Crashworthiness of automobile made of HDPE/kenaf and HDPE/MWCNT polymer composites

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Abstract. The present work deals with the crashworthiness of high-density polyethylene/kenaf and high-density polyethylene/multi-walled carbon nanotube polymer composites. The purpose of using polymer composites for the crashworthiness is their high specific energy absorption due to the low weight of the polymer composites. The various mechanical properties (Young’s modulus, tensile yield strength, and ultimate tensile strength) of the stated polymer composites have been predicted by a uniaxial tensile test. Further, these properties have been used as the input for the crash simulation. A widely known finite element method (FEM) package ANSYS has been used for the crashworthiness of the automobile. In the present study, HDPE/kenaf and HDPE/MWCNT polymer composites with 20 wt. % of reinforcement have been considered. The CAD geometry of automobile structure is modelled in SolidWorks and further analyze in ANSYS-explicit dynamics. Numerical results are presented in the form of equivalent (von Mises) stress and directional deformation of the automobile’s body panel with respect to time. It has been observed that the body panel made of HDPE/kenaf polymer composite induces relatively higher magnitude of equivalent (von Mises) stress and lower directional deformation by 42.85 %.

1. Introduction
Occupants safety is of prime importance in road accidents. To save the occupants from injury air-bags, anti-braking system, seat belts etc are installed within the automobile’s body. However, a situation arises where the body panel damages causing the death of the occupants. In such a situation, body panel deforms causing the reduction of the occupants seating area. Hence, the body panel’s stiffness must be good enough to sustain the excessive deformation of the body panel [1]. To reduce the death rate, safety equipment in an automobile is increased, vehicle’s crashworthiness has been increased along with the increased highway standards [2].

Crashworthiness is the ability of the automobile’s body to protect the occupants from the injury during the impact. Crashworthiness can be checked by the deformation of the automobile’s structure, deacceleration experienced by the automobile during the impact, the probability of injury to the occupants etc. These are some of the commonly used criteria for the judgment of the crashworthiness of the automobile. The automobile must plastically deform in order to absorb as much as possible energy during the impact [3]. If the automobile does not deforms plastically, then the deacceleration caused during the impact will be high. High deacceleration rate increases the probability for the injury of the occupants [4]. Hence, plastic deformation of the body panel increases the crashworthiness of the automobile.

One of the important parameter to measure the crashworthiness of the automobile is specific energy absorption (SEA). Specific energy absorption depends on the material’s ability to absorb the energy
upon impact and also on the mass of the impactor. Mass of the polymer composites for the same volume of the material is less as compared to the metals. Hence, the specific energy absorption of the polymer composites is high [5–7]. Therefore, automobiles made of polymer composites are of great interest in research. Polymer composites are widely used in an automobile for the door panels, dashboard, body panel etc [8]. H.D.Gopalakrishna et al. studied the specific energy absorption for polycarbonate and compared with other metals and found that the SEA of polycarbonate was highest [3].

Tony et al. studied the SEA of carbon fibre, E Glass fabric, steel, and aluminum. The author found that the carbon fibre has the highest SEA [5]. Abhishek Jain et al. studied the equivalent stress and found that the polycarbonate has the highest value of equivalent stress out of steel, aluminum alloy and magnesium alloy [9]. Shuyong et al. studied the structure optimization for crashworthiness and observed that the optimum radius and thickness of material increased the SEA and decreased the peak load [10]. Andre et al. studied the performance of thermoplastic polyamide 66 with 30 % glass fibre and concluded that there is an 80 % reduction in tibia compression with the reinforcement of the polymer composite [11].

