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Comparative Evaluation of Steel and Composite Side Impact Beams at Low Speed Impact

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Abstract:

Side impact beam is important safety device; strengthen the door of car and lower the risk of side collision. It provides passenger protection in crash situation. Based on the available design of steel side impact beam; the glass fibre reinforced composite side impact beam is designed for different cross section and thickness. The parameters like weight reduction, load carrying capacity, energy absorption capacity and reduction in displacement are comparatively studied for composite and steel side impact beams. Numerical analysis is performed using explicit dynamic analysis in ANSYS workbench 14.5. This analysis is done according to testing availability and FMVSS NO. 214. The glass fibre reinforced composite beam is fabricated using hand layup process. Three point bend test at low speed is performed on the steel and composite side impact beams. Numerical and experimental results are validated and indicate that the use of alternative composite material is possible to design side impact beam.

Keywords — **Explicit dynamic analysis, FMVSS NO. 214, glass fibre reinforced composite, side impact beam.**

I. INTRODUCTION

The automotive industry in India is one of the largest automotive markets in the world. Passenger car crashes will continue to occur in spite of all human efforts to prevent them. There are three types of collisions are front rear and side impacts. The most fatal collision among these three types of collisions is side impact collision because there is no space for deformation. The severity of the side collision in the passenger cars can be reduced by increasing the load carrying capacity and energy absorption characteristics of the side impact beam. They are interdependent on the parameters like material, diameter and thickness of side impact beam. To increases the efficiency of the beam suitable material selection is necessary. The conventional way of making side impact beam was by press forming high-strength steel sheet which is replaced recently by light weighted composite beams. According to researchers' study in composite materials and its applications shows the importance of composites in automobile industries and the growing use of natural fibres in composite manufacturing. These research papers shows, the efficient design and increased use of composite materials into the manufacturing of automotive parts directly influences the car safety, weight reduction and gas emission, because the efficient design can absorb more deformation.

II. LITERATURE REVIEW

Cheon*et al.* [1] developed composite side-door impact beams and found that the composite impact beams had up to 50% weight reduction with a constant impact energy absorption capability based on the static and dynamic tests. Here the glass fibre composite material is selected to compare with steel beam and based on the finite element analysis in ABAQUS simulated the experimental results. Results found out that the composite impact beams not only reduce the weight of the impact beams by more than 50% but also had a constant impact energy absorption capability with respect to environmental temperature variation. Tae Seong*et al.* [2] studied the crashworthiness of beam. The side door beam plays a significant role in damping external forces and absorbed side impact energy by resisting bending in impact phenomena. Composite impact beam was mounted on the front side-door of a compact passenger car for testing under static bending moment. 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. From these papers, this work considering glass fibre reinforced composite material with its dimensions and stacking sequence as a reference for bamboo fibre epoxy composite material. Ghadianlou, A., Shahrir, B. A., [4] focused on only low speed side pole impact condition which causes permanent damages of vehicle frontal door. Two significant parameters such as geometry and material of a side door beam are discussed here to reduce permanent damage of the door. Results of this paper gives that designing the side door beams with the ribs installed opposite and parallel to the normal vector of the crash direction had better impact performance**.** Pathak A. *et al.*[5] studies the effect of beam layout and its specifications on the overall strength of the door with an experimental approach. Beam of different specification and orientation are tested to get the best intrusion beam. Based on this literature study, the load carrying capacity, energy absorption capacity of an impact beam has been tested by using quasi static bending test according to testing availability and FMVSS NO. 214. Due to the very specific characteristic of fibre reinforced composites in comparison with convectional steel beam material; side impact different cross sections and thickness are presented in this paper is made from the glass fibre reinforced composite using CATIA V5 and simulation is done using explicit dynamic analysis in ANSYS workbench 14.5. The test is carried out at low speed condition. The glass fibre reinforced composite side impact beam is manufactured using hand layup process. The numerical and experimental results are compared.Saraf S.C. *et al.*[6]studied the design & develop competitive side impact beam w.r.t current market demand & achieve as much as cost cutting. The Hyundai Verna car's side impact beam is used and the crash test in performed according to Insurance Institute For Highway Safety (IIHS), Euro NCAP. This study proves that the circular side impact beam made from rubberized concrete is best for car.

III. PROBLEM STATEMENT AND OBJECTIVE

There is very small space for deformation during side impact for the protection of passengers of the car. Passenger's safety is characterized by various tests and regulations of side impact beam.

