Crashworthiness Evaluation of Low Weight Recyclable Intrusion Beam for Side Impact

Avinash P. Pawar *Student*, S. H. Mankar, Professor, Mechanical Engineering Department,
Trinity college of Engineering and Research, Pune.

***Abstract*—In the event of a side impact, intrusion beams mounted in the door of a car are the only responsible members to absorb the maximum kinetic energy of the impact. Most of the times it proves to be very dangerous and fatal as hitting body may come in direct contact with the occupant. Injury level in such cases can be reduced significantly with the use of composites which offer high specific strength and high impact energy absorbing capability with the reduced weight as compared with conventional steel. In this project thermoplastic glass epoxy fiber composite material for the side door intrusion beam is proposed and evaluated with the help of Finite Element Analysis (FEA). Obtained results are verified as per the guidelines prescribed in Federal Motor Vehicle Safety Standard (FMVSS) – 214 for passenger cars.**

Keywords- Side Impact, FMVSS 214, Finite Element Analysis (FEA), Thermoplastic composite.

I.INTRODUCTION

In the present day accidents happen every hour around the world and most of these are very dangerous. Side impact collisions are the second leading cause of the death and injury in the traffic accidents after frontal crashes. Fig. 1 shows the comparison of different crash scenarios involved in the traffic mishaps. It can be observed that the number of frontal impact crashes is higher than the side impact crashes. However the space required for any structure in the event of side impact to absorb energy is very less than the frontal impact. In side impact collisions occupant interacts directly with the vehicle structure with very little protection. Other crashes involved are rollover and rear impacts. They contribute to a lesser number as compared with side or frontal impacts. [2]

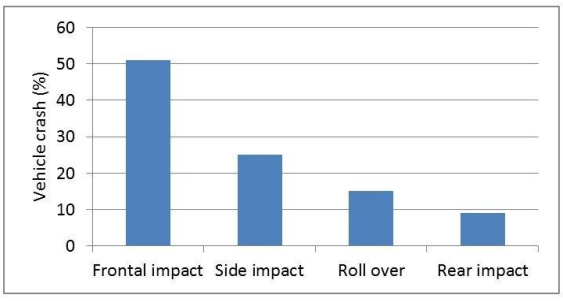

Fig. 1. Comparison of different crash scenarios [8]

Crashworthiness evaluation needs to assess the ability of a vehicle structure to absorb the impact energy and prevent it from being transferred to the occupants thus limiting the occupant injuries in the accidents. The vehicle standards currently in use have well defined crashworthiness requirements for side doors of a car. The intrusion beam of a car needs to resist crash forces and absorb the maximum kinetic energy for a minimum prescribed intrusion of a hitting structure thus minimizing its penetration in the passenger compartment in the accident. [9]

Composite made up of Glass fiber is used and proposed in this research to replace the current intrusion beam made up of steel from the Ford Taurus car. Thermoplastic and glass epoxy fiber composites are known for their high impact energy absorption characteristics. The car door intrusion beam made of thermoplastic glass epoxy fiber composites offers many advantages including reduced human body injuries with increased occupant safety. [3]

Strengthening of car door for side impact needs more attention as it has very less impact zone area and lower rigidity. Continuous study is going on to improve the design of the beam with reduced weight and cost.

II. LITERATURE REVIEW

Previous researches have proved that increased use of composites for the automotive components increases the car safety along with reducing total weight of a car. The composite materials possess high specific strength along with very high impact energy absorption and excellent damping characteristics. These properties of composites can be used effectively to reduce the injury level in the accidents. [1]

