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Dynamic Analysis of Passenger Car Composite Side-Door Beam

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Abstract— Over the years, the presentation of composite materials in secondary automobile composition has shown superiority over metals. Currently, there is increasing interest to use composites for primary structures for higher weight savings and potential cost reduction. For this reason, a stringer-stiffened panel, with the potential to be used in automobile composition, is considered. In this experiments steel and composite materials were used and rectangular and circular beams types considered and compared to find the best suitable by using finite element models.

Keywords— circular beam, composite, finite element models, rectangular beam, Side door,

I. INTRODUCTION

Crashworthiness is the ability of the vehicle structure to sustain impact loading and to prevent the occupant injuries at the time of accidents. Side impact crash is generally dangerous, since there is no room for large deformation of the vehicle structures. In United States side impacts is the second most common type of vehicle impacts after frontal impact that results in injuries to occupants which account to 25 percent of fatalities due to impacts between passenger cars and light trucks and approximately 30 percent between passenger car crashes [1]. The fuel efficiency and gas emission regulation of the passenger are also very important in the contemporary world. Every day the price of the fuel and the requirement of the fuel is increasing randomly, eventually emission of chemicals from the vehicle exhaust pollute the environment and increase the global temperature [2]. The major factors in considering the materials for the side door are load path and maximum resisting load of the door. The load carrying capacity and intrusion of the side door structure mainly depends on mechanical properties, shape, size and thickness of its components. The proper combination of these features can dramatically change the behavior of the structure, providing an efficient design [3]. The side impact beam should have the ability to absorb as much deformational energy as possible without breaking. Steel is still the most widely used material for beam members, but the steel increases the total weight of the car. However, breakthroughs in the application of lighter materials, such as composite, are being initiated in the automotive industry. Correct fiber orientation and stacking sequence of the cross-ply laminate contribute to higher energy absorption when compared to steel equivalent [4]. The impact beams normally have large static strength and high impact energy absorption capability, which properties are seldom possessed simultaneously by conventional metals because usually metals with high strength have low toughness and vice versa. To meet the high strength and high toughness properties, impact beams are made up of high strength alloy steel with several heat treatments. However the steel impact beams increase the weight of the car and the heat treated steel impact beam usually has a low nil-ductility temperature. The best way to reduce the structural weight of the impact beam is to employ the composite materials as fiber reinforced composite materials have very high specific strength [5]. Door panel intrusion is still the most significant contributor in occupant injuries. Before the implementation of the side impact standard, it was likely that the lower door panel would intrude and result in pelvic fracture. The stiffness, geometry and intrusion of door panels in side impact result in specific injury patterns. In order to avoid the side door intrusion into the passenger car compartment, the vehicle manufacturers generally reinforce the side doors with intrusion beams [6]. Composite materials have been used in aircraft and space vehicles as they have high specific strength (Strength/Density), high specific stiffness (Stiffness/Density) and very good fatigue properties. With the composite material the designer can vary structural parameters, such as geometry and at the same time vary the material properties by changing the fiber orientation, fiber content. These properties of the composite materials create the auspicious environment in automobile industries, since they provide required strength for less weight when compared to steel and aluminum [7]. Carbon fiber reinforced composites are known for their high impact energy absorption characteristics. The carbon fiber composite have very high specific strength and specific stiffness. The car body made of carbon fiber composites bring about an increase in fuel efficiency, reduction in atmospheric pollution and human body injuries when accidents occur [8]. 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). They also have very high impact load absorbing and damping properties [9].

II. SIDE – DOOR BEAM

The door beam, a small-sized part for attachment in a limited space inside a vehicle door, is required to provide energy absorption to soften the shock of collision, and to prevent the door from being grossly deformed. The door beam is required to have high rigidity and strength in spite of its limited dimensions.

