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Study and Validation of Effect of Beam Layout and Specification on Side Door Strength of Passenger Car Using FEA

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Abstract—The risk of injury to the driver or passengers in the event of a side impact crash is very high as compared to frontal or rear impact as the energy absorption areas in the front and rear of the vehicle are larger, whereas limited space is available to dissipate the impact energy in the event of a side impact. In such a case, the strength of the side door beam plays a very important role in protecting the occupant. A side door beam in door structure contributes significantly towards the lateral strength and helps in limiting the structural intrusion into passenger compartment. Hence it is important to understand the effect of beam layout and specification on the strength of the side door. These factors also affect the weight targets and hence their study and analysis are of utmost importance.

In this project, quasi-static three-point bending tests were carried out to evaluate the performance of side door beams made of AHSS and aluminium alloy. The side door beam was also tested for different orientations and sections so as to obtain an optimum setting of the door beam. We have used and reviewed a methodology from an existing research paper published by GayanRathnaweera, Yvonne Durandet, Dong Ruan and Michael Hajj. This experimentation was done using the commercial software package LS-DYNA.

Keywords— Side impact, Energy absorption, Finite element analysis, Side door intrusion beam, LS-DYNA

I. INTRODUCTION

Crashworthiness is the ability of a vehicle to absorb impact energy and protect the vehicle occupants in case of an accident. Cars are designed with multiple protective systems which intend to increase the vehicle crashworthiness. One of those elements is the side intrusion beam (SIB). This element is installed inside the vehicle doors and has the main goal of increasing passengers safety during a side crash. As the door assembly is all that stands between the passenger and the external object, all of its components, including the SIB, play a major role regarding the vehicle's crashworthiness.

Maximizing energy absorption efficiency and attenuating the impact peak force are two crucial factors when designing a side intrusion beam. Energy absorption efficiency means having the lightest beam absorbing the maximum impact energy. This concern rises from the imperative need of decreasing vehicle's weight in order to achieve international environmental milestones. Controlling the impact peak force is of very importance as well, since occupant damage may arise from two situations: direct contact between the impactor, or any other car component, and the passenger, or extreme accelerations induced to the human body, which are a direct result from the applied forces during the crash event. The SIB can, in these cases, help preventing the crushing of the occupant compartment and simultaneously induce a slower deceleration of the impacting vehicle leading to a lower peak force and a softer collision event.

The three-point bending test is a simple and effective procedure to evaluate the bending performance of beams. Authors have used this test to compare different thin-walled beams geometries and materials. RathnaweeraGayan et al conducted a study in which quasi-static and dynamic three-point bending test to evaluate the performance of beams made of different materials for their application and their side impact protection.

Regarding the beam shape and orientation, multiple designs have been tested and studied but still, a globally accepted solution has been the most effective in preventing passenger's injuries is not available. There are many different kinds of beam profiles that can be used and are mainly divided into two large groups; Open and Close sections. Standard close sections were firstly used with tubular shapes. Stiffness requirements, however, led to the testing of new and more complex shapes which include the addition of internal walls to the traditional tubular closed section. Open sections usually use S or C shapes in order to enhance energy absorption. Besides the beam's cross section, its connection to the main frame must also be considered. The SIB may be welded or bolted to the door panel through intermediate components named brackets. These can be manufactured as an extra part (tubular shapes typically), or they can be stamped, for instance, alongside the beam's main cross Section.