Ali G [1] et.al., studied about the applied permanent damages of vehicle frontal door caused by pole impacts.Seong Sik Cheon [2] et.al., developed the side-door impact beam for passenger cars using glass-fibre-reinforced composite. Static tests were carried out to determine the optimum fibre tacking sequences and cross-sectional thickness for the composite impact beams taking consideration of the weight saving ratio compared to the high strength steel. Dynamic tests were carried out at several different temperatures using the pneumatic impact tester which was developed to investigate the dynamic characteristics of impact beams at a speed of 30 mph.the comparison, it was found that the results from the

finite element analyses showed good agreement with the experimental results although several assumptions were made in the finite-element analyses. Tae Seong Lim [7] et.al., investigated a composite side-door impact beam for passenger cars to reduce the weight of steel impact beam using glass fiber reinforced composite. The static bending tests of the beams were performed for the optimum fiber stacking sequence followed by the static tensile tests of the joint between the composite beam and the brackets on the car body. In order to increase the energy absorption characteristics of the composite impact beam the mechanical joint was designed to fail with fiber shear-out mode from which the impact energy might be dissipated during the side door collision of passenger cars. From the test, it was found that the composite impact beam with 70% weight of a high strength steel beam had comparable static bending strength.

III.METHODOLOGY

1. Objective

The main objective of this project work is to replace the current side impact / intrusion beam with the better design and using a glass epoxy fiber composite material instead of currently used high strength steel (AISI 4340) in order to reduce the total weight of the car without sacrificing the safety of the passenger. Ford Taurus car is selected for the design and analysis of the beam. Therefore in this study in accordance with the basic principles of crashworthiness which state that the intrusion of the striking vehicle should be minimum and the energy absorbing capability of the deforming structure should be high, the usage of the glass epoxy composite material side impact beams on the car door has been proposed and its effectiveness in reducing intrusion has been evaluated.

The Project begins with the development of the better designed side impact / intrusion beam, then comparing its performance with a current high strength steel beam for the average force reuired to deform the beam and the load carrying capacity.

Effectiveness of the current high strength steel beam and glass epoxy fiber composite beam is studied by installing the beams in a door model and finding the crush resistance offered by both beams for a prescribed pole intrusion test according to the FMVSS 214 for side impact analysis. [6]

2. Design of composite impact beams

The intrusion beam used in the selected ford taurus car is made up if high strength steel (AISI 4340). It is 945 mm in length and has a “S” shaped cross section with 3.2 mm thickness. The weight of the beam is 3.38 kg. The mechanical properties of the AISI high strength steel are as shown in the table 1.

Table 1. Material properties of High Strength Steel (AISI 4340)

Density	7870 kg/m^3
Young’s Modulus	210 GPa
Poison’s Ratio	0.3
Yield Strength	470MPa

To obtain the weight reduction and increased impact resistance, glass fiber epoxy material with the fiber orientation of 0° is used for the beam. After testing the beam for different cross sections and dimensions, rectangular cross section (40 mm x 40 mm) with 5 mm thickness is selected. Table 2. Shows the mechanical properties of glass fiber epoxy composite. New beam with changed material shows significant reduction in the weight as it reduces from 3.38 kg to 1.98 kg.

Table 2. Material properties of Glass Fiber Epoxy Composite

Density	1980 kg/m3
Young’s Modulus Ex	43.3GPa
Young’s Modulus Ey	14.7GPa
Shear Modulus G_{XY}	4.4 GPa
Poison’s Ratio	0.3
Yield Strength	192 MPa

To manufacture the thermoplastic glass epoxy fiber composite impact beams design parameters such as the type of composite material, stackingsequences, shape and the thickness of cross sections need to be determined.

3D CAD model of the intrusion beams with different cross sections and dimensions and whole door assembly is modeled with the help of CATIA R20. For finite element analysis Hypermesh 12, Ansys and LS Dyna is used. Post processing is done with the help of Hyper view.

A three point static bending test was carried out on the impact beam made up of composite to determine the maximum load carrying capacity and deflection.

IV. RESULTS AND DISCUSSION

1. Finite Element Analysis

A door model is a complex assembly, so it would be a advantageous to study the load carrying capacity on a simplified model. A static analysis is carried out to find the deflection of the beam in which beam is constrained at both ends and an impact force of 50194.5 N is applied at the middle of the beam.