A. *Problem Statement*:

The energy absorption capability of the composite materials offers a unique combination of reduced weight and improves crashworthiness of the vehicle structures. for this work, study of glass fibre reinforced composite material is consider for replacement of steel side impact beam using three point bend test, with the 30% reduction of weight and higher energy absorption capacity.

B. *Objective:*

The objective is to perform a three point bend test (static load test) on side door beams with different cross-sections to on glass fibre reinforced composite material:

1. Identify the design cross-section of side door beam with best specific energy absorption characteristics.
2. Perform the three point bend test on composite and steel beam for validation.

IV. SIDE POLE IMPACT TEST

The FMVSS NO. 214 side pole impacts is a new test that simulates a car crashing sideways into a pole. During the crash, the rigid pole impactor of 300 mm in diameter is stationary, and the test vehicle is propelled sideways at 32 km/hr. so that its line of forward motion forms an angle of 75^0 with the vehicle's longitudinal centreline. FMVSS NO. 214 pole impact sets limits on passenger's injury criteria with no structural performance requirements. According to the two types of test methods are used first is static bend test and second is dynamic impact test. There is no dummy models are used for this analysis. For the numerical analysis, three point bend test consider as a static bend test. The performance was assessed based on the distance between pole impactor and the side impact beam which is parallel to the geometrical centreline of the car. Generally, the maximum intrusion of pole impact occurs at the front door.

A. *Steel Side Impact Beam*

Automobile industries widely uses steel beam as the side impact beam in the passenger cars. Therefore circular steel beam is considered as a reference design for the comparative analysis. Fig. 1 shows the three point bend test in which circular steel beam having outer diameter 25.6 mm, length 788 mm and thickness 1.75 mm respectively. The span length is 500 mm and the roller support having diameter 25.4 mm.

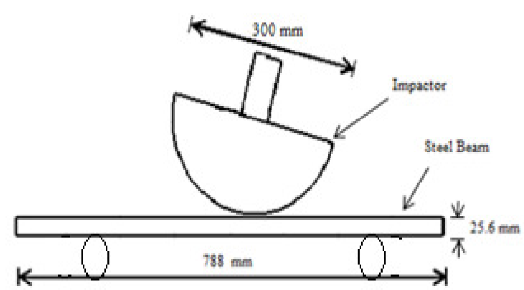

Fig. 1 Three point bend test

B. *Composite Side Impact Beam*

Now days industries are started to move towards light weight and less environmental hazardous materials without compromising the strength. Advanced study in material shows that composite materials also having good strength and light weight compared to metals. The specific criteria for material selection are based on the low density, less modulus of elasticity, easy availability and easy bulk manufacturing possibility. For this work according to literature study and material selection criteria, some light weighted composite materials are considered for the comparison. As per the purpose of beam design; heavy, rare and already used metals should be eliminated. By considering this criterion, glass fibre reinforced composite material is selected for the comparison of beam design. The glass fibre is cross woven bidirectional material of thickness 1.5 mm considered as the raw material for beam manufacturing.

TABLE 1
MATERIAL SELECTION

Sr. No.	Material	Density (g/cm^3)	Young's Modulus (GPa)
1	Steel AISI 4340	7.87	210
2	Glass Fibre Reinforced Composite	1.950	35.5

The properties of the materials used for the testing are described in the Table I.

V. METHODOLOGY

There are different methodologies that can be carried out in a crash test analysis. Here Quasi-Static testing is considered as per the FMVSS NO.214 for the low speed side pole impact and the market availability of testing. The experimentation is carried using three point bend test.

A. Numerical analysis

To study the beam behaviour, as per side pole impact test FMVSS NO. 214, three point bend test method is used. An impactor of diameter 300 mm having feed rate 50 mm/min used for testing. In Quasi static side door impact test, beam contributes mainly up to 100 mm of displacement, therefore for beam evaluation considered maximum 200 mm displacement for 60 millisecond (ms) with 788 mm beam length. The angle between the beam and the impact is also 75^0. The beam of different composite material having variable cross section area and thickness were identified and tested. The bidirectional and cross woven type composite materials are selected to get the more strength.The beam impactor assembly is shown in Fig. 2.