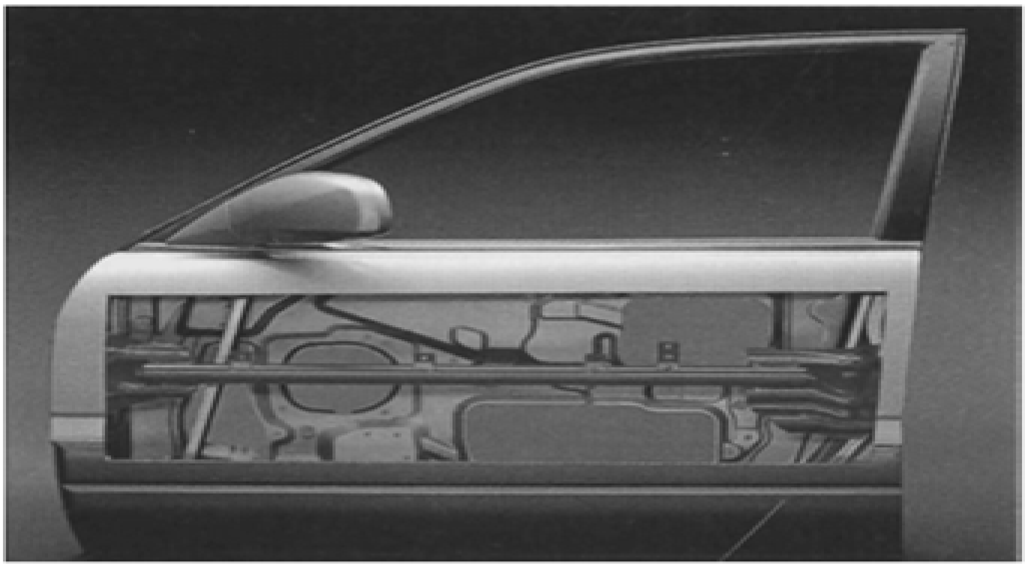


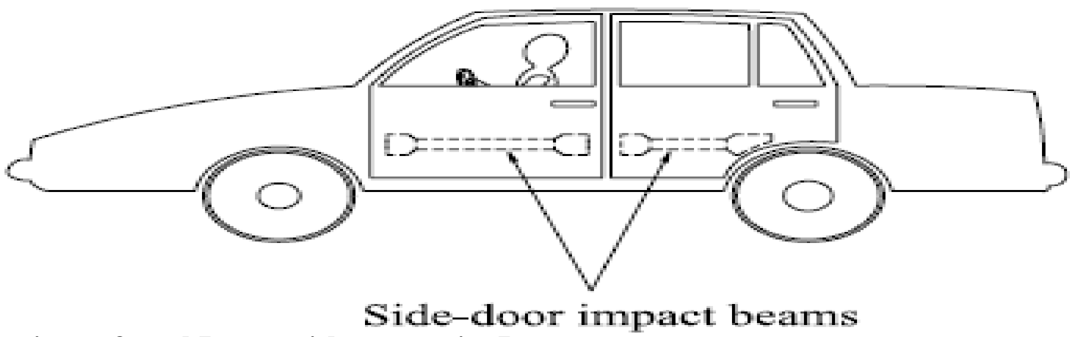
Fig. 1 Side door structure

III. BACKGROUND

Crashworthiness is the ability of the vehicle structure to sustain impact loading and to prevent the occupant injuries at the time of accidents. Side impact crash is generally dangerous, since there is no room for large deformation of the vehicle structures. In United States side impacts is the second most common type of vehicle impacts after frontal impact that results in injuries to occupants which account to 25 percent of fatalities due to impacts between passenger cars and light trucks and approximately 30 percent between passenger car crashes. The fuel efficiency and gas emission regulation of the passenger are also very important in the contemporary world. Every day the price of the fuel and the requirement of the fuel is increasing randomly, eventually emission of chemicals from the vehicle exhaust pollute the environment and increase the global temperature. Therefore the safety and gas emission regulation of passenger car are very important issues in automotive industry. They directly impact the final vehicle design. The manufacturers meet the requirements of a particular crashworthiness standard and fuel efficiency by making the approximate design change in their vehicle structure and by introducing necessary structural components that satisfy the overall design objectives. The present vehicle standard requires each door to resist crash forces that are applied by loading cylinder. The manufacturers are generally required to meet the requirement of the side door strength by reinforcing the doors with door beams (intrusion beam). The main function of the side-impact beam is to provide the occupant with a high level of safety. Side Impact beam is fitted to the inside of car door in the lower third of the door frame and designed to minimize the passenger compartment penetration in the event of side crash. Stiffness of the material plays a major role in optimal design of side door structures. The intrusion of the side door structure should be minimal and the force exerted on the side door during the crash must be distributed over the surface in such a way that the passenger in the structural cage is affected as little as possible. In regard to these directions FMVSS 214 of American standard NHTSA should be taken into consideration when designing the side door impact beams. Composite materials have been used in aircraft and space vehicles as they have high specific strength (Strength/Density), high specific stiffness (Stiffness/Density) and very good fatigue properties. With the composite material the designer can vary structural parameters, such as geometry and at the same time vary the material properties by changing the fiber orientation, fiber content. These properties of the composite materials create the auspicious environment in automobile industries, since they provide required strength for less weight when compared to steel and aluminum. Carbon fiber reinforced composites are known for their high impact energy absorption characteristics. The carbon fiber composite have very high specific strength and specific stiffness. The car body made of carbon fiber composites bring about an increase in fuel efficiency, reduction in atmospheric pollution and human body injuries when accidents occur. 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). They also have very high impact load absorbing and damping properties.

