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 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.

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 improve the performance of utilizing 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 and concluded with double hat profile (DHP) as a best one out of eight concepts.

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 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) shown that the ribbed bumper increase the rigidity and enhance the impact force by 7% in steel bumper beam.

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. It is concluded that the ribbed bumper beam decrease the deflection by 11% and increase the strain energy by 11.3% compared with unribbed bumper beam. The result can increase 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 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). The property of the material which is conducted from the previous study was imported to the ABAQUS V16R9.

The low-speed impact (ECE R42) was simulated in ABAQUS Ver16R9. A pendulum with weight 1000 kg and speed 4 km/h at the contact point, hit to the bumper beam, while is fixed from both sides by two energy absorbers to the block which present the car weight (center of mass at X=530). Figure 1 shown pendulum and boundary conditions.
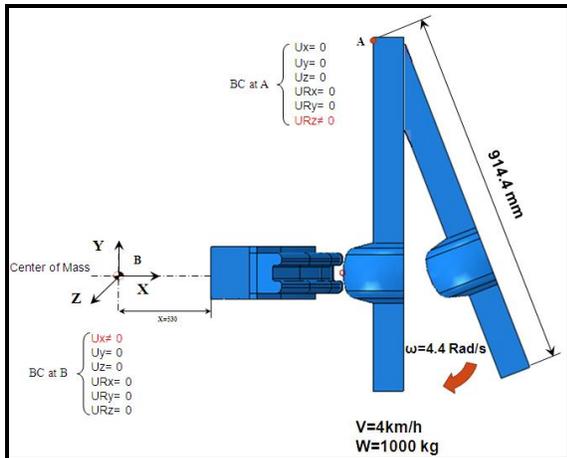

Figure 1. Low impact test simulation and boundary condition

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

Table1. 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 is defined separately in ABAQUS with thickness 0.8 mm and 0, 90 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 2).
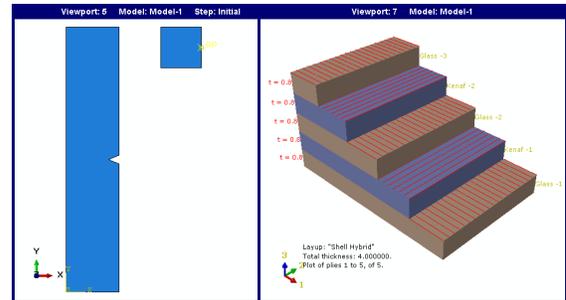

Figure 2. Hybrid kenaf/glass modeling for verification with impact test condition

The low-impact test condition is defined for elastic deformation of the bumper beam (AISI, 2006). Since the bumper beam is fixed from both end's 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, matrix tension as an initiation step of failure is considered.

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

$\sigma_{22} \geq 0$

$\sigma^{\circ} = $ effective stress

$\sigma = $ true stress

$d_f, d_m, d_s = $ damage variables

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.

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

Eight vertical ribs (200 mm distance between adjacent ribs and end cap) with 4 mm thickness is inserted in longitudinal direction of the bumper beam. The ribs are placed along the X direction for ejection purposes except end caps (Figure 3).
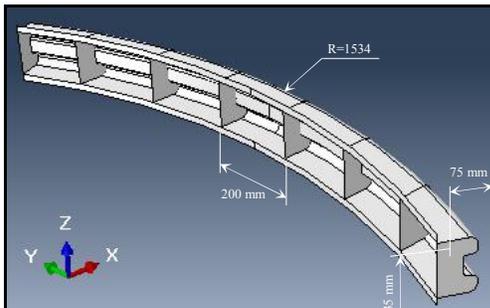