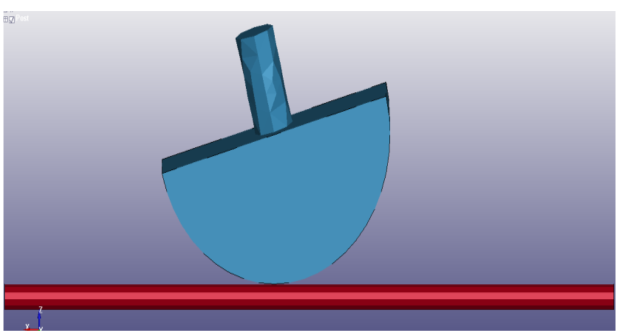

Fig. 2 CAD model of beam and an impactor assembly

The development of the composite impact beam requires high bending strength and the ease for mass production. Generally the rectangular cross sectional shape has more bending strength than circular one. Therefore the rectangular and trapezoidal cross section is considered for the analysis as discussed in Table II. Due to the variable cross section and thickness of the side impact beam the weight of beam changes significantly. The model of composite side impact beam is calculated by using duct formulae for different cross sections. The modelling and analysis of the beam impactor assembly done by using CATIA V5 and the explicit dynamic analysis (LS-DYNA export) respectively, the graphical representation are studied using LS-DYNA 2018 pre-processor.

TABLE II
VARIABLE DESIGN PARAMETERS OF THE SIDE IMPACT BEAM

Sr. No.	Material	Cross section	Thickness (mm)
1	Steel	Circular	1.75
2	Glass Fibre Reinforced Composite (GFRC)	Circular	5.4, 6.5
3		Rectangular	
4		Trapezoidal	

B. Numerical analysis according to FMVSS NO. 214

The numerical analysis is performed for steel beam is only for circular cross section and 1.75 mm thickness because it is a practical application. All the three cross section for glass fibre reinforced composite material are considered for analysis. The two thicknesses are considered based on previous research study.

TABLE III
COMPARISON OF NUMERICAL ANALYSIS ACCORDING TO FMVSS NO. 214

Sr. No.	Thickness (mm)	Cross Section	Load (kN)	Energy Absorption Capacity (J)	Displacement (mm)
1	5.4	Circular	1.57	0.943	33.4
2		Rectangular	5.77	5.09	55.3
3		Trapezoidal	2.15	3.76	59.9
4	6.5	Circular	2.17	3.36	53.6
5		Rectangular	2.30	4.18	52.1
6		Trapezoidal	1.63	1.61	54.3

The Table III shows that for both thickness comparison rectangular cross section gives more load carrying capacity and energy absorption capacity. Therefore, Fig. 3 and Fig. 4 give the displacement of the rectangular GFRC side impact beams after impact.

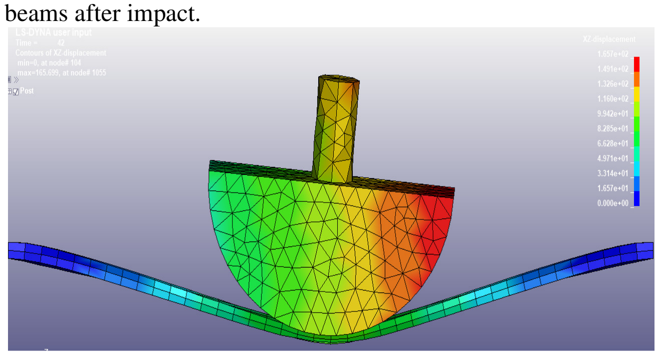

Fig. 3 Rectangular GFRC beam having 5.4 mm thickness after impact

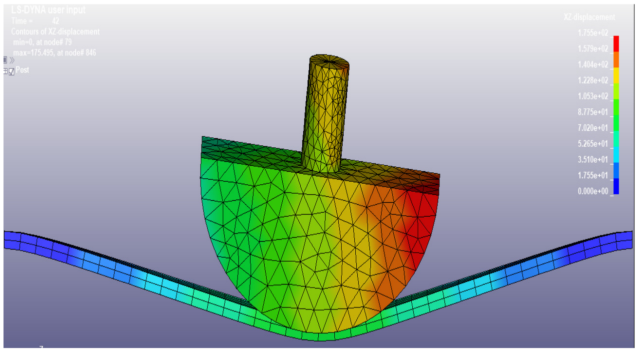

Fig. 4 GFRC beam of rectangular cross section and 6.5 mm thickness after impact

C. Numerical analysis as per testing availability

The mass of the impact tub and velocity of impact become 231.52 N and 0.835 mm/s respectively according to testing availability. This numerical analysis described in Table IV shows that the steel beam gives the maximum load carrying capacity and energy absorption capacity compared to rectangular GFRC beam of thickness 5.4 mm. The minimum displacement is achieved by GFRC beam.