The current intrusion beam made up of steel with “s” shaped cross section is subjected to the impact force of

50194.5 N. This produces a total deformation of 104 mm in the pole as shown in Fig. 2.

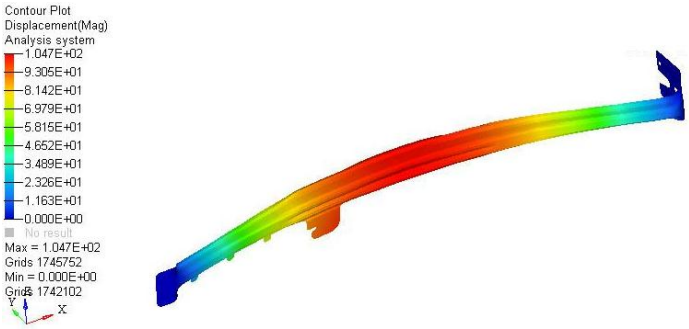

Fig. 2. Non-linear deformation of "s" shaped steel intrusion beam

After this, rectangular shaped glass fiber thermoplastic beam is subjected to the impacting force of 50194.5 N. This produces a total deformation of 47.8 mm in the rectangular beam as shown in Fig. 3.

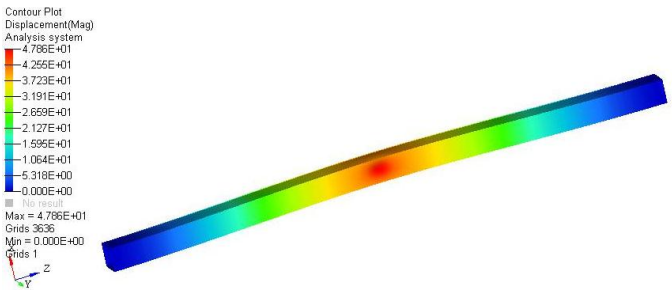

Fig. 3. Non-linear deformation of thermoplastic glass epoxy fiber composite intrusion beam

Similar static test is carried out for beam with circular cross section by assigning material properties of glass fiber composite.

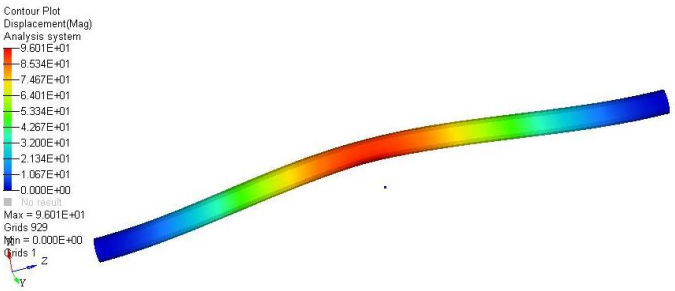

Fig. 4. Deformation of circular beam made up of glss fiber composite

Test produced a 96 mm deformation in the beam as shown in Fig. 4. Obtained deformation values are tabulated below.

Table 3. Comparison of displacement of intrusion beam with different materials

Beam Description	**Displacement (mm)**
"S" shaped steel intrusion beam	104
Glass fiber composite circular beam	96
Glass fiber composite Rectangular beam	47.86

From Table 3. It is concluded that the Glass fiber epoxy composite beamwith rectangular cross section is more suitable for the passenger car because of its high energyabsorption capability, low displacement and more impact resistance ability. Hence the Rectacgular beam with glass fiber composite is considered with whole assembly.

Another test is carried out to confirm the increased impact resistance of the whole door due to the better designed intrusion beam. Here steel beam from the door assembly is replaced with new rectangular beam with glass fiber epoxy composite. The primary purpose of this test is to calculate the crush resistance offered by beam also called as average force required to deform the beam over prescribed movement of rigid cylinder.

As the rectangular shaped beam produces less deformation as compared with "S" shaped beam, it is then analysed with whole door assembly. Cad model of the door assembly is shown in fig. 5. Fig. 6. shows the meshed model of door assembly.

