MODELING AND FINITE ELEMENT ANALYSIS OF SIDE BODY IMPACT BEAM OF A PASSENGER CAR

Beruk Hailu a, T.Ashokkumar a*

a Department of Mechanical Engineering, Institute of Technology, Haramya University, P.O Box 138, Dire Dawa, Ethiopia.

Abstract: The study uses process-based cost modelling to gain insights into the cost-feasibility of a new fiber-reinforced composite body-in-weight against the existing steel design. The results show that the potential for fiber-reinforced composite bodies-in-weight to be competitive against steel is greater than it has been in the past. However, while this paper demonstrates that composite technology is an economically viable alternative from the perspective of composite BIW production economics, there are many additional issues (Such as: cost of owner-ship concerns such as repair costs, environmental concerns such as recyclability, and safety concerns including the public perception that composites are less safe that matter the acceptance of composites in wide range. The paper deals the modelling and finite element analysis of side body impact beam of a passenger car.

Key words: Modelling, crashworthiness, Optimization, Composite Structures, finite element analysis

1. INTRODUCTION

Automobile body structure is the core element of passenger safety. The car body comprises of different components. It houses the drive train and most importantly carries and protects passengers and cargo. The body structure needs to be rigid to support weight and stress, and to securely tie together all the components. Furthermore, it must resist and soften the impact of a crash to safely protect the occupants. In addition, it needs to be as light as possible to optimize fuel economy and performance as well as reduced gases emission [1], [2] & [3]. Although the quantity of rear impacts is much less than the number of front or side impacts, the whiplash injuries caused by these types of accidents are complicated, hard to recover from, and can cause fatalities. For safety against rear impact, special attention must be given to the structural integrity of the fuel tank and fuel lines, seat resistance especially seat backs, and to head restraints. For rear impacts, vehicle designs are regulated by FMVSS 224 in the U.S., by CMVSS 224 in Canada, and by ECE R-42 in Europe [4], [5]. In rollover accidents, the whole vehicle structure along with vehicle interior must protect occupants from injuries. Seat belts are particularly important in these accidents and the roof must provide resistance to deformation. During rollover accidents, the doors must not open by themselves and special valves must ensure that fuel lines are closed and fuel ventilation is directed to a charcoal canister to preventer hazards [2]. The lightweight composite materials are already finding the exciting break in the automotive field as a means to increase the fuel efficiency. The vehicle weight directly contributes about 75 percent of fuel consumption. The vehicle industry can anticipate an aggressive 6 to 8 percent reduction in fuel consumption with 10 percent decrease in vehicle weight. This reduces around 20 kilogram of carbon dioxide emission per kilogram reduction in weight over the vehicle’s lifetime [6]. A number of safety benefits have been identified for composites, including the high Specific Energy Absorption (SEA) and specific strength being translated into the ability to prevent intrusion. The safety benefits of composites can be divided into two general classifications based on their usage. The first classification includes structural components that may be used to absorb energy during an impact, either with another vehicle or with a stationary object. For such structures, the property that is being exploited using...
Composites are less safe (1). The orthogonality of the vehicle structures is limited by the key limitation scale economics limits polymer strategies, technologies to achieve high specific stiffness and high tensile strength. The results show that the potential for fiber reinforced composite body structure in a hypercar, I.J.R.A.R. (2018) (2), describes the design, fabrication, and assembly approach used for the carbon fiber reinforced composite body structure in a hypercar. The study uses process based cost modeling to gain insights into the cost feasibility of a new fiber-reinforced composite body-in-white design against the mild grade steel body currently on the road. The study shows that the potential for fiber-reinforced composite bodies-in-weight to be competitive against steel is greater than it has been in the past. However, while this paper demonstrates that composite technology is an economically viable alternative from the perspective of composite BIW production economics, there are many additional issues such as: cost of owner-ship concerns such as repair costs, environmental concerns such as recyclability, and safety concerns including the public perception that composites are less safe that matter the acceptance of composites in wide range.

The paper deals the modeling and finite element analysis of side body impact beam of a passenger car.
2. EXPERIMENTAL STUDY

Beruk Hailu and Ashokkumar T, 2018 have designed a new Accident proof material for B-pillar of a car and also develop material property for the side body structure of sedan passenger car [12 and 13]. Side impacts result in additional safety threats to vehicle occupants because of the minimal available crush space in the side structure of a vehicle. While the mass of a side-impacting vehicle directly affects the kinetic energy that must be absorbed, the compatibility of the impacting vehicle, both in terms of vehicle height as well as the stiffness and crush force of the impacting vehicle are also of high importance. More detailed testing is required to investigate which characteristics are most important in defining safety risks from side impacts. Greater reinforcement of the occupant compartment and installation of side curtain airbag offer increased protection to such side impacts. The key parameters affecting the prevention of intrusion under such impacts are the strength of the passenger compartment and the height and crush strength of the colliding object. Consider, however, the case of a vehicle impacting a stationary object. The heavier the vehicle is, the greater the kinetic energy that must be absorbed by the vehicle’s crush structure. Thus, higher mass vehicles require crush structures with greater energy absorption capacity to produce the same level of safety as lower mass vehicles. For any vehicle mass, an increase in the crush distance provides additional protection to the vehicle occupants, as discussed in the following section.