TABLE IV
COMPARISON OF NUMERICAL ANALYSIS ACCORDING TO TESTING AVALIABILITY

Sr. No.	**Beam**	**Cross section**	**Thickness (mm)**	**Load (kN)**	**Energy absorption capacity (J)**	**Displacement (mm)**
1	Steel	Circular	1.75	11.4	4.67	77.3
2	GFRC	Rectangular	5.4	2.02	3.29	47.1

VI. EXPERIMENTAL ANALYSIS

The beam manufactured using the hand layup technique for this process. The wooden container bigger the size of beam is required for the beam manufacturing. The weighing machine is used for the measurement of epoxy resin and hardener. The wooden blockhaving length of 850 mm. It isused as the mold. Teflon sheet is used as the cover for mold because it sustained the high temperature.

The glass fibre material is cut into the length of 830 mm length. It is deepening into container and start wrapping around the beam from bottom side. Extra mixture of resin and hardener is removed using roller. This process is carried for 14 times to get 5.4 mm thickness. The GFRC beam with mold is tightening with transparent nylon thread. It is enclosed with transparent sheet and side tape the vacuum is created inside it. The weight of 25 kg is put on the beam and dries the beam for 48 hours at room temperature. After the 48 hours, the beam is removed from that plastic sheet and mold. The mold is removed by pulling it from the beam. After that the beam is kept into the oven for 120° C for 3 hours for post curing purpose.The post curing method is used to strengthen the beam.

A. Three point bend test

The exact side pole testing method according to FMVSS NO. 214 is not possible because of its expensive to perform for academic purpose. Therefore for this testing, 300 mm impactor and 0.835 mm/s velocity is selected. The circular steel beam and the newly manufactured rectangular GFRC impact beam are used for experimental analysis. The test setup for circular steel beam and rectangular GFRC beam is shown in Fig. 5 and Fig. 6 respectively.

Fig. 5 Circular steel beam testingsetup

Fig. 6 Rectangular GFRC beam testing setup

VII. RESULTS AND DISCUSSION

The numerical analysis according to FMVSS NO.214 also shows that rectangular cross section gives maximum load carrying capacity compare to circular and trapezoidal cross section. It suggested that the rectangular cross section having maximum bending stiffness. The comparisons of numerical and experimental analysis of beams are given in Table V. It shows that, the maximum load carrying capacity and energy absorption capacity achieved by steel beam compare to GFRC beam. But the displacement of the GFRC beam is less. Also the weight of the GFRC beam is also reduced compared to steel.

TABLE V
VALIDATION FOR BEAM

Sr. No.	Beam	Parameter	Numerical	Experimental	Deviation (%)
1	Circular Steel Beam	Load (kN)	11.4	12.35	7.69
2		Displacement (mm)	77.3	69.7	9.83
3		Weight (N)	7.765	7.95	2.32
4	Rectangular GFRC Beam	Load (kN)	2.02	1.88	6.93
5		Displacement (mm)	47.1	43.8	7.00
6		Weight (N)	5.82	5.52	5.15

The numerical results are validated with the help of the experimental results, for the steel material and glass fibre material. For the steel material it is suggested that, the load carrying capacity and weight of beam increased by 7.69 % and 2.32 % respectively also reduction in displacement is achieved by 9.83 %. Similarly for GFRC beam, it is validated that the load carrying capacity and weight of beam increased by 6.93 % and 7.0 % respectively also reduction in displacement is achieved by 5.15 %. Comparison of GFRC beam with steel beam shows that due to the defect in manufacturing process, composite beam cannot achieve the maximum load and energy absorption capacity. Therefore the replacement of steel side impact beam by GFRC beam is possible by using new advanced composite beam manufacturing method.

VIII. CONCLUSION

The numerical and experimental analysis of steel, glass fibre reinforced composite side impact beams carried out to study the load carrying capacity, energy absorption capacity and weight reduction property. The conclusions are,

1. The numerical analysis for different cross sections and thickness of the beams concluded that, Rectangular cross section beams of 5.4 mm and 6.5 mm thickness gives the better load carrying capacity compare to circular and trapezoidal beam.
2. The rectangular GFRC beam of 5.4 mm thickness is selected for the beam design because of the maximum load carrying capacity of 5.77 kN and energy absorption capacity of 5.09 J compare to GFRC beam of thickness 6.5 mm.
3. From the numerical and experimental analysis it is concluded that, GFRC beam of 5.4 thickness gives reduction in weight up to 31.76 % with minimum displacement compare to steel beam. Also it gives the minimum load carrying capacity compare to steel.
4. Comparison of glass fibre reinforced composite with steel beam shows that due to the defect in manufacturing process, composite beam cannot achieve the maximum load and energy absorption capacity. Therefore the replacement of steel side impact beam by glass fibre reinforced composite beam is possible by using new advanced composite beam manufacturing method.

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