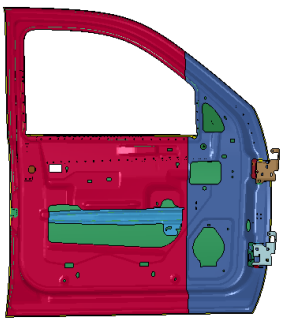

Fig. 5. CAD model of Left Hand (LH) door of Ford Taurus

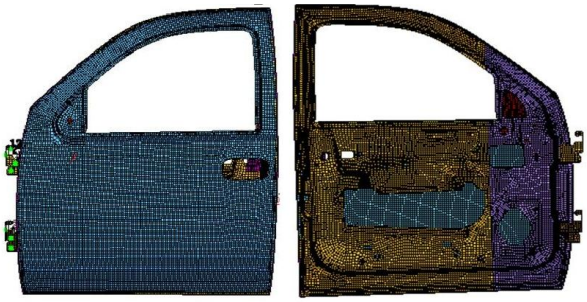

Fig. 6. Meshed model of door assembly

The solid cylinder or pole is modeled as an impactor body. It is considered as an analytically rigid body with mechanical properties of the steel and weight around 417 kg. The diameter of the impacting body is 300mm and the height is of 760mm. The impacting body is meshed with 2D shell elements. [6]

Door is constrained at the hinge locations and both the beams are mounted in the door model one by one. Pole impacts the door at a speed of 52 kmph as shown in the Fig. 9.

Fig. 7. Meshed car door model with impacting pole

When the test is complete, crush resistance offered by both the beams is measured and compared. Fig. 8. shows the crush resistance v Deformation Graph of S Shaped Steel Intrusion Beam. Maximum crush resistance offered by steel beam is 77.1 kN after the pole moves 450 mm in 120 ms.

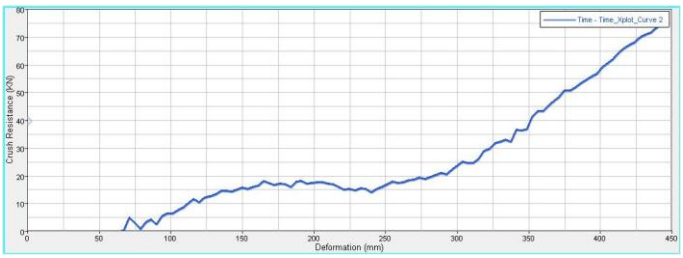

Fig. 8. Crush resistance vs. Deformation graph of "s" shaped high strength steel intrusion beam

Fig. 9. shows the crush resistance v Deformation Graph of rectangular Shaped glass fiber composite Intrusion Beam. Maximum crush resistance offered by composite beam is 103 kN after the pole moves 450 mm in 120 ms.

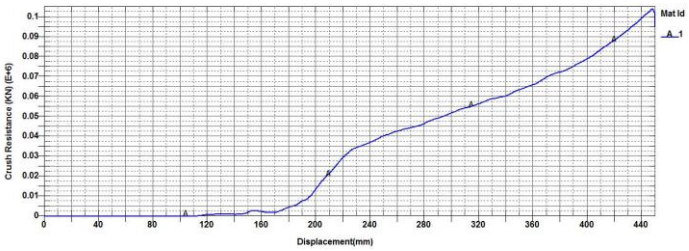

Fig. 9. Crush resistance vs. Deformation graph of glass fiber epoxy composite intrusion beam

Table3. Shows the comparison of crush resistance offered by steel beam with composite beam when pole moves 450 mm within 120 ms.

