Effect of the Strengthened Ribs in Hybrid Toughened Kenaf/ Glass Epoxy Composite Bumper Beam

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Abstract: The growth of car production governs new environmental regulations "End-of Life Vehicles" (ELV) to enforce car manufacturer to substitute synthetic material to bio based materials. Low mechanical properties of natural fibre composite confine their application in automotive non-structural components. Hybridizations of kenaf with glass fibre along with epoxy PBT toughening did not completely fulfill the required impact property of the developed bio-composite bumper beam to substitute with typical material of the bumper beam glass mat thermoplastic (GMT). Therefore, in the first stage of the geometrical improvement "concept selection" concluded that the double hat profile (DHP) is the most suitable concept out of eight bumper beam concepts when six parameters with different weight (strain energy, deflection, weight, cost, manufacturing and rib possibility) are determined. In second trial, the usage of strengthen rib is employed to improve the impact property and performance of the bumper beam for utilization of hybrid kenaf/glass fibre as a car bumper beam. The low-speed impact test based on the (ECE R42) regulation is modeled. Eight vertical ribs with thickness 4 mm are located along the bumper beam. The pendulum hit to the middle of the bumper, while it is fixed to the vehicle chassis through two energy absorbers. The strain energy and deflection were determined and compared with the same profile, but in un-ribbed condition. It is concluded that the ribbed bumper beam decrease the deflection of the bumper beam by 11% and strain energy by 11.3%. The ribbed bumper beam increases the structural safety factor and its reliability for utilization in automotive structural components.
[Majid Davoodi Makinejad, Mohammad Sapuan Salit, Aidy Ali, Desa Ahmad. **Effect of the Strengthen Ribs in Hybrid Toughened Kenaf/ Glass Epoxy Composite Bumper Beam.** Life Science Journal.2012;9(1):285-289]. (ISSN:1097-8135). http://www.lifesciencesite.com. 40

Keywords: Bumper beam; Finite element analysis; Hybrid material; Natural fibre composite

1. Introduction

Strengthen ribs are exploited to improve the structural strength of hybrid kenaf/glass epoxy composite bumper beam in second trial of geometrical improvement in order to enhance the performance of the developed material in structural component's applications. Strengthen ribs increase distortion resistance and structural stiffness with fewer materials in slender wall (Al-Ashaab, Rodriguez, 2003). It can decrease the bumper beam deflection, elongation and increase impact energy (Brydson, 1999, Hosseinzadeh, Shokrieh, 2005, Marzbanrad, Alijanpour, 2009). The previous result showed that the toughened hybrid kenaf/glass fibre epoxy composite cannot fulfill the GMT impact strength. The geometry improvement commenced with bumper concept selection within six criteria with different weight. It is concluded that the bumper beam concept, double hat profile (DHP), as a best one out of eight concepts (Davoodi, Sapuan, 2011). This study focused on geometry improvement by adding the vertical ribs to the selected concept and compares the strain energy and deflection with the un-ribbed bumper beam.

There are different parameters that effect in the rib strength (pattern, thickness, top and bottom fillet, weld line area, position) (Harper, 2006, Smith and Suh, 1979, Zhang, Liu, 2009). Besides, load direction, load position, material and manufacturing process should be considered in rib design (Samaha, Molino, 1998). Hosseinzadeh, Shokrieh 3) compare the bumper beam made from sheet molding compound (SMC) and GMT with and without ribs. It is resulted that the rib in the GMT bumper beam can decrease the deflection of the beam 13% and slightly increases the impact force; however, the ease of manufacturing should be focused. Marzbanrad, Alijanpour 4) showed that the ribbed bumper increase the rigidity and enhance the impact force by 7% in steel bumper beam. Murata, Shioya 10) used the high density EPP with rib structure to increase the energy absorption capacity. He showed that the fine tuning of the rib design (thickness, height, spacing) while combine with EPP can optimize the energy absorption.