Materials selection is as much of an intricate process as designing its cross-section. Actually, they cannot be done separately since both stiffness and energy absorption depend on either one of them. Nonetheless, when combining structural requirements with materials' properties, it becomes possible to narrow the selection to a shorter list of possible solutions. Steel, aluminium and composites are the three larger groups which comprise the available market solutions. In fact, not only for the SIB but also for the entire frame of the vehicle. Building affordable vehicles while respecting the crash standards has always been possible with steel. Nevertheless, steel's increased weight comes with an environmental print, as fuel consumption and resulting gas emissions also increase (higher future costs for the consumer). Aluminium and composites are the alternatives. The main reason why these materials are not widely used in the industry is linked to their high development and raw material costs. Aluminium is the main competitor of the steel industry. Despite its lower strength, aluminium has a lower density which, globally, turns out in lighter vehicle solutions. Composites are also an alternative due to their low weight/high strength relationship. However, their significant weight reduction comes alongside a major cost increase, is frequently used in higher rate vehicles (e.g. sports cars). Finally, there is a recent class of materials whose mentioning is entirely relevant. They are a new class of steels, advanced high strength steels, AHSS. Their development arose from the traditional steels' competitive need facing the growth of aluminium usage in the industry. With AHSS, steel producers sought to create a stronger material in order to reduce the volume, hence the vehicle's weight, required to support the desired strengths. Steel producers claim they achieved a reduction in mass that can reach 25%. Even so, new aluminium alloys are also being developed in what is already a tough competition for the market recognition of which is the best material for vehicle manufacturing.

II. LITERATURE REVIEW

Rathnaweera G et. al. [1] carried out the quasi-static and dynamic three-point bending tests to evaluate the performance of tubes made of different materials for their application in side impact protection. The load carrying capacity, total and specific energy absorption, and fracture characteristics were determined for cylindrical welded tubes of an advanced high strength steel (AHSS) and cylindrical extruded tubes of aluminium alloys 6061T6 and 7075T6. The results showed that the peak bending load and energy absorption best correlate to the tube's yield strength and wall thickness. In addition, finite element analysis was performed using the commercial software package LS-DYNA®. The simulation outputs showed good agreement with experimental data. Among the studied tubes, AHSS showed the highest total energy absorption while 7075T6 showed the highest specific energy absorption in both static and dynamic test. A good correlation between FEA and experiments was observed except for 7075T6 tubes after the onset of fracture. A failure criterion applied to improve the current model and to determine the tube dimensions for optimum performance as vehicle side door intrusion beams. The finite element model will be used in the future parametric studies.

Beam specification and orientation on side door strength are the factors which affect the strength but also the cost and weight targets. Risk of injury to an occupant in the event of a side impact is considerably higher compared to frontal or rear impact as the energy absorbing zones at the front and rear of the vehicle is high whereas limited space is available to dissipate the impact energy in the event of side impact. In such scenario strength of side door plays an important role in protecting the occupant. Side door beam in door structure contributes significantly towards the lateral stiffness and plays a dominant role in limiting the structural intrusion into passenger compartment. Hence it is interesting to understand the effect of beam specification and orientation on side door strength. Since these factors not only affect the strength but also the cost and weight targets. Pathak, A. et. al. [2] studied and analyzed it's important with respect to door design. Their paper showcases the effect of beam layout and its specifications on the overall strength of the door with an experimental approach using physical test. Beams with different specification and orientation were tested and based on the test results; a co-relation is built with Side door intrusion test as per IS 12009.

The growing demand for more fuel-efficient vehicles to reduce energy consumption and air pollution provides a challenge for the automotive industry. The best way to increase fuel efficiency, without sacrificing safety, is to employ aluminium alloy within the body of cars, due to its higher strength to weight ratio than that of conventional steel. MohdFadzliAbdollah et. al. [4], were studied structural modifications using Finite Element Analysis (FEA), during the early design stage, to determine a suitable cross-section shape for the side-door impact beam. The impact energy absorption characteristics of aluminium alloy and high-strength steel were investigated using a Charpy impact test. The fracture and surface contour of both materials were observed after impact testing. The preliminary results showed that a square hollow cross-section type was suitable for side-door impact beam use, due to its yield at the highest bending load. Both materials exhibited differential fractures and surface contours after impact testing, which directly indicates that aluminium alloy experienced a ductile fracture and had higher impact energy absorption than the high-strength steel. Since aluminium possesses the higher strength to weight ratio than that of conventional steel it is selected as a potential material for side-door impact beams. Proton Wira which is Malaysian manufactured car is considered for adopting side door impact beam dimensions. Impact beam with outside & inside diameter of 40.2 mm & 34.2mm respectively having length 830 mm is seen to be installed in the side door of the car. Universal impact tester utilized to capture impact energy absorption using Charpy impact test. Furthermore, the impact energy absorption characteristics of aluminium alloy and high-strength steel were also investigated using a Charpy impact test. The FEA showed that the most suitable shape of a side-door impact beam is a square hollow cross-section type because it yielded at a higher bending load than the I-type, C-type, and the circular hollow cross-section type.