2.1 Modeling and analysis of door side impact beam

The strength of the beam depends on the section modulus. Section modulus (Z) is defined by Z = I/Y-max, I=Moment of Inertia, Y-max=distance from the Neutral axis. The common sections used for side impact beam are circular tubes, C sections, and rectangular tubes as discussed in element level analysis. In all these sections resistance to the deformation is increased by increase in the thickness. The proposed beam to design is in accordance to fit the existing door with dimensions of 1080mm height, 1100mm outer skin width and 1000mm, 650mm height to glass. The beam contains the double curved side wings which offer additional strengthening, which cause the deflection to decrease. Some part of the beam is under tension and some part of the beam under compression, so that the spring back effect is more in such a type of cross sections. The largest proportion of the beam absorbed energy, taken upon by side wings is in plastic range of the material deformation. It is expected that the side wings will curve inward under the applied load. Smooth passage from one cross section to the other ensures that high stress concentration is avoided [2].

2.2 Geometric modeling of anti-intrusion side impact beam

Three-dimension view of Side Impact Beam is shown in Figure 1. The side impact beam with a dimension of 900 mm length and 110 mm width. The strengthening region, where highest deflection and stress are expected and was chosen regarding to the position of the applied load. The beam cross section is shaped like double- hat section. It is 35 and 20 mm wide in narrowest section and 55 mm wide in widest section. The thickness of the three dimensional is 2.00 mm for steel and 4.32 mm for carbon fiber composite and is constant throughout the whole structure.
2.3 MATERIAL MODELING

Shell elements are quite similar to beam elements in the sense that they also have both degrees of freedom - displacements and rotations. Shell elements are typically taken to model a structure subjected to a bending load that is thin in two dimensions relative to a third. When a thin structure is idealized using shell elements one should know the following: by means of shell elements one actually predicts the structural behavior of the mid surface of the thin structure.

The Steel plate was modeled in ANSYS using a SHELL63 element for the steel plate analysis because the element has both bending and membrane capabilities and is widely used for a linear elastic analysis. Each node of the element has six degrees of freedom, three translational degrees of freedom and three rotational degrees of freedom. In order to model the layers of the composite plate, the SHELL181 element was used to create the finite element model in ANSYS. The SHELL181 element is similar to the SHELL63 element in that they are both 4 nodal elements with six degrees of freedom at each node. The result is the best one, since the effect of shear stresses is also included in the analysis. The materials that to be modeled for the study is structural; linear elastic; orthotropic for carbon/epoxy composite material and isotropic for traditional steel materials. This type of material modeling helps predict statistical analysis result at elementary level before dynamic analysis.

The carbon fiber composites are light weight material because of its low density. The mechanical properties of the carbon fiber are very much suitable as they have high impact energy absorption before fail and also they have high strength requirements. The mechanical properties of the carbon fiber composites can be changed according to the requirement by changing orientation of the fiber in the loading direction, layer stacking and by changing the volume fraction of the fiber and the matrix. Carbon fiber composite can sustain for the same load as of steel even with the 40 times of the steel weight. The carbon fiber composites have very high specific strength and specific stiffness when compared to steel. The material properties of steel is shown Table-1, Carbon Fiber-epoxy resin Laminate with Vf = 60% is shown in Table-2. Beam Model summary is given in Table-3. Carbon/epoxy composite side Impact Beam with Mesh is shown in Figure-2.
Table 1: Material Property for Steel

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Density</td>
<td>7.8 g/cm³</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>200 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Yield Stress</td>
<td>215 Pa</td>
</tr>
</tbody>
</table>

Table 2: Material Properties for Carbon Fiber-epoxy resin Laminate with Vf = 60%

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Density</td>
<td>1.58 g/cc</td>
</tr>
<tr>
<td>Longitudinal Modulus E1</td>
<td>142 GPa</td>
</tr>
<tr>
<td>Transverse Modulus E2</td>
<td>10.3 GPa</td>
</tr>
<tr>
<td>Transverse Modulus E2</td>
<td>10.3 GPa</td>
</tr>
<tr>
<td>In-plane Shear Modulus G12</td>
<td>7.2 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.27</td>
</tr>
<tr>
<td>Longitudinal Ultimate Tensile Strength σ1t</td>
<td>1575 Mpa</td>
</tr>
<tr>
<td>Transverse Ultimate Tensile strength σ2t</td>
<td>73 MPa</td>
</tr>
<tr>
<td>In-plane shear Strength σ12</td>
<td>90 MPa</td>
</tr>
<tr>
<td>Longitudinal Ultimate Compressive Strength σ1c</td>
<td>954 MPa</td>
</tr>
<tr>
<td>Transverse Ultimate Compressive Strength σ2c</td>
<td>185 Mpa</td>
</tr>
</tbody>
</table>