This study focused on the bumper beam structure under low speed impact test with vertical strengthening thin-walled ribs and analyzing the energy absorption improvement of the selected concept. It emphasize on the structural performance of the ribbed bumper beam with developed toughened hybrid kenaf/glass epoxy. The material model of the developed hybrid bio-composite was extracted from the previous study experimental test and checked with the same simulated impact condition. The parameters of the model such as type and size of the element and meshes were modified to match the results together. Then the exact low speed impact test condition (ECE R42) was simulated by finite-element software, ABAQUS Ver16R9. The impact loads defined while the impactor with 1000 kg hit to the bumper beam, which is fixed from both end sides while attached to a solid block, which represent the car weight in center of mass at x= 530. The meshes, steps, interactions and jobs are defined. Strain energy and deflection of double hat profile (DHP) is analyzed when the vertical ribs are added. The ribbed bumper stands more effective against the impact load and increases the reliability of the developed hybrid bio-composite material for utilization in the car bumper beam.

2. Material and Methods

The ingredients of the hybrid bio-composite material consist of kenaf fiber, glass fibre, epoxy and polybutylene terephthalate (PBT) respectively were provided from Institute of Tropical Forestry and Forest Products (INTROP) (Malaysia), Fibreglass Enterprise (China), LECO Corporation (USA), CBT® 160 (PBT) from CYCLICS Corporation (USA). Three plies of glass fibers, and two plies of stretched twisted long kenaf with orientation (0, 90, 0, 90, 0) are prepared. The PBT 5% (w/w) is added under structure-less method to the epoxy and sprayed to the prepared plies and compressed by a preheated mold T=85° C under controlled conditions (P=80 bars and T=85° C) (See Figure 2). The property of the material which is conducted from the previous study was imported to the ABAQUS V16R9 (Davoodi, Sapuan, 2012).

The low-speed impact (ECE R42) was simulated in ABAQUS Ver16R9. A pendulum with unladen weight (1000 kg for normal car) and speed 4 km/h at the contact point, hit to the middle of the bumper beam, while is fixed to the chassis (block present the car weight, center of mass at X=530) through two traverse energy absorbers. Figure 2 shown pendulum and boundary conditions.

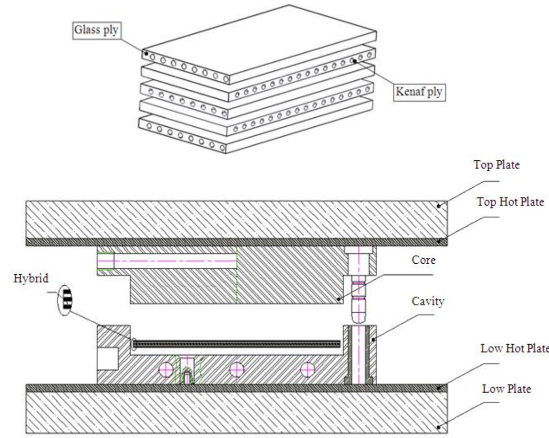

Figure 1. Compression mould for hybrid bio-composite

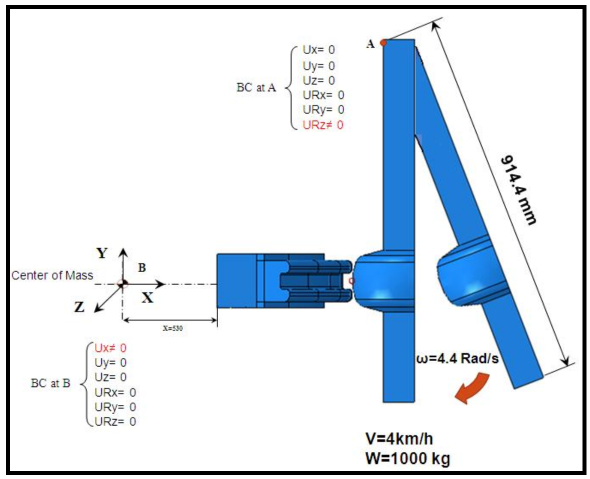

Figure 2. Low impact test simulation and boundary condition

The whole of the simulated components elements characteristics are introduced in Table 1.

