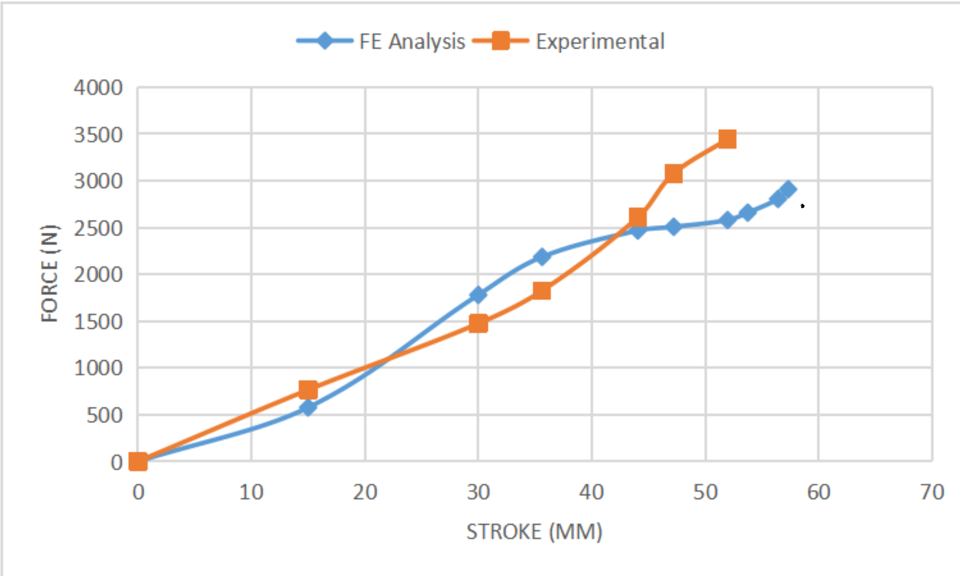


Figure 3: Example of Force versus stroke (displacement) graph for model Thickness (3.2mm B0)

4. Conclusion

The static simulations were carried out using the Abaqus finite element software and the small cross-head speed applied, the tube wall thickness and density of bamboo foam were analysed. Each model is energy absorption performance was determined.

The simulation result was agreed well with the experimental. Clearly, both of the method shows that increasing the wall thickness significantly increase the energy absorbed up to a deflection. The effect of foam filled and the wall thickness influenced the deformation modes and force-displacement behaviour. Therefore, foam filled circular tubes had higher energy absorption than the empty circular tubes.

The cylindrical tubes filled with bamboo foam structures have good characteristic in energy absorption. It is an efficient device in absorbing energy and suitable to apply to the various vehicle especially car in order to avoid occupant from severe injury when the crash occurred. Besides, bamboo fibre usage as foam filler is said green and can protect our environment due to it is natural fibre. In addition, these devices have relative constant crushing force and make desirable energy absorbance. In fact, the energy absorbed can be characterized by a smooth load deflection relation.

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