Pathak, A. et. al. [5] studied and analyzed it's important with respect to door design. Their paper showcases the effect of beam layout and its specifications on the overall strength of the door with an experimental approach using physical test. Beams with different specification and orientation were tested and based on the test results; a co-relation is built with Side door intrusion test as per IS 12009.

ChinmoyMuzumdar et. at [6] discussed challenges faced in the layout of door beam for a new vehicle program. Limitation in use of CAE analysis for achieving actual results, and design & layout modifications to be carried out to meet side door intrusion criteria effectively.

Dhaneesh K. P. et al. [7] attempted to the change the current car door impact beam with the modified design and using a high strength steel of yield stress 1.2 GPA instead of low strength steel of yield stress 0.366 GPA in order to reduce the intrusion of side closure structure to reduce the injury of the occupant. The usage of the high strength impact beam on the car door has been implemented and its effectuality in the reduction of intrusion of the door structure has been evaluated using case. Effectuality of total energy absorbing capability of the current side impact beam, new side impact beam with current material and new beam high strength steel beams is compared by testing the beams according to the regulation FMVSS 214. By replacing the newly designed side impact beam there is a considerable reduction in the intrusion of the side door structure, which leads to decrease the injuries of side impact crashes.

III. OBJECTIVES AND SCOPE

Standards are not available regarding the configuration and orientation of the door beam in passenger cars for optimum performance during side crash. Hence observations and conclusions of this study can be used as a guiding factor for beam selection while designing side door to get optimum results.

- To replicate three-point bending test for testing of Advanced High Strength Steel and Aluminium alloy side door beams.
- Analysis of both beams for different orientations and cross-sections.
- Find out optimum material, orientation and cross-section for a side door beam.

IV. METHODOLOGY

- Study of automotive safety, lateral safety and side intrusion beam.
- Study of crash analysis, plasticity models and literature review.
- Study of the research paper entitled "Performance of advanced high strength steel and aluminium alloy tubes in three-point bending", published in the 'Sustainable automotive technologies 2012' Springer journal.

- Deck setup planning for quasi-static analysis and optimization for a deck setup which will have least simulation time.
- 3D geometric modelling and finite element modelling in HyperMesh.
- Pre-processing
- The solution in LS DYNA.
- Post-processing.
- Conclusion.

V. SIMULATION WORK

The development of the side intrusion beam was conducted using a powerful FEA tool, HyperWorks. Simulating a crash event with a full vehicle has proven to be time expensive thus, in order to perform an extensive study on several geometries and materials, a simpler and faster model is required. For that reason, a three-point bending model was designed with the intent of assessing the beam's bending performance in a simple simulation. In fact, for side impact, the thin-walled beams will collapse in bending mode which lays a common ground between a complete vehicle side crash simulation and a simple three-point bending test. This model was first validated to match the results in 'Performance of Advanced High Strength Steel and Aluminium Alloy Tubes in Three-Point Bending' [1] in which the three-point bending process has been simulated on software and experimentally validated. Then, different geometries and materials were tested using the same simulation and performance results were compared. Concerning material selection, a wide variety of materials were considered.

A. Material

Fuel economy, greenhouse gas emissions, carbon regulation and crashworthiness are most important issues being addressed in the research and development of new generation of vehicles. One solution to these issues is by reducing vehicle weight. Active research is being dedicated to innovative designs that involve advanced high strength steels (AHSS), lightweight materials such as aluminium, magnesium and engineering plastics in order to bring down the weight of vehicles while maintaining or improving safety.

