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A New Accident Proof Material Design for B - Pillar of A Car

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Abstract : Side impact is the second most frequent mode of accidents. It is defined as the incident when a striking vehicle hits a target vehicle in the area of one or more of its A ,B ,C - pillars, and doors during which the kinetic energy is transformed into deformation of both vehicles. The capability of impact energy absorption in B- pillar is discussed in the study. Analyses on the performance of pillars in side crashes include displacement and intrusion or deformation extent of structures and analysis of maximum induced stress. This study results indicate that the carbon/epoxy composite side impact pillars have considerable potential for reducing occupant injuries. The present results are compared with solutions available in the literature and obtained by the help of AUTODESK COMPOSITE SIMULATION and ANSYS software. The AUTODESK COMPOSITE SIMULATION software has also a composite workbench used to model the composite ply lying to analyze the carbon composite body structure at coupon or elemental level to find the correct material data.
Key words : A B C Pillars, carbon/epoxy, Steel, Accident proof, Finite element.

1. Introduction

The strain energy (toughness) of the side pillers plays a major role in occupant's safety, i.e., it must be strong to resist intrusion. The pillers are important in controlling the deformation to protect the occupant. The inside layout is an important factor as well in minimizing injuries due to interaction between the occupant's body and the vehicle interior. For side impacts, vehicle designs are regulated by FMVSS 214 in the U.S., by CMVSS 214 in Canada, and by ECE R-59 in Europe [1], [2].A- B-and C-pillar and upper and lower rails reinforcements Composite inserts were applied to the A- and B-pillars and the thickness of steel pillars was reduced. Both pillars were gauged down 20%. The crash performance of composite inserts in vehicle structure was studied by Park *et al*. [3]. The light-weighted A- and B pillars were evaluated by component tests which show that their crash performance is equivalent to the originals. The 35% glass reinforced polyamide is also applied to door beams, transmission crossbeam, and oil pans along with design changes. The new modeling is intended to develop and demonstrate the use of carbon fiber composite structures to generate significant weight savings for an automobile and safety. For the structural analysis of the impact beam and B; Pillar, Finite Element Method was used since it is the most widely used computational method in the automotive industry. Steel is still used as the material for this component. However, lighter materials such as the Fiber Reinforced Plastics (FRP) are initiated in the automotive industry. FRP can be used as a substitute for steel

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for this component as they offer higher energy absorption than the steel. As discussed earlier Composites have high strength and stiffness; to; weight ratio in the fiber direction and as well as the in the direction perpendicular to the fiber even though their Young's Modulus is lesser than the steel. This means that the composites have an increased thickness than the steel and larger second moment of inertia to reduce the effect of elastic bending. There are also some disadvantages of composites, which includes higher production and tooling costs, whereas processing of the complex parts in one piece is much easier. Also, by using composites as the materials for the B; Pillar, reduction in weight can be observed which lead to lesser fuel consumption. The composite material was for the first time introduced to the formula-1 in 1980 by McLaren[4]team. Since then the crashworthiness of the racing cars has improved beyond all recognition. They used the carbon fiber composite to manufacture the body, which is low weight, high rigidity and provided the high crash safety standards [5]. Fuel efficiency of the vehicle directly depends on the weight of the vehicle. The carbon fiber composite body structure is 57% lighter than steel structure of the same size and providing the superior crash protection, improved stiffness and favorable thermal and acoustic properties [6]. The level of fragmentation, corresponding to the fineness of the debris created, determines the level of energy absorption. One widely quoted source of comparison data lists the Specific Energy Absorption (SEA) for carbon thermo set composites at more than 100 kJ/kg (33.5 x 103 ft-lb/lb), compared to an SEA of approximately 30kJ/kg (10.1 x 103 ft-lb/lb) for aluminium and 20 kJ/kg (6.7 x 103 ft-lb/lb) for steel.[7], [8]. finite element analysis was carried out to model the crushing process of continuous; fiber; reinforced tubes by Farley et al [9]. The method obtained a reasonable agreement between the analysis and the experiment. Thornton et al.[12] examined the energy absorption capability in graphite/epoxy, Kevlar/epoxy and glass/epoxy composite tubes. The composite tubes collapsed by fracture and folding mechanisms. The load compression curves for the graphite/epoxy and the glass/epoxy tubes had similar characteristics but the Kevlar/epoxy composite tubes collapsed by buckling [10]. Farley[9] investigated the geometrical scalability of graphite/epoxy by quasi; statically crush testing them. All circular cross section graphite/epoxy exhibited a progressive brittle fracturing mode. It was found that carbon/epoxy exhibited large changes in their energy absorption characteristics with a range of values of diameter (D), wall thickness (t) and (D/t) ratio. In this study, (D/t) ratio was determined to significantly affect the energy absorption capability of the composite materials [3].Previous studies by different researches show that the efficient design and increase use of composite materials into the automotive parts directly influences the car safety, weight reduction and gas emission, because the efficient design can absorb more deformation and composite materials have high specific strength (strength to density) and high specific stiffness (stiffness/density). The work presented in this paper differs from previous studies in several ways are applies new component and assembly modeling techniques using ANSYS-15 and AUTODESK COMPOSITE SIMULATION DESIGN and evaluates the competitiveness of carbon/epoxy composites against traditional steel A, B, C pillars.