IV. MODELING AND ANALYSIS OF THE IMPACT BEAM

The Finite Element Method (FEM) is used for the computational analysis of the behavior of new side door impact beam under impact loading with the aim to compare the capability of the impact energy absorption in relation to a current steel impact beam.



4.1 Comparison of steel Beam with composite Beam

1. Current beam has C cross section.
2. Current beam has uniform width throughout but the new beam has more strengthening in the middle.
3. Current beam has cornered edges, so there will be discontinuity in force distribution. The new beam has round edges, so smooth force distribution.

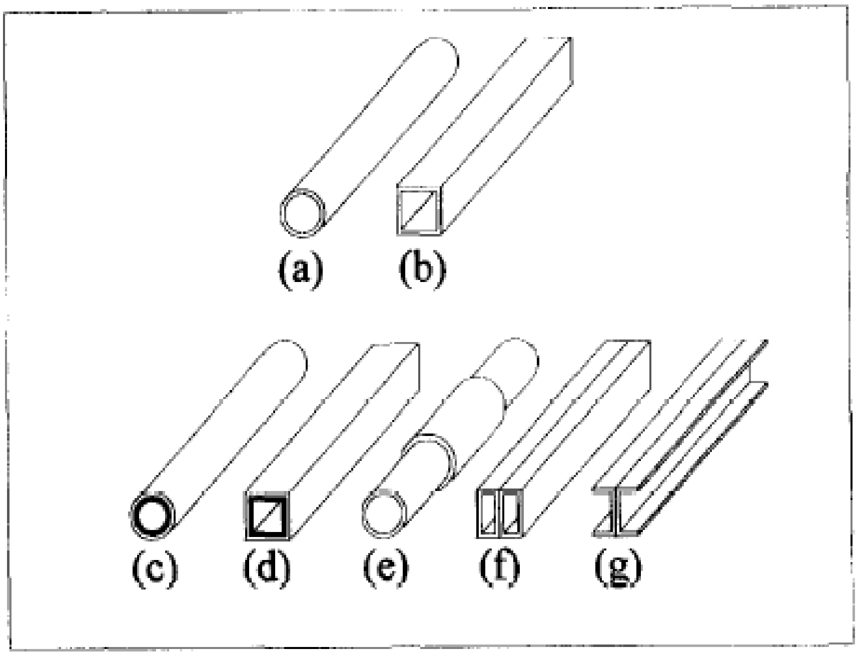


Fig 2 various cross sectional shapes for the side door beam

4.2 Material Description

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 the same load as of steel even with the 40 percent of the steel weight. The carbon fiber composites have very high specific strength and specific stiffness when compared to steel.

Mass Density	**1.58 g/cc**
Longitudinal Modulus E1	**142GPa**
Transverse Modulus E2	**10.3GPa**
Inplane Shear Modulus G12	**7.2GPa**
Poisson's Ratio	**0.27**
Longitudinal Tensile Strength F1t	**1830Mpa**
Transverse Tensile strength F2t	**57MPa**
Inplane shear Strength F6	**71MPa**
Longitudinal Compressive Strength F1c	**1096MPa**
Transverse Compressive Strength F2c	**228Mpa**

Table 1 Material Properties for Carbon Fiber Laminate

Mass Density	7.8 g/cc
Young's Modulus	200 GPa
Poison's Ratio	0.3
Yield Stress	0.215 GPa

Table 2 Material Property for Steel

4.3 Model Description

The beam is of length 947 mm. The strengthening region, where highest deflection and stress are expected, is 547 mm long and was chosen regarding to the position of the applied load. The beam cross section is shaped like one of the above cross section. The dimensions are related with the car SEDAN.