There has been considerable research into the bending deformation of tubes experimentally and numerically. They found that the bending deformation of tubes runs through three phases: pure crumpling, bending and crumbling and structural collapse. In addition, the bending behaviour varies with the tube dimensions and experimental conditions. However, most of these studies have used the tubes made of conventional aluminium alloys and steel, very less work has been published on the behaviour of emerging metals AHSS and high strength aluminium alloys. In this project beam made of advanced high strength steel (AHSS) and aluminium alloys, 6061T6 were used.

A power law isotropic plasticity material model, MAT_018, was used for the tube material.

This is Material Type 18. This is an isotropic plasticity model with rate effects which uses a power law hardening rule.On the other hand, the indenter and supports were modelled as rigid bodies with default Belytschko_tsay shell elements and MAT_020 due to their high modulus of elasticity and negligible elastic deflections compared to the tube.

TABLE. 1

MATERIAL PROPERTIES

Material	d_o(g/cm^3)	E (Gpa)	ny(Mpa)	k (Mpa)	n
AHSS	7.8	207	1460	1534.15	0.01
6061T6	2.7	67.5	313	410.00	0.05

B. Beam cross sections

Regarding the beams cross section, there has never been a constant cross-section. Over the last few years, many different sections have been used.After a lot of research and literature review, we decided to conduct tests on circular beams, square beams and C section beams.The circular beams have different dimensions for AHSS and 6061T6 materials. Whereas the square and C section beams were considered to have common dimensions for both the materials. Details of the circular beam's dimensions are given in the table and the details of the square and C- section beam are shown in the fig 1.

The layout of the beam in the door structure has a considerable effect on the side doors performance during a crash. Since there is no set parameter for beam layout with respect to side door structure, hence it becomes all the more important to study the effect of beam layout. After conducting a study on the beam orientations of various automobile manufacturers and models observed that the beam orientation generally varied between 0 to 30degrees, and hence decided to do the same.

TABLE 2

CIRCULAR HOLLOW BEAM DIMESIONS

Material	Outer diameter(mm)	Wall thickness(mm)
AHSS	35.25	2.0
6061T6	35	3.0

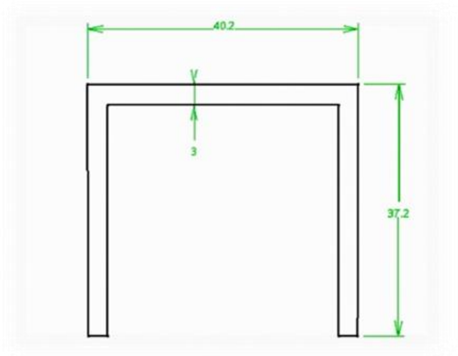

Fig.1 C-section beam dimensions

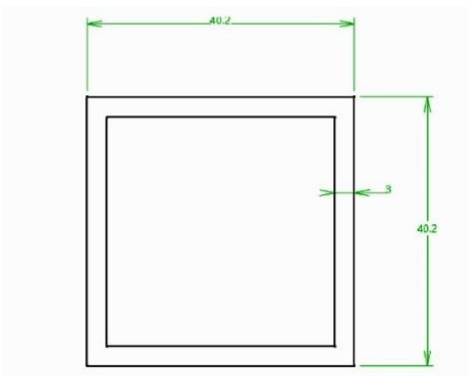

Fig. 2Square beam dimensions

C. Geometry

The beam length is taken as 340mm. The support span was 260mm and the outer diameter of supports and the impactor is 21.05mm. The thickness of the supports and impactor is taken as 2mm. The geometry was created in HyperMesh v14.0

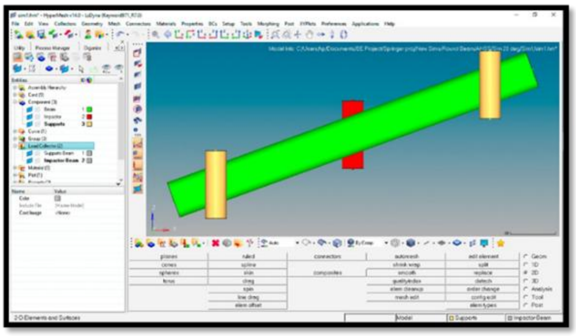

Fig. 3 Circular beam geometry at 20 inclination