Table 1. Elements characteristics in FEA

No	Part Name	Element type	Element No.	Node	Element Name
1	Barrier	C3D4	2196	620	tetrahedral
2	Mass	C3D8R	16510	19712	hexahedral
3	Left Holder	S4R	513	509	quadrilateral
4	Right Holder	S4R	520	517	quadrilateral
5	Beam	S3	1228	1328	triangular
Total			20967	22686	

Every plies of the hybrid composite are defined separatly in ABAQUS with thickness 0.8 mm and 0° (glass fibre), 90° (kenaf fibre) direction. The main properties extracted from experimental test and defined in ABAQUS. Since impact property is the main interested objective in this study, the same impact condition was simulated to match the compatibility between experimental by changing the parameters such as type and number of element and method of meshing (Figure 3).

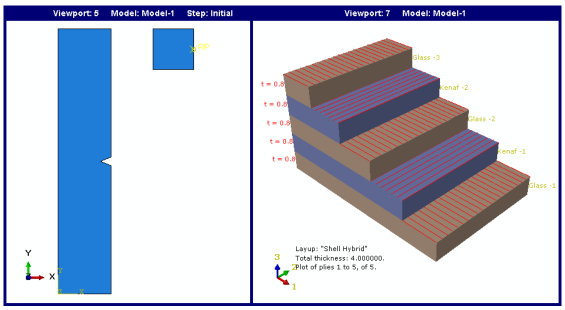

Figure 3. Hybrid kenaf/glass modeling for verification with impact test condition

The low-impact test condition is defined for elastic deformation of the bumper beam (AISI, 2006). Since the bumper beam is fixed from both traverse sides, the applied impact load tends it to bend. In bending, the composite failure initiates with matrix cracking followed by debonding between layers, delamination and finally fibre fracture. In ABAQUS, the progressive damage and failure prediction of both fibre and matrix failure determine based on Hashin theory (Hashin, 1980). The Hashin introduced four criteria modes: fibre tension, fibre compression, matrix tension and matrix compression. In this study, the bending of the hybrid composite bumper beam in the outer layers causes the matrix tension and cracking. So, matrix tension is considered as an initiation step of failure.

$$F_{mt} = \left[\frac{\sigma^{\circ}{}_{22}}{Y^T}\right]^2 + \left[\frac{\sigma^{\circ}{}_{12}}{S^L}\right]^2 = 1$$

F_{mt} = Failure in matrix tension

d_f, d_m, d_s = Damage variables

σ = True stress

σ° = Effective stress

$\sigma_{22} \geq 0$

Y^T = Traverse tensile strength

S^L = Longitudinal shear strength

The effective stress can determine from product of the following matrix to the true stress. However, in the software just should input the requested parameters for Hashin criteria consideration.

$$\sigma^{\circ} = \begin{bmatrix} \frac{1}{1-d_f} & 0 & 0 \\ 0 & \frac{1}{1-d_m} & 0 \\ 0 & 0 & \frac{1}{1-d_s} \end{bmatrix} \sigma$$

Eight vertical ribs (200 mm distance between adjacent ribs and end cap) with 4 mm thickness are located in longitudinal direction of the bumper beam. The ribs are placed along the X direction for ejection purposes except end caps (Figure 4).

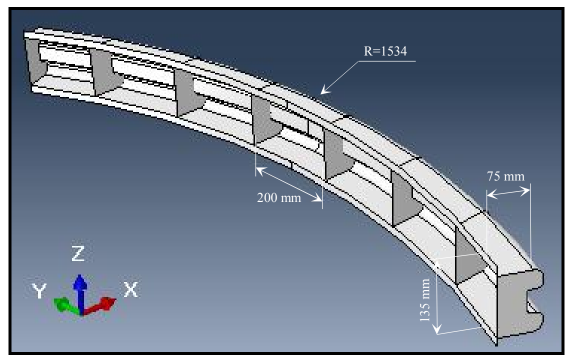

Figure 4. The strengthen ribs of bumper beam

3. Results

Deflection of the both bumper beams during the impact is shown in figure 5.