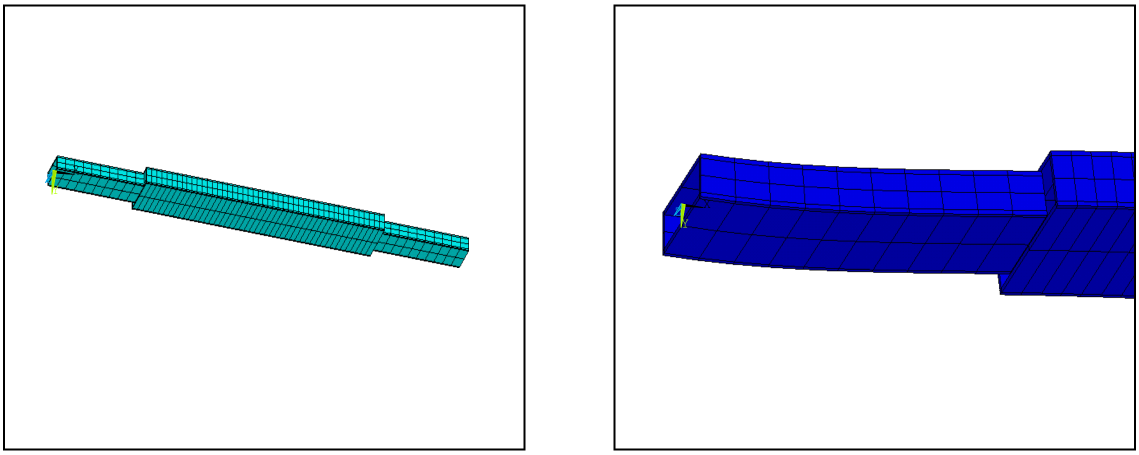


Fig 3 Model 1 – Rectangular Beam

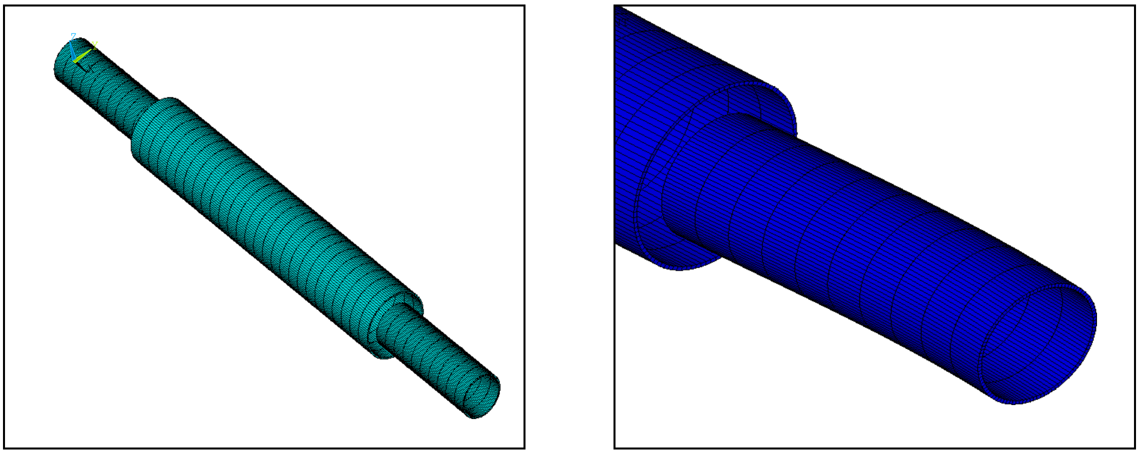
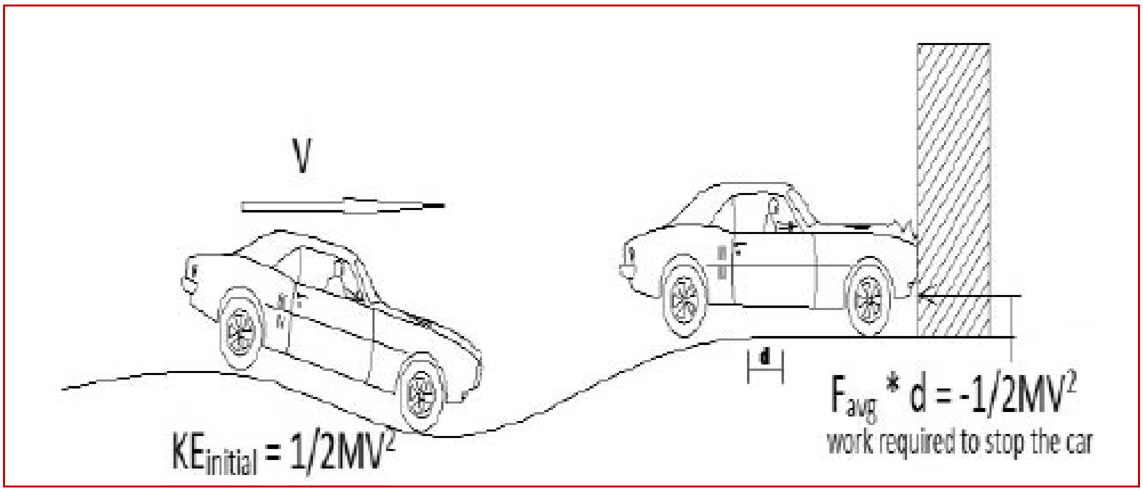