2. Experimental Study

The model of the body has been designed using CATIA V5 R21. A conventional mild steel automotive side body panel of 4/5 passengers 4-door sedan car will be used for this studyto develop a sample model of composite body pillars. Detail dimensions of the metal body panel will be recorded and used as an initial data for its composite counterpart. Modeling simple vehicle structural components, for use both analytical and experimental approaches to study of the behavior of the composite body panel. Geometric modeling will be carried out using CATIA V5 R21 software as it has a capability to construct complicated surface shapes later converted in to solids. The AUTODESK COMPOSITE SIMULATION software has also a composite workbench used to model the composite ply lying to analyze the carbon composite body structure at coupon or elemental level to find the correct material data.

2.1 Design of side body A, B, C-pillar

Like doors, body pillars(A, B, C…) and rails are double skinned and the most sophisticated parts of the automobile body on which doors are hinged and locked. Therefore, components have to meet the design requirements and specifications.Figure1 shows the position of pillars in a car. There are two skins in the pillar, one is the outer skin and the other is the inner skin. These two skins are made of steel and they are welded together.The distance between the pillars and the occupant is very less in side impact when compared to the frontal impact with the crumble zone. In addition, when the impact occurs, the B- Pillar or structures in the B-Pillar has to absorb more energy with minimal deforming peed. The other A- and C-pillars have a reinforced by other body structures; like engine compartment or firewall structure and fuel thank on the rear respectively.

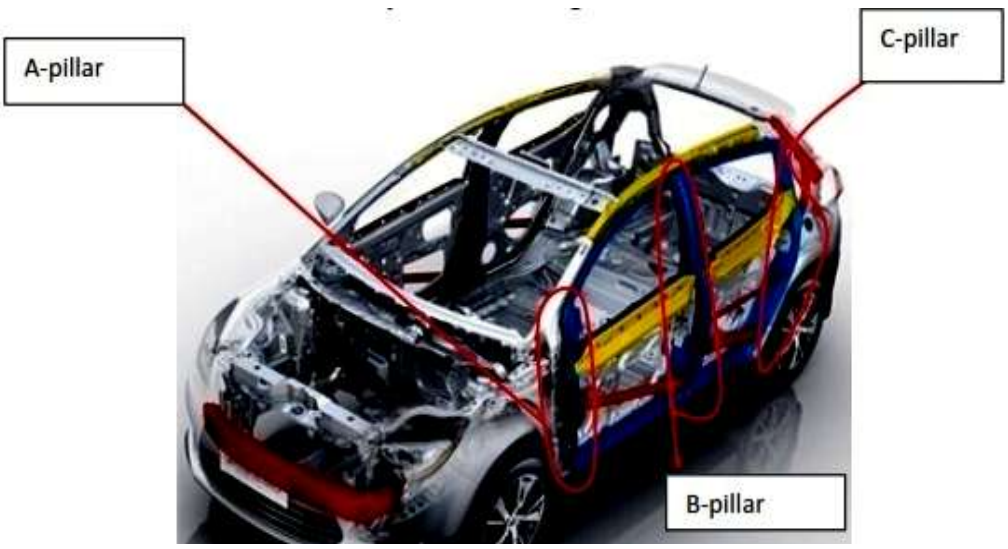

Figure 1 : Position of B-Pillar in a car

Because of very less distance between the B-Pillar and the occupant special care has to be taken in the design and manufacture of the B-Pillar. Safety is the main concern in this design.

In this study mainly focused on modeling and analyzing a composite B-Pillar to replace the present heavy steel pillar and thus reducing the weight of the car without sacrificing the safety of the occupant. As per the crashworthiness standards, which require minimal displacement and higher energy absorption, the use of composite in the safety B- Pillar is proposed and the efficacy of the B- Pillar designed is studied. There are several areas in the field of crash; impact dynamics that need to be studied to improve the crashworthy design of the B- Pillar. To date, there have been many contributions in understanding and analysis of the energy absorption characteristics. In this study, Finite Element Method is used as an alternative method in studying the energy absorption and stability of a B- Pillar.

3. Results And Discussion

3.1 Material modeling

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 new modeling is intended to develop and demonstrate the use of carbon/epoxy composite structures to generate significant weight savings for an automobile and safety. This study proposed variable thickness panels to maximize the structural efficiency at minimum mass. The wall thickness is constrained to be at 4.32 mm. As discussed earlier Composites have high strength and stiffness; to; weight ratio in the fiber direction and as well as the in the direction perpendicular to the fiber even though their Young's Modulus is lesser than the steel. This means that the composites have an increased thickness than the steel and larger second moment of inertia to reduce the effect of elastic bending. There are also some disadvantages of composites, which includes higher production and tooling costs, whereas processing of the complex parts in one piece is much easier. Also, by using composites as the materials for the B- Pillar, reduction in weight can be observed which lead to lesser fuel consumption.