From the literature, it can be concluded that polymer composites exhibit higher specific energy absorption capacity. Due to the favorable characteristics of the polymer composite, it can be analyzed for crashworthiness behavior for automobile application. The objective of present work is to investigate crashworthiness capacity of high-density polyethylene/kenaf and high-density polyethylene/multi-walled carbon nanotube-polymer composites for automobile panel application. This paper is structured into the four sections. The first section is the introduction where the problem background has been discussed. The second section describes the problem. In this section overview of the modelling problem with the algorithm has been discussed. The third section consists of results and discussion. Here the geometry, meshing and other important field variables like velocity and boundary condition have been discussed. The fourth section is the concluding section of the present work. This section lists the various outcomes of the numerical modelling followed by references and the acknowledgment.

2. Problem formulation
The crashworthiness of the automobile can be increased by improving the geometry factors involved in the design of the automobile. Another factor which helps to improve the crashworthiness of the automobile is the material optimization [9]. As SEA is the measure of the crashworthiness, so the lightweight materials are the good candidates for the crashworthiness. The present work deals with material optimization of the automobile’s body panel. The crashworthiness of body panel made of HDPE/kenaf and HDPE/MWCNT have been investigated in ANSYS 16.0 (explicit dynamics module). Where the automobile is made to strike on a structural steel pole. The strength model of the polymer composites is based on the tensile yield strength and the tensile ultimate strength in the ANSYS-workbench environment.

2.1 Proposed algorithm
Following computational algorithm has been implemented to test the crashworthiness of the HDPE/kenaf and HDPE/MWCNT polymer composites.
   a. Generation of the body panel in SolidWorks 2011.
   b. Providing material inputs in ANSYS-engineering data.
   c. Import geometry to explicit-dynamics.
   d. Generation of a rigid pole in the design module.
   e. Assignment of material, boundary condition, mesh generation, analysis setting in the mechanical module.
   f. Solution and results generation.
3. Results and discussion

3.1 Geometry and modelling
Figure 1 shows the geometry of the model along with the pole on which the impact occurs. The model of automobile (body panel) shown represents the entire body panel of the automobile. For modelling the body panel, a much-known design tool, SolidWorks 2011 has been used. CAD geometry of the body panel is then imported to ANSYS 2016 (explicit dynamics module). The dimensions of the body panel are 300×150×90 mm³ (length×width×height). The dimensions of the body panel have been scaled down to reduce the meshing complexity. Thereafter the pole, on which the impact has to occur, is modelled in design module in ANSYS workbench.

![Figure 1. Geometry of the model along with a pole.](image)

![Figure 2. Meshed model.](image)

The radius and height of the modelled pole are 10 mm and 160 mm respectively. The shortest distance between the bumper of the body panel and the pole is 7 mm. Figure 2 shows the complete meshed model in ANSYS-mechanical module. The meshing of the model is done with the default mesh in the mechanical module. Default mesh option generates the mesh size based on the full model geometry, so as to give the optimal solution time. The default option generated 2689 nodes and 8665 elements for the body panel and 560 nodes and 378 elements for the pole.

3.2 Boundary Conditions
The body panel moves with a constant velocity of 15 m/s in the positive Z-direction (towards the pole). It is assumed that there is no air friction on the body panel, and the body panel moves with the constant velocity before the impact. Hence, the conversion of energy takes place at the point of impact between the body panel and the pole. The bottom side of the pole on which the impact occurs is kept as fixed and the upper side is kept free. This is to resemble the situation where the automobile impacting on a tree or a pole.

3.3 Analysis settings
Low-velocity impacts are those where the impact velocity is less than 10 m/s. High impact situation has impact velocity higher than 50 m/s, so the present impact situation comes under the category of the intermediate impact velocity. Such explicit dynamic situation requires more than $10^5$ computational cycles, thus the computational cycles for the present work are set as $10^7$ with the maximum energy error of 0.1. To save computational time all the impact cases have been studied for the time period of 1 ms.