Fig 4 Model 2 – Circular Beam

4.4 Impact Load determination and analysis

The Finite Element Method (FEM) is used for the computational analysis of the behavior of new side door impact beam under impact loading with the aim to compare the capability of the impact energy absorption in relation to a current steel impact beam and also to find out the strength, stiffness, absorbed energy and weight.

To complete the above objective, the FEA based analysis software ANSYS is used.



Velocity = 49km/hr = 13.61m/s

Weight of car

$$KE = \frac{1}{2}MV^2 \quad = \frac{1}{2}(1451)13.61^2$$

$$= 130270.78Nm$$

$$F_{avg} = \frac{\frac{1}{2}MV^2}{d}$$

$$= 427397.58\ N$$

$$= 43\ tons$$

Where,
d = 0.3048m after impact

Force is required to stop the car in a distance of 0.3048m

V. RESULT AND DISCUSSION

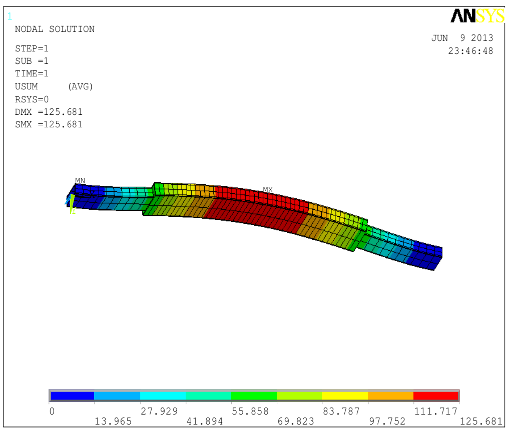


Fig 5 Deformation of Steel Beam

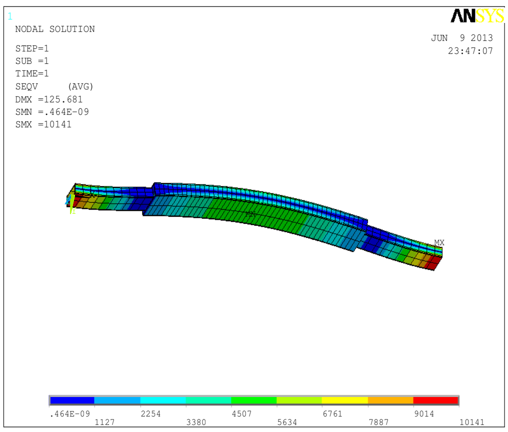
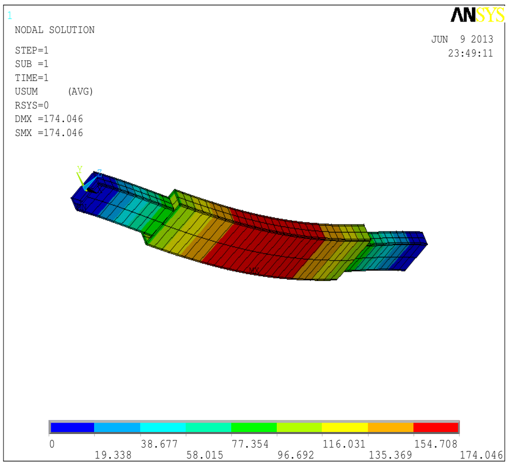