3.2 Geometric modeling of side body A, B, C-pillar structures

The B-pillar with a dimension of 1120 mm length and 400 to100 mm tapered width. The strengthening region, where highest deflection and stress are expected and was chosen regarding to the position of the applied load. The B-pillar cross section is shaped like a box section made from hat-section since it is double skin structure. 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.

Curvature of a composite component increases the measured crush stress due to the support offered by the band tension/compression forces generated in the direction transverse to the crush loading. Typically this support increases the buckling force required to produce crushing, giving a higher crush stress. The 3-D CATIA Model with views are shown Figure 2

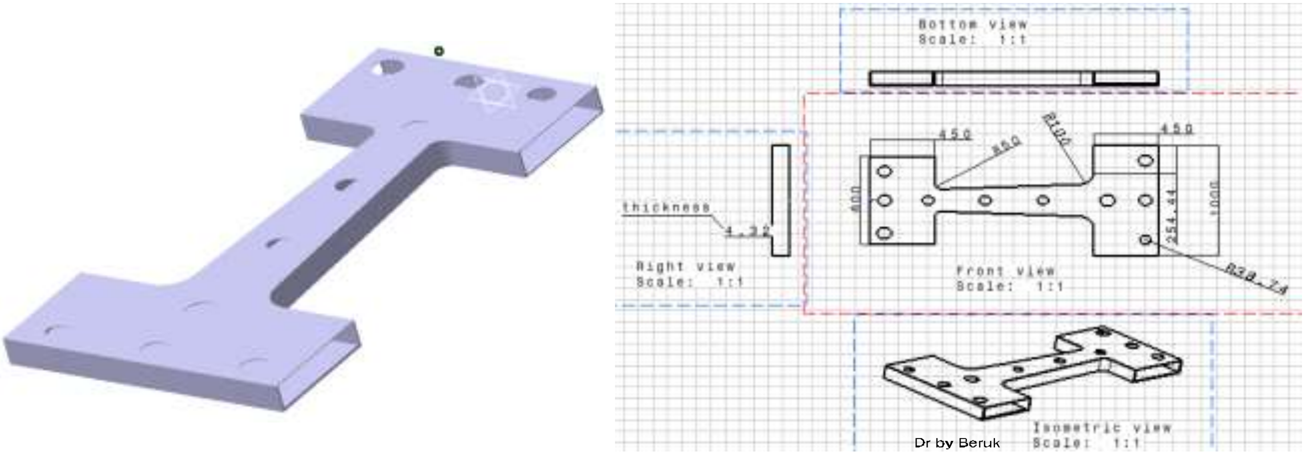

Figure 2: 3-D CATIA Model with views

3.3 Finite Element solution to side body A, B, C-pillar structure

The geometric modeling of the B-pillar 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 pillar is uniformly meshed with 10 mm element size. The pillar is meshed with shell 3D 4-node 181 for tetrahedron elements. The ends of the pillar are constrained in all degree of freedom or both in 3- translational and 3-rotational. The Finite

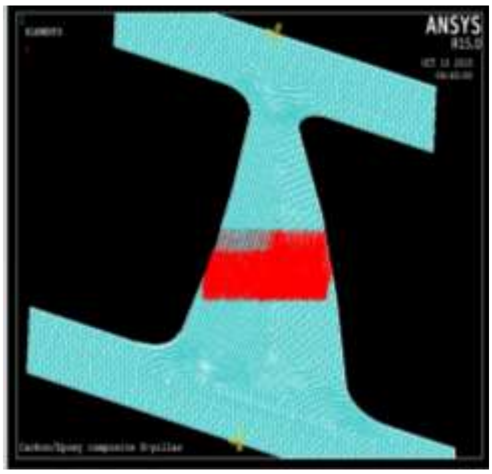

Figure 3: Finite Element model with applied loads and boundary conditions

Element model with applied loads and boundary conditions is shown in Figure 3.The next step is to analyze the response of the laminate pillar under different loadings and with different fiber orientations as the door side impact beam. The beam used is a 12-layer symmetric laminate with the dimensions show in figure 6. There is a force 10KN in the Z-direction at the free edge of the pillar. Composite B-pillar Response to a Transverse Point Load.