Figure 2: Carbon/epoxy composite side Impact Beam with Mesh
3. RESULTS AND DISCUSSION

FE analysis used to determine critical section requirements to achieve side impact intrusion/energy absorption. Door beam maximum resistance of intrusion or crush load and displacement targets predicted. Rocker beam structural stability achieved to facilitate high confidence in achieving required side impact occupant injury level criteria. The geometric modeling of the side impact beam is done by using ANSYS bench work and mesh, boundary conditions, material properties and section properties are defined using ANSYS Mechanical APDL/LS_DYNA. The beam is uniformly meshed with 10 mm element size. The beam is meshed with shell 3D 4-node 181 for elements. The ends of the beam are constrained in all degree of freedom or both in 3-translational and 3-rotational. The next step is to analyze the response of the laminate beam under different loadings and with different fiber orientations. Figure 3 shows the laminated beam constrained at one end and free at the other end. There is a force 10KN in the Y-direction at the free edge of the beam.

<table>
<thead>
<tr>
<th>Element Length</th>
<th>10mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>4023</td>
</tr>
<tr>
<td>Number of Elements</td>
<td>2198</td>
</tr>
</tbody>
</table>

Figure 3: Side impact beam with Fixed-Fixed Boundary Conditions Loaded with Fy =10KN

3.1 Steel side impact beam Response for a Transverse Point Load in Y-direction

Figure 4: Displacement in the Y-Direction Due to Fy=10KN
It is observed from Figure-4 that maximum displacement in force direction /Y-direction at the bottom of the steel impact beam. This is resulted in large intrusion toward the inner compartment of the door.

It is observed from Figure-5 that Von Misses Stress Distribution and the maximum equivalent stress result due to Fy=10KN at the bottom of the steel impact beam. The result shows that steel beam responds to the applied load by deforming beyond its plastic limit. Therefore, its deformation is permanent deformations.

It is observed from Figure-6 that Von Misses Strain Distribution Due to Fy =10KN shows that the maximum strain rate along the force direction at the bottom of the steel impact beam.

It is observed from Figure-7 that The energy absorption of the steel impact Beam
From the Figure-7 it is observed that Strain energy Distribution to absorb the external work done by $F_y = 10\text{KN}$. shows that the maximum strain energy along the force direction at the bottom of the steel impact beam.

### 3.2 Carbon/epoxy composite impact beam response for a Transverse Point Load

Because the beam was loaded with a force in the $Y$-direction, displacement in the $Y$-direction was used to compare how the stiffness of the beam changed with orientation angle.

![Figure 8: Displacement in the $Y$-Direction for a [0/±45/90]$s Due to $F_y = 10\text{KN}$](image)

It is observed from Figure-8 that maximum displacement in force direction /$Y$-direction at the bottom of the impact beam. This is resulted in lesser intrusion toward the inner compartment of the door.

![Figure 9: Von Misses Stress for a [0/±45/90]$s Due to $F_y = K10\text{N}$](image)

From the figure-9 above it is observed that Von Misses Stress distribution and the maximum equivalent stress result due to $F_y = 10\text{KN}$ at the top of the composite impact beam. The result shows that composite impact beam responds to the applied load by deforming within its elastic limit. Therefore, the result indicates it is safer than steel beam.
There are a number of important observations from Figure-10 and 11:

1. The stress in the bottom layers was constant over the length of the composite impact beam for a given fiber orientation in the outer layers. Because the fibers are perpendicular to the applied force and are not stressed axially. It is the matrix material that experiences the higher levels of stress.

2. Conversely, the stress in the outer layers was not constant over the length of the beam for a given orientations angle. In the above figure, the stress in the outer layers is plotted in two locations: at the fixed end of the beam at that middle of the beam. The two locations reach a relative maximum and minimum stress at opposite locations.

Figure 10: Von Misses Strain for a [0/+-45/90]s Due to Fy=10KN

As with the Von misses stresses, there are a few important observations from the strain plot:

1. The strain in the inner layers is not constant over the length of the beam. Strain at the fixed end of the beam reaches a maximum value at low orientation angle at the bottom of the beam and remains elevated until all of the fibers of the beam begin to align with the mid plane fibers. However, further away from the fixed edge, the strain in the inner layers is not affected by the angle of the outer layers. At approximately L/4 away from the fixed edge, the strain in the inner layers becomes constant.

2. The strain at the end of the beam is not plotted because it is the same as the strain in the inner layers of the beam away from the fixed end. Strain at the end is minimal because it is displacing more than it is changing length.
4. CONCLUSIONS

- The laminate is to be designed for maximum flexible structure with minimum stress and stiffness. The recommended orientation angle for the outer layers is approximately 40°-65°.
- The laminate is to be designed for maximum rigidity and toughness, such as car body structures and frame. The recommended orientation angle for the outer layers is 0°-30°. In this orientation angles, strain, displacement, and stiffness are minimized. However, stress is very high, so a more thorough failure analysis must be done.

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