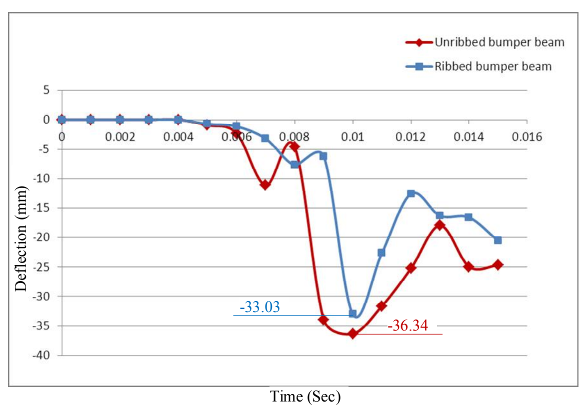

Figure 5. Deflection of ribbed and unribbed bumper beam

From the graph, it is evident that the maximum deflection of the unribbed bumper is 3.31 mm more than the ribbed bumper. In other words, the vertical ribs decreased deflection of the bumper beam by 11%. Moreover, the unribbed bumper beam deflection commenced earlier than ribbed one, since it has less solidified.

Figure 6 shows the strain energy of both ribbed and unribbed bumper beam. It is evident that the strain energy in the ribbed bumper beam commenced earlier than unribbed one because of more stability of the ribbed bumper beam in energy absorption, cause faster response to the external impact load. Moreover, it is presented that the maximum amount of strain energy in the ribbed bumper beam increased by 11.3% compare with unribbed bumper beam because of rigidity enhancement of the structure. The strain energy undulation of the ribbed bumper beam cause by the rib zone strain energy removal and unsteady load distribution from the rigid pendulum to the beam and side energy absorbers.

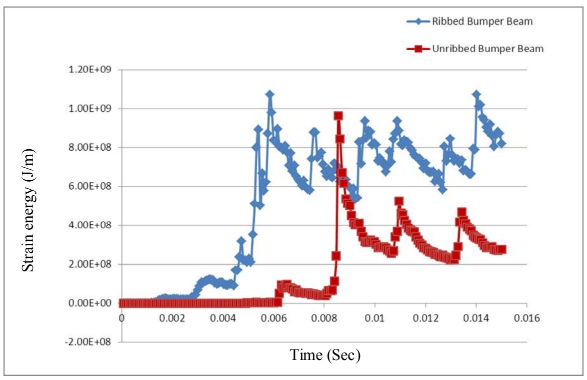

Figure 6. Strain energy of ribbed and unribbed bumper beam

It is evident, there are eight pick points in strain energy graph, which might be because of the energy dissipation of the ribs during the energy damping process.

4. Discussions

The accurate design of the strengthened ribs and its effective parameters such as features, spacing, thickness, height, can increase the energy absorption capacity (Murata, Shioya, 2004) as well as decrease the shrinkage and thermal expansion in the bumper beam. The unribbed bumper beam makes less-rigid sections and may absorb more impact energy by elastic deformation without damage (Rosato and Murphy, 2004).

The additional ribs slightly increase strain energy and decrease deflection in bumper beam, but cause weight rises and manufacturing difficulty (Hosseinzadeh, Shokrieh, 2005, Marzbanrad, Alijanpour, 2009). Besides, it requires more pressure to flow the material to the ribbed cavities and cause bumper beam denser and more solid. The vertical ribs with thickness 4 mm prevent the deflection of the lateral beam surfaces. Making ribs in the beam needs specific cavities in the die, which makes a difficulty in mold making and production. It causes higher compressive pressure to flow the material to the thin cavity for forming the ribs. The author recommends the experimental approach in order to verify the developed toughened hybrid kenaf/glass epoxy composite to control various parameters for a reasonable replacement solution of new developed material. Moreover, since the strength improvement of the ribbed bumper beam is not quite significant, fabrication of the whole bumper beam in real processing method can show the manufacturing difficulty by the developed material for making the ribbed bumper beam.

Acknowledgements:

The principal author wishes to thank the Universiti Putra Malaysia for supporting this research financially through the Research University Fellowship Scheme.

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1/5/2012