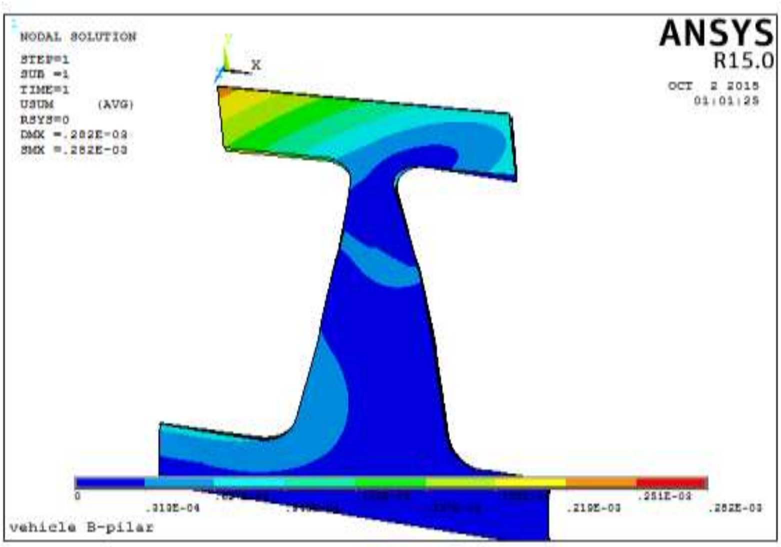

Figure 4: Displacement in the Z-Direction for a [0/+-45/90]s Due to Fz=10KN

From the figure 4 it is observed that the maximum displacement in force direction or Z-direction near the top of the B-pillar and the majority strikes energy disperses upward along the B-pillar to rails of both top and bottom. This is resulted in lesser intrusion toward the inner compartment of the car.

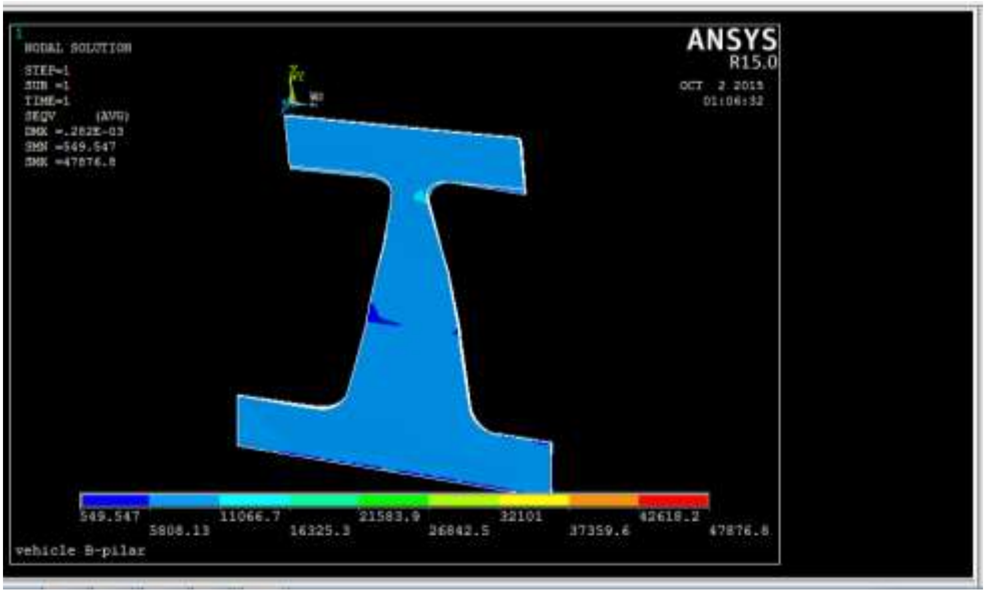

Figure 5: Von Misses Stress for a [0/+-45/90]s Due to FZ = K10N

From the figure 5 it is observed that Von Misses Stress distribution and the maximum equivalent stress result due to Fz=10KN at the top of the composite the pillar where it attached to the rail. The result shows that composite pillar responds to the applied load by deforming within its elastic limit. Therefore, the result indicates it is safer as the result shown in the door impact beam.

3.4 Optimization of the Composite side body structure

The ply orientation and the thickness of the composite beam and pillars are found out by simulating the composite beam and pillars for different orientation and different thickness to improve the required design parameters stated in 4.3mm which is shown in figure 6.