3.4 Material properties
In this work, three different materials have been chosen. The material for the pole is kept fixed as structural steel. Material properties of the structural steel are taken from the ANSYS material library. Two different materials for the body panel have been chosen as (a) HDPE/kenaf and (b) HDPE/MWCNT. Density and Poisson’s ratio of HDPE/kenaf and HDPE/MWCNT are calculated using the rule of mixture. Equation 1 and 2 shows the rule of mixture for the density and Poisson’s ratio respectively. Density and Poisson’s ratio of matrix and reinforcement have been taken from the literature.
and then the final value of density and Poisson’s ratio for the composite has been calculated [12–14]. Young’s modulus, tensile yield strength and tensile ultimate strength of both the polymer composites have been predicted using the experimental analyses. Composites were processed by the microwave energy. The weight percentage of reinforcement is 20 %. ASTM D3039 has been followed for the tensile test of the prepared specimens. By the tensile test various mechanical properties have been predicted, which have been used for the present work. Bulk modulus and shear modulus of the composites have been calculated using equation 3 and 4, respectively. Table 1 shows the various material inputs for numerical simulation.

\[ \rho = \rho_m \times V_m + \rho_r \times V_r \]  
(1)

\[ \nu = \nu_m \times V_m + \nu_r \times V_r \]  
(2)

\[ K = \frac{E}{3(1-2\nu)} \]  
(3)

\[ G = \frac{E}{2(1+\nu)} \]  
(4)

Table 1. Material properties.

| Property                  | Materials      | HDPE/kenaf | HDPE/MWCNT | Structural steel |
|---------------------------|----------------|------------|------------|-----------------|
| Density (Kg/m³)           |                | 800        | 1136       | 7850            |
| Young’s modulus (GPa)     |                | 1.8        | 1.25       | 200             |
| Bulk modulus (GPa)        |                | 2.6        | 1.74       | 166.67          |
| Shear modulus (GPa)       |                | 0.65       | 0.45       | 76.92           |
| Poisson’s ratio           |                | 0.38       | 0.38       | 0.33            |
| Tensile yield strength (MPa) |            | 12         | 10         | 250             |
| Tensile ultimate strength (MPa) |        | 18         | 19         | 460             |

3.5 Effect of material on the equivalent (von Mises) stress

Figure 3 shows the equivalent (von Mises) stress with respect to time when the body panel strikes the pole at the (a) center, (b) left side and (c) right side. It can be seen from figures 3 (a, b and c) that the equivalent (von Mises) stress of the body panel made of HDPE/kenaf polymer composite is higher than HDPE/MWCNT. It is due to the fact that the HDPE/kenaf polymer composite has higher Young’s modulus than HDPE/MWCNT polymer composite. Also, the HDPE/kenaf has a higher ductility than HDPE/MWCNT; hence, the yielding of HDPE/kenaf takes place at higher stress than the yielding of HDPE/MWCNT. Therefore, the strength of the HDPE/kenaf is more than the strength of the HDPE/MWCNT polymer composite.

From figure 3 (b and c) i.e. the impact occurring on the left and right side of the body panel, it can be observed that the equivalent (von Mises) stress for the HDPE/MWCNT is less as compared to the impact occurred at the center (figure 3 (a)) of the body panel. It may be due to the fact that at the corner sides there is stress concentration due to the geometry of the body panel. Hence, the stress generated at the time of impact in corners is higher than the stress generated in other parts of the body panel. Therefore, the material yields at lower equivalent (von Mises) stress in the corners as compared to other parts of the body panel. For HDPE/kenaf, it can be observed that there is not much change in the equivalent (von Mises) stress at the left and right side as compared to the center. It may be due to the higher ductility of the HDPE/kenaf than the HDPE/MWCNT. Hence, the effect of stress concentration at the corners is not that strong as that the case with the HDPE/MWCNT polymer composite. Therefore,
there is not the appreciable change in the equivalent (von Mises) stress for the HDPE/kenaf at the different impact positions.

Figure 3. Equivalent (von Mises) stress with respect to time at (a) center, (b) left and (c) right side.