Fig 6 Stress in the steel beam



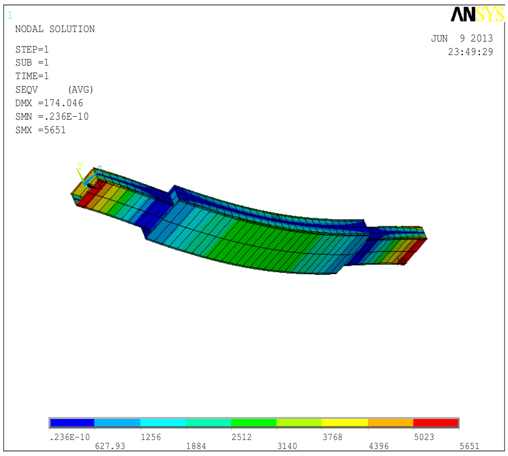
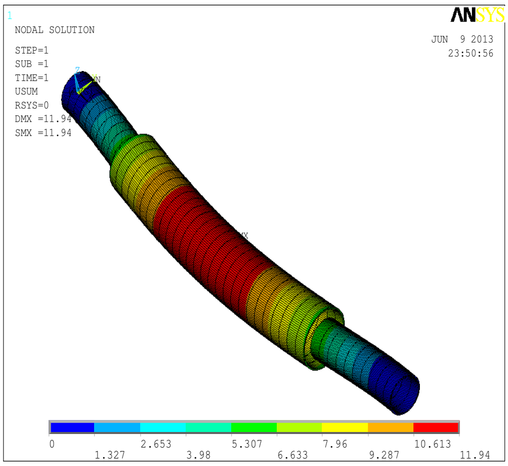


Fig 7 Deformation of composite beam

Fig 8 Stress in composite Beam



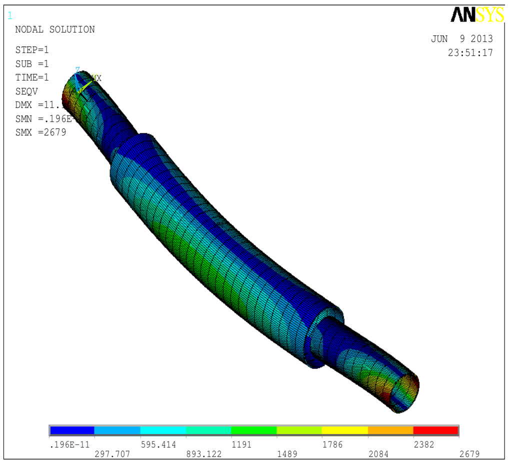
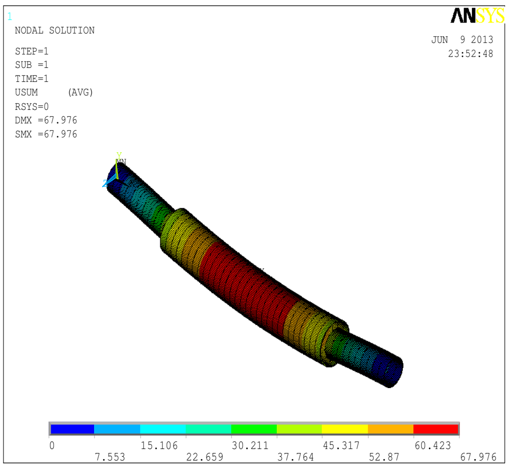