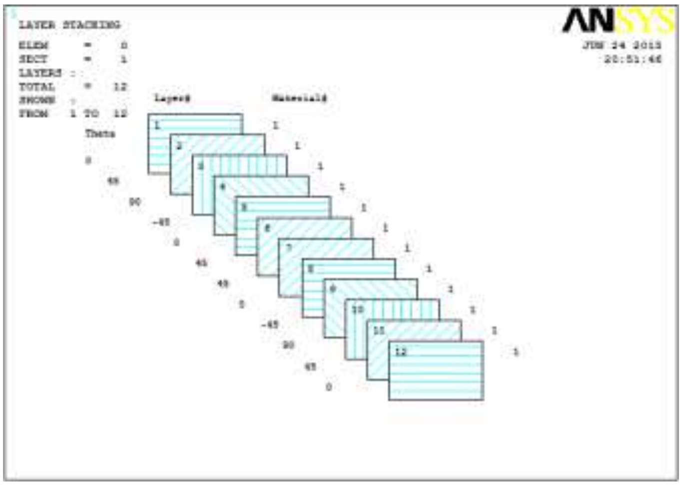

Figure 6: Carbon/Epoxy composite ply stack up

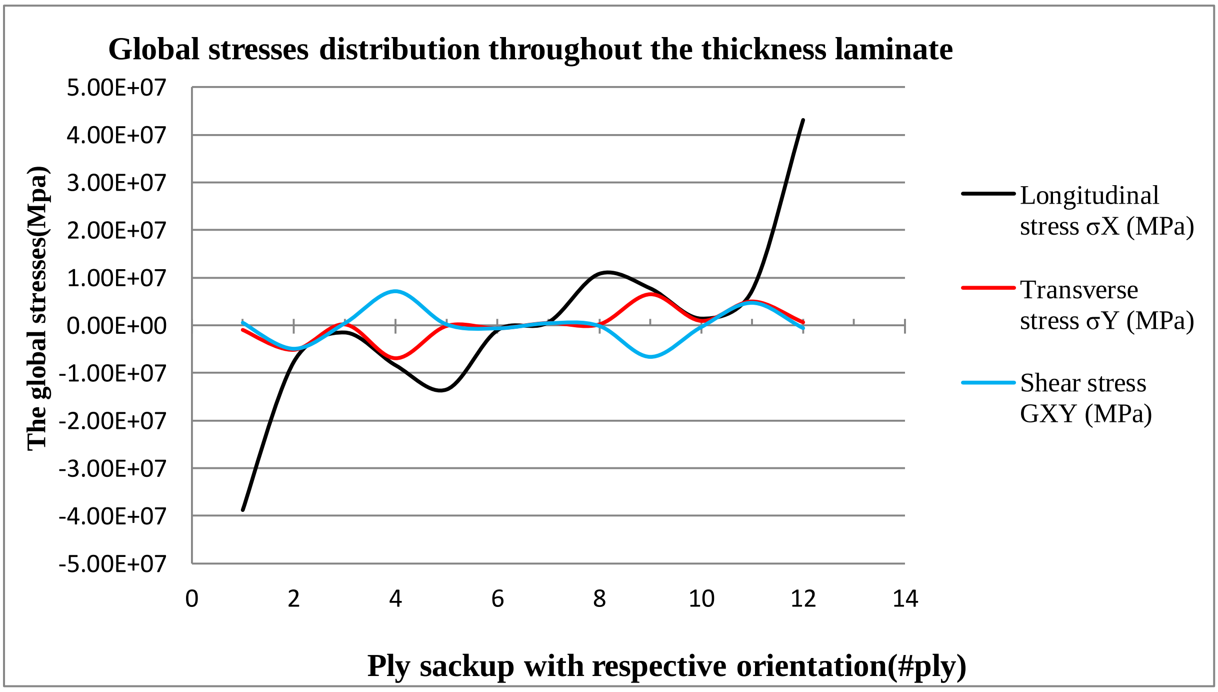

Figure 7: The global stress distributions curve

The global stresses of longitudinal stress, transverse stress, shear stress distribution with respect to ply is given in figure 7.

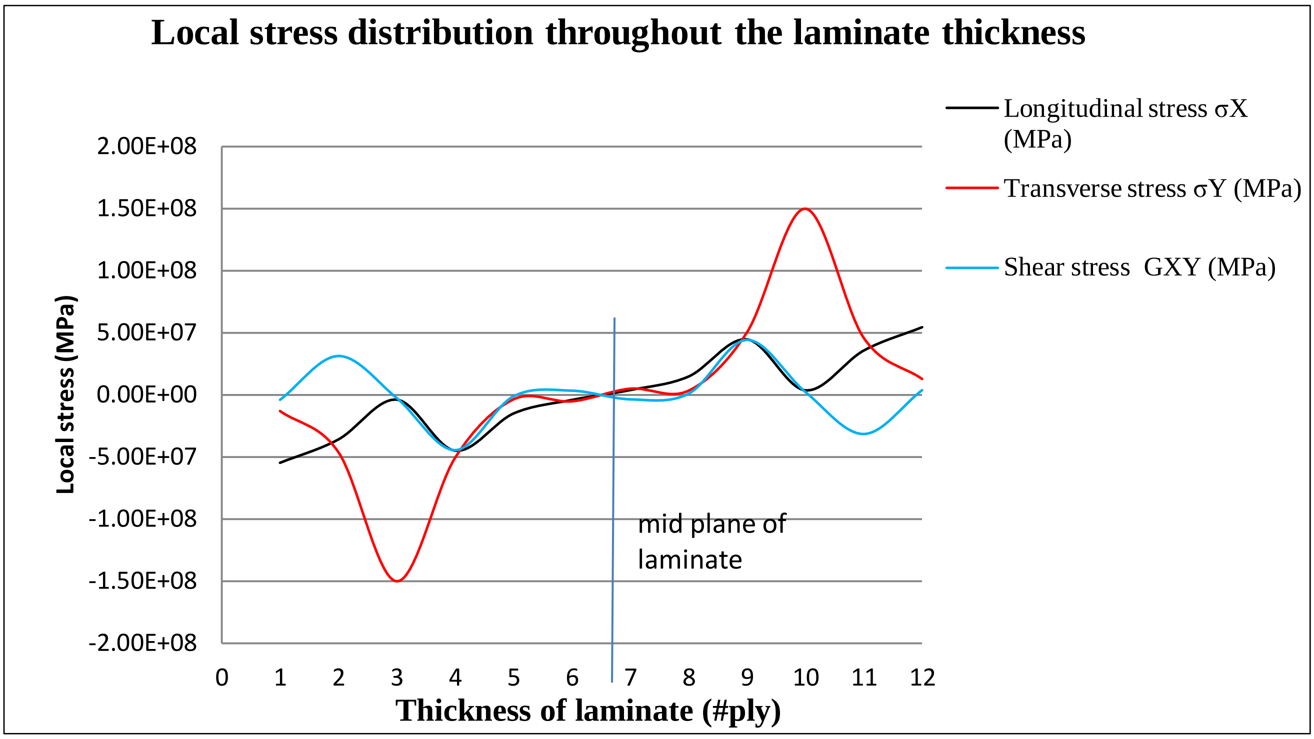

Figure 8 : **The local stress distributions curve**

The local stress distribution of longitudinal stress, transverse stress and shear stress with respect to laminate thickness is plotted in figure 8.