Table 4. Crush resistance offered by beam made up of steel and composite

	Rigid cylinder travel along Y-direction (mm)	Observed crush resistance force (Steel) (KN)	Observed crush resistance force(Glass Epoxy Composite) (KN)
Initial mean crush resistance (KN)	0-150	15.7	5.0
Intermediate mean crush resistance (KN)	150-300	23.80	52.50
Peak crush resistance (KN)	300-450	77.14	103.00

As per the requirement [6], initial mean crush resistance up to first 150 mm should be greater than 10 KN, and observed crush resistance in S shaped steel beam is 15.7 KN were as in thermoplastic glass epoxy fiber composite is 5KN as it is below the criteria due to improper location of the beam and can be increased with improved beam placement. For displacement from 150 mm – 300 mm, the Intermediate mean crush resistance should be greater than 15.6 KN and for 300 mm – 450 mm displacement, peak crush resistance should be greater than 31.2 KN. For both intrusion beams, observed crush resistance is well above the required criteria. However crush resistance offered by composite beam is way more than that of steel beam. As composite beam offers 125 kN crush resistance as compared with 77.1 kN offered by steel. It can be seen that composite beam absorbs more energy than that of steel. Thus intrusion of hitting body in the passenger compartment can be drastically reduced by using composite beams in the car side door.

2. Experimental Testing

As the glass fiber epoxy composite with rectangular cross section (40 mm x 40 mm) with thickness of 5 mm produces less deformation for the applied impact loading as compared with "s" shaped and circular beams, it is selected and manufactured for furthur testing.

A three point static bending test is carried out using Universal Testing Machine (UTM) to determine the maximum load carrying capacity and deflection of the beam. A jig and loading cylinder were arranged as per the requirements of FMVSS 214 (Federal Motor Vehicle Safety Standard 214). A jig span was set to 470 mm and impact beam was supported by two cylinders of diameter 25.4 mm. The load is given at the midpoint of the impact beam.

From the experiment, it was found that the maximum load carrying capacity of the composite beam was 32.6 kN which is significantly higher than that of steel which has 27.3 kN. [10]

Also the deflection on the beam was recorded to 36.7 mm at the loading location.

V.CONCLUSION

The experimental results show similar deflection pattern as that of finite element analysis (FEA). The FEA results vary with the experimental results by 23.2% which can be asuumed is due to the approximations in the FEA.

The regular rectangularcross-section composite impact beams, especially strengthened by the glass epoxy fiber, canresist external loads when compared with that of the high strength steel impact beams. The glass epoxy fiber composite impact beam has a 41.4% weight reduction compared to the high strength steel intrusion. By implementing the thermoplastic glass epoxy side impact beam, the intrusion of the side door can be reduced eventually reducing the occupant injuries.

REFERANCES

[1] A.Farhaninejad et. al. "Simulation of Square Beam Subjected to Side Impact" Proceedings of the World Congress on Engineering and Computer Science 2012 Vol II, WCECS 2012, October 24-26, 2012.

[2] Ali Ghadianlou, Shahrir Bin Abdullah, "Crashworthiness design of vehicle side door beams under low speed pole side impacts," Thin Walled Structures 67; 25-33, 2013.

[3] Ban. Bakir et. al. "Effect of Fiber Orientation for Fiber Glass Reinforced Composite Material on Mechanical Properties" International Journal of Mining, Metallurgy & Mechanical Engineering (IJMMME) Volume 1, Issue 5, 2013.

[4] Cheon, S.S., Dai, G.L., and Kwang, S.J., "Composite side-door impact beams for passenger cars," Composite Structures, Vol 38, No 1-4 pp. 229-239, 1997.

[5] Dong Seok Kim et.al., "Vehicle design parameter study for side impacts using full vehicle simulation", DAEWOO Motor Company, LTD, Paper number: 98-S8 W16.

[6] Federal Motor Vehicle Safety Standards (FMVSS) No.214 "Side Impact Protection, 2005.

[7] Hansun Chan et.al., "An analysis of ncap side impact crash data", Paper number: 98-Sl l-O-12.

[8] National Crash Analysis Center, http://www.ncac.gwu.edu/vml/index.html

[9] Rainer B. Nees and Clark Alatalo, "Vehicle door intrusion beam", United States Patent, Dec. 3, 1996.

[10] Tae Seong Lim and Dai Gil Lee, "Mechanically fastened composite side-door impact beams for passenger cars designed for shear-out failure modes", Composite Structures, Vol 56 pp: 211–221, 2002.