Fig 9 Deformation of steel beam

Fig 10 Stress in steel beam



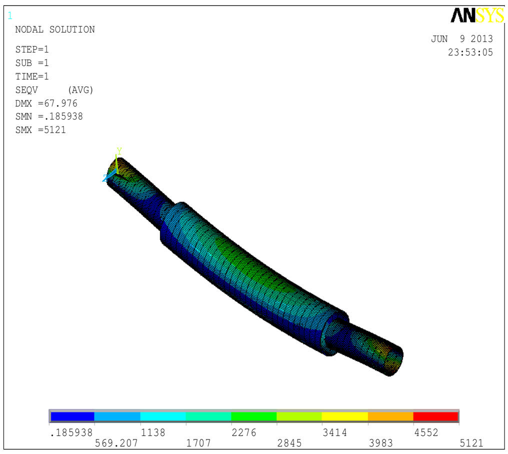


Fig 11 Deformation of composite beam

Fig 12 Stress in composite beam

5.1 ENERGY ABSORBED DURING SIDE IMPACT

Material	Steel		Composite	
Beam type	Displacement (mm)	Energy Absorbed (J)	Displacement (mm)	Energy Absorbed (J)
Rectangular	125.681	26875	174.04	37410
Circular	11.9	2558.5	67.9	14598.5

Table 3 Dynamic Non linear behavior

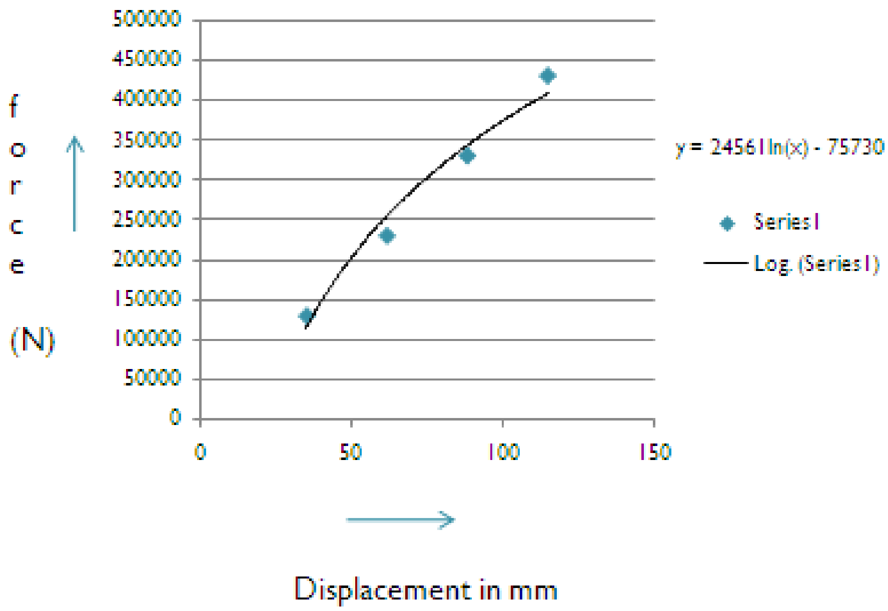


Fig 13 Displacement vs Force

The total energy absorption of the Impact Beam is found out by finding the area under the force displacement curve. The total energy absorption of the new composite impact beam and steel Impact beam is compared. From the table it is clearly seen that the total energy absorption of composite beam is about five times more than the total energy absorption of the steel beam in the case of circular cross section and slightly more than in the case of rectangular cross section also. The advantage of the above analysis is concerned with the weight of the Beams. The weight of the steel beam is 2.64 kg and the weight of the composite beam is 0.90 kg. Total weight of the composite is 65 percent less when compared to the total weight of the steel beams and absorb more deformational energy.

VI. CONCLUSION

The comparative analysis of the Impact beam is carried out by finding the total energy absorption of the beam under impact loading. The energy absorption of the new beam with steel property is compared with the carbon fiber composite beam. The total energy absorption of the composite beam is more than that of steel beam. And also Rectangular beam is more than that of circular beam This indicates that the composite beam absorbs more energy and deforms less when compared to the steel beam. By comparing the computational results of steel beam with the composite beam it can be concluded that,

- There is considerable reduction in the weight of the beam.
- Composite beam can absorb more deformational energy than steel and more effective than steel even 65 percent reduction in weight.
- Composite beam is more effective for both FMVSS 214 and IIHS side impact protection standards.
- One can optimize the mechanical properties of the composite material by changing the fiber orientation and fiber matrix volume ratio.
- Composite materials are replaceable where high strength and high stiffness are required.

Although the composite beams fail by buckling during impact loading, by proper design, fiber orientation and fiber matrix combination buckling failure can be reduced.

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