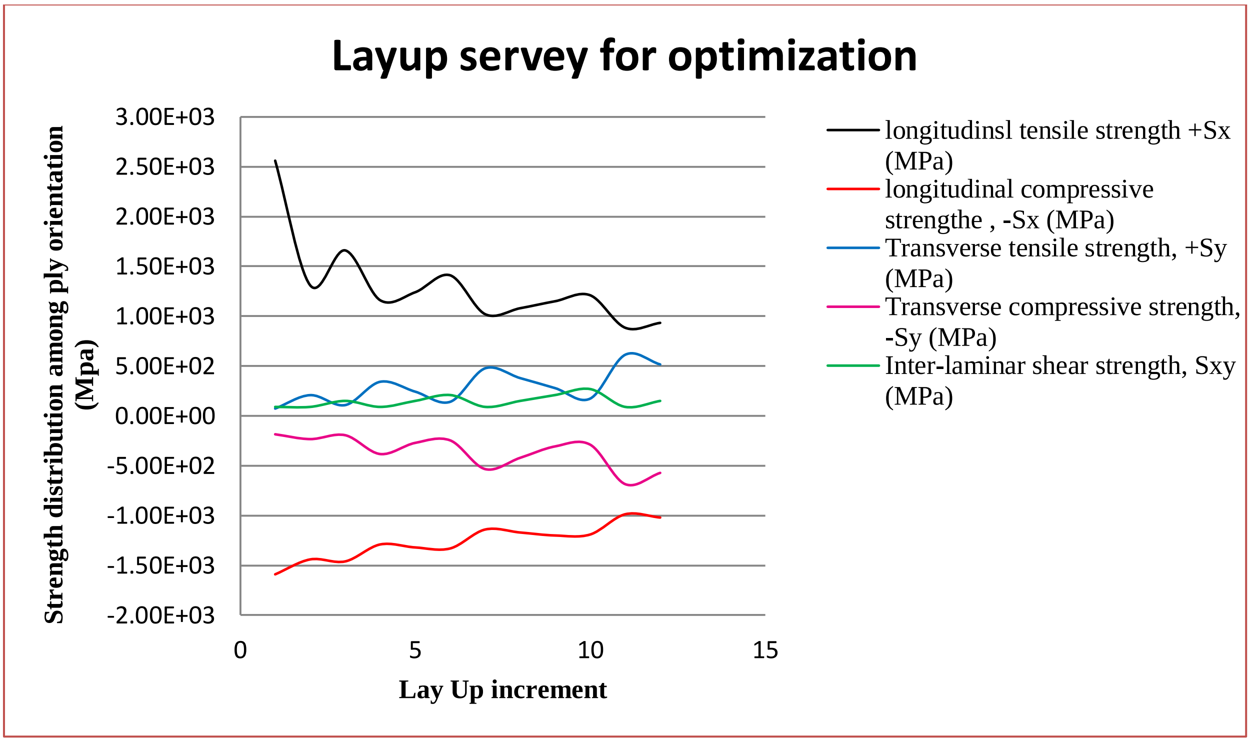

Figure 9 : The strength layup survey curve

The strength layup survey curve is plotted to find the optimum strength result which is given in Figure 9.

3.5 Analytical Calculations for Carbon/Epoxy composite and steel

Consider 1330 kg vehicle mass traveling at 54Km/h or 33.5 mph or 15 m/sec is colliding with a pole or rigid barrier on its B-pillar get crash. Carbon/Epoxy composite B-pillar dimensions except the thickness are the same with the steel: where L (length) =900mm, W (width) = 110mm, and T (thickness) = 2.00mm for steel and 4.32mm for composite side impact beam as well as B-pillar. B-pillar absorbs the impact energy through deformation.

Maximum strain energy (in form of plastic deformation) a material can store per unit volume is toughness.

$$U_{max} = \frac{1}{2}\frac{\sigma_{ult}^2}{E} \quad (1)$$

Where, σ_{ult} = ultimate strength of the material that the maximum stress induced in the material to respond for critical applied load

E = the material elastic modulus

U_{Max} = strain energy for a given volume to respond.

For maximum strain energy stored a material must have high strength. Considering the representative values for IM7-Carbon/Epoxy composite and 1025 Steel materials and each material deforms until ultimate point [11]. The Comparison of energy absorption for composite and steels are listed in Table 1.