Figure 4. Directional deformation with respect to time at (a) center, (b) left and (c) right side.
3.6 Effect of material on the directional deformation

From figure 4 (a, b and c) it can be observed that the deformation in the body panel made up of HDPE/MWCNT is more as compared to the deformation of body panel made up of HDPE/kenaf polymer composite. Negative deformation shown in the figures means the deformation occurring in the negative Z-direction. It may be due to the fact that as Young's modulus of the HDPE/kenaf is more than that of HDPE/MWCNT, hence, for the same loading for the two materials HDPE/MWCNT undergoes larger deformation. Another important thing which can be observed from figure 4 (a, b and c) that the deformation occurring at the left (figure 4 (b)) and right side (figure 4 (c)) is less than the impact occurring at the center (figure 4 (a)) of the bumper. It is due to the material present at the corners. There is more material at the corners to suppress the deformation at the corners of the bumper. Hence, there is more deformation at the center of the bumper than at the corners.

Directional deformation contours at the end of analysis time have been shown in figure 5-10. Figure 5 (a and b), figure 6 (a and b), and figure 7 (a and b) shows the side and top view of deformation contour of HDPE/MWCNT when impacted at center, left side and at the right side of body panel respectively. The deformation contours by the side view and top view of the body panel of HDPE/kenaf when impacted at center, left side and at the right side has been shown in figure 8 (a and b), figure 9 (a and b) and figure 10 (a and b) respectively.

Figure 5. Directional deformation contour of HDPE/MWCNT when impacted at center (a) side view and (b) top view.

Figure 6. Directional deformation contour of HDPE/MWCNT when impacted at left side (a) side view and (b) top view.
Figure 7. Directional deformation contour of HDPE/MWCNT when impacted at right side (a) side view and (b) top view.

Figure 8. Directional deformation contour of HDPE/kenaf when impacted at center (a) side view and (b) top view.

Figure 9. Directional deformation contour of HDPE/kenaf when impacted at left side (a) side view and (b) top view.

Figure 10. Directional deformation contour of HDPE/kenaf when impacted at right side (a) side view and (b) top view.
4. Conclusions
The present work deals with the comparative numerical analyses of crashworthiness for the body panel made of HDPE/kenaf and HDPE/MWCNT polymer composite. Effect of body panel’s material on the equivalent (von Mises) stress and the directional deformation has been investigated. The following conclusions can be drawn from the presented numerical modelling:

- The body panel made of HDPE/kenaf polymer composite induces comparatively higher equivalent (von Mises) stress.
- In the case of impact occurs at the center of the bumper, HDPE/kenaf polymer composite showed 6.25% less deformation as compared with the HDPE/MWCNT polymer composite. But when the impact occurred at the left side of the bumper, the deformation showed by HDPE/kenaf is 42.85% less than the HDPE/MWCNT polymer composite.
- It can be concluded on the bases of the equivalent (von Mises) stress and the directional deformation that the body panel made of HDPE/kenaf polymer composite has higher crashworthiness than the body panel made of HDPE/MWCNT polymer composite.

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Appendix

| HDPE/MWCNT | High-density polyethylene/multiwalled carbon nanotube-polymer composite |
|------------|--------------------------------------------------------------------------------|
| HDPE/kenaf | High-density polyethylene/kenaf fibre reinforced polymer composite |
| E          | Young’s modulus                                                                 |
| G          | Shear modulus                                                                   |
| K          | Bulk modulus                                                                    |
| V          | Poisson’s ratio of the composite                                                |
| v_m        | Poisson’s ratio of matrix                                                        |
| v_r        | Poisson’s ratio of reinforcement                                                 |
| \(\rho\)   | Density of composite                                                             |
| \(\rho_m\) | Density of matrix                                                                |
| \(\rho_r\) | Density of reinforcement                                                         |
| V_m        | Volume fraction of matrix                                                        |
| V_r        | Volume traction of reinforcement                                                 |

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