Figure 3. The strengthen ribs of bumper beam

3. Results

The vertical ribs with thickness 4 mm prevent the deflection of the lateral beam surfaces. Making ribs in the beam needs cavities in the die, which makes a difficulty in mold making and production. It causes the compressive pressure increase to flow the material to the thin cavity for forming the ribs. Deflection of the both bumper beams during the impact is shown in figure 4.
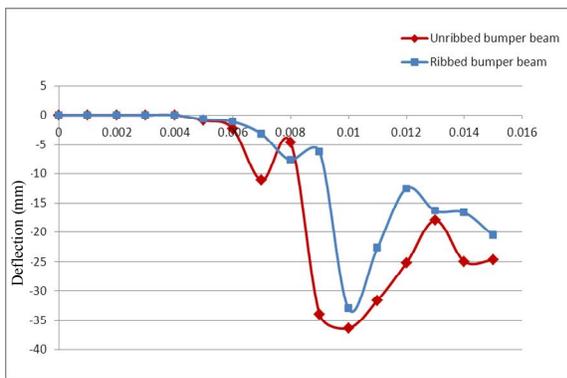

Figure 4. Deflection of $^{Time\ (Sec)}$ and unribbed bumper beam

From the graph, it is evident that the maximum deflection of the unribbed bumper is 3.30 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 5 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.
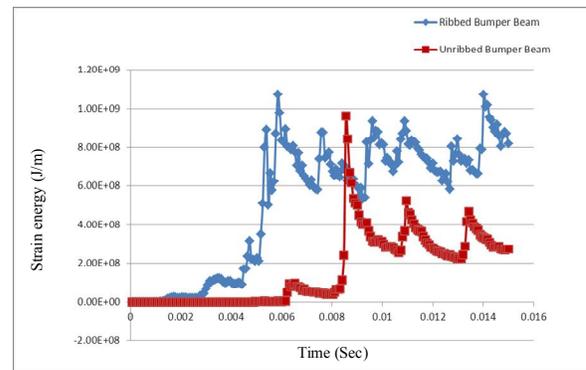

Figure 5. Strain energy of ribbed and unribbed bumper beam

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 reduce 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 author recommends the experimental approach in order to verify the developed toughened hybrid kenaf/glass epoxy composite for low weight passenger car application and control various parameters for a reasonable replacement solution of new developed material.

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References

1. Al-Ashaab, A., et al., Internet-based collaborative design for an injection-moulding system. Conc. Eng., 2003; 11(4): 289.
2. Brydson, J.A., Plastics Materials. New Delhi: Butterworth-Heinemann; 1999.
3. Hosseinzadeh, R., Shokrieh, M., and Lessard, L., Parametric study of automotive composite bumper beams subjected to low-velocity impacts. Compos. Struct., 2005; 68(4): 419-427.
4. Marzbanrad, J., Alijanpour, M., and Kiasat, M., Design and analysis of an automotive bumper beam in low-speed frontal crashes. Thin. Walled. Struct., 2009; 47(8-9): 902-911.
5. Harper, C.A., Handbook of plastic processes: Wiley-Interscience; 2006.
6. Smith, K.L. and Suh, N.P., An approach towards the reduction of sink marks in sheet molding compound. Polym.Eng.Scien., 1979; 19(12): 829-834.
7. Zhang, Z., Liu, S., and Tang, Z., Design optimization of cross-sectional configuration of rib-reinforced thin-walled beam. Thin. Walled. Struct., 2009; 47(8-9): 868-878.
8. Samaha, R.R., Molino, L.N., and Maltese, M.R. Comparative performance testing of passenger cars relative to FMVSS 214 and the EU 96/EC/27 side impact regulations: phase I. 1998.
9. Hashin, Z., Failure criteria for unidirectional fiber composites. Journal of applied mechanics, 1980; 47: 329.
10. Murata, S., Shioya, S., and Suffis, B., Expanded Polypropylene (EPP): A Global Solution for Pedestrian Safety Bumper Systems. 2004.
11. Rosato, D.V. and Murphy, J., Reinforced plastics handbook: Elsevier Advanced Technology; 2004.

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