Table 1 : Comparison of energy absorption for composite and plastic materials

Material	**σ_{ult} (MPa)**	**E (MPa)**	**U_{Max} strain energy (MN/m2)**
IM7-Carbon/Epoxy composite Vf = 60%)	1575.6	11592	107.08
1025 Steel	215	200000	0.116

For the same unit volume, IM7-Carbon/Epoxy composite material absorbs more strain energy (toughness) than Steel. Therefore, based on strain energy absorption approach, composite material is better than steel.

Ø The kinetic energy of the car is:

$$K.E = \frac{1}{2}mv^2 \quad (2)$$

$$K.E = \frac{1}{2}1330Kg * (15\ {}^{m}/_{s})^2$$

K.E= 149625 N-m

K.E= 149.625 KN-m

➢ The total strain energy (toughness) that the composite structure can absorb is:

$U_{total} = U_{max.}$ [Side impact beam Volume] (3)

U_{total} = [107.08MN-m/m3] [0.90 m x 0.11 m x 0.00432 m]

U_{total} = 4.604 MN-m

U_{total} = 4604.4 KN-m

$U_{total} = U_{max.}$ [B-pillar Volume] (3)

U_{total} = [107.08MN-m/m3] [0.329m^2 x 0.00432 m]

U_{total} = 0.1522 MN-m

U_{total} = 152.2 KN-m

➢ The total strain energy (toughness) that the 1025 Steel can absorb is:

$U_{total} = U_{max.}$ [Side impact beam Volume]

U_{total} = [0.116 MN-m/m3] [0.90 m x 0.11 m x 0.002 m]

U_{total} = 22.968KN-m
U_{total} = 22.968KN-m
$U_{total} = U_{max.}$ [B-pillar Volume]
U_{total} = [0.116 MN-m/m3] [0.329m^2 x 0.002 m]
U_{total} =0.076328KN-m
U_{total} = 76.3 N-m

Table 2: The total strain energy (toughness) that the car body structure can absorb

S.No.	material	Crashing Energy(Ke)in KJ	Total Energy absorbing of side impact beam [KJ)	Total Energy absorbing of B-pillar [KJ)
1	IM7-Carbon/Epoxy composite Vf = 60%)	149.625	4604.4	152.2
2	1025 Steel	149.625	22.968	0.0763

The total strain energy (toughness) of composite and steel are given in Table 2.The total strain energy of composite material is many times greater than the energy of a car moving or crashing load at 15 m/s, because 4604.4 KN-m (for carbon/epoxy composite side impact beam) and 152.2 KN-m (for carbon/epoxy composite B-pillar) greater than 149.625KN-m (moving car) crashing load. However, for the case of steel very less energy can absorbed than energy of 149.625KN-m (moving car) crashing load. The results indicate carbon/epoxy composite material can easily absorb the impact energy caused by moving car colliding against pole.

3.6 The Boundary Condition and applied Load

Determining the boundary condition and the applied impact load over the side impact beam and B-pillar is necessary in the analysis of ANSYS software. The minimum load applied over the side impact beam and B-pillar length (uniform pressure) and not a point load. The car the side impact beam and B-pillar are fixed at its symmetric ends at five points and all the three translational and rotational DOF (degree of freedom) are zero at these points. These conditions are applied to both IM7-Carbon/Epoxy composite and 1025 Steel materials.

3.7 Percentage of mass saving

Percentage of mass saving in a B-pillar

Percentage of mass saving= $\frac{(\rho \text{ of steel}*\text{Volume})-(\rho \text{ of Carbon/Epoxy}*\text{Volume})}{\rho \text{ of steel}*\text{volume}} \times 100$

%of mass saving = $\frac{(7.8g/cc*658cc)-(1.58g/cc*1421.28cc)}{7.8g/cc*658cc} \times 100$

%of mass saving = 56.2%

Total mass of the composite is 56.2%less when compared to the total mass of the steel B-pillar and absorb more deformational energy. Thickness of the composite B-pillar is of 4.32 mm in order to maintain the equivalent stiffness and energy absorption.

3.8Response of the B pillar with respect to fiber orientation

The carbon/epoxy composite structure was simulated to test the response variations on four locations impact beam and B-pillar for the transverse applied load (i.e., F_Y=10KN on the door side impact beam and Fz=10KN on B-pillar).

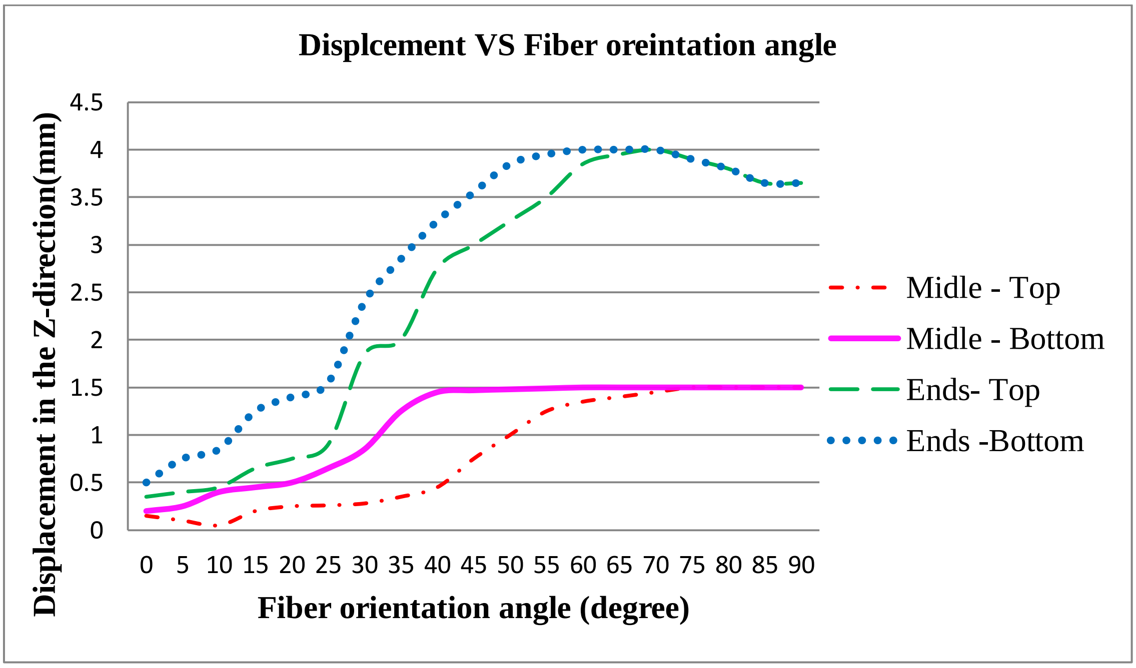

Figure 10: Displacement in the z-Direction Due to Fz=10KN

Four locations on the carbon/epoxy composite structure are plotted: the top and bottom of the pillar at half length and the top and the bottom of the pillar at full length. The bottom of the pillar, both at the middle and end locations, displaces more than the top of the pillar until the orientation angle is approximately 65^0-75^0. At this point, the pillar begins to behave as if all of the fibers are aligned in the same direction. The converging line illustrates this behavior. The bottom ends of the pillar lead the top ends in z-displacement because the other –layers are in the center of the laminate and the angled fibers to force direction are on the outside of the laminate. Due to the force in the z-direction, the angled fibers will begin to curl around the x-axis. This curling effect will cause the bottom edge of the layer to displace more than the top edge. The same case also observed on the door side impact beam.

4. Conclusions

The conclusion drawn from the study is given below

- There is considerable reduction in the weight of B pillar is 56%
- Carbon/epoxy composite B pillar can absorb more deformational energy than steel and more effective than steel .
- Carbon/epoxy composite materials are replaceable where high strength and high stiffness are required.

References:

1. OnurSaymanet al.(2007),” An Analytical Solution Procedure to Analyze Material Nonlinear Behavior of Laminated Beams”.Journal. Reinforced plastics and composites, Vol. 26, No. 4/2007, Denizli, Turkey.
2. Pederson, Joy, "Finite Element Analysis of Carbon Fiber Composite Ripping Using ABAQUS" (2006). All Theses.Paper 512.
3. Chung-Kyu Park Cing-Dao (Steve) Kan , ‘Investigation of opportunities for light-weighting a body-on-frame vehicle using advanced plastics and composites’, Chung-Kyu Park Cing-Dao (Steve) Kan National Crash Analysis Center, The George Washington University USA William Thomas Hollowell WTH Consulting LLC USA Paper Number 13-0023
4. Savage, GM, Metals and Materials, Vol.7, No.10, PP 617, 1991

5. L. Xu, Y. Shi, L.D. Domenico et al,(2005), "Vehicle mass, stiffness and their relationship", The 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC, USA, 2005.
6. Lakhwinder Singh et al. 2012. "Latest Developments in Composite Materials". IOSR Journal of Engineering (IOSRJEN). Volume 2, Issue 8 (August 2012), PP 152-158.
7. Honnagangaiah. K, (2006), "Design and Evaluation of Car Front Sub frame Rails in a Sedan and its Corresponding Crash Injury Response", M.S. Thesis, Department of Mechanical Engineering, Wichita state university, 2006.
8. MIL-HDB (2002),"Composite materials handbook", Polymer matrix composites Materials usage, design, and analysis, volume 3. IL-HDBK-17-3F, JUNE 2002
9. Gary L. Farley, Robert M. Jones,, Crushing Characteristics of Continuous Fiber-Reinforced Composite Tubes, Journal of Composite Materials, Volume: 26 issue: 1, pp: 37-50,1992
10. Gamble, K., et al.(1995), "An Automated Finite Element Analysis of the Initiation and Growth of Damage in Carbon Fiber Composite Materials", Composite Structures, Vol.32, 1995, pp. 265-274.
11. Patberg, L., et al. (1998), "Testing of New composite Side Door Concepts", SAE Special Publications, 980859, Vol. 1320, Feb 1998, pp. 23-30.
12. P.H. Thornton, Energy Absorption in Composites Structures, Journal of Composite Materials 13 (1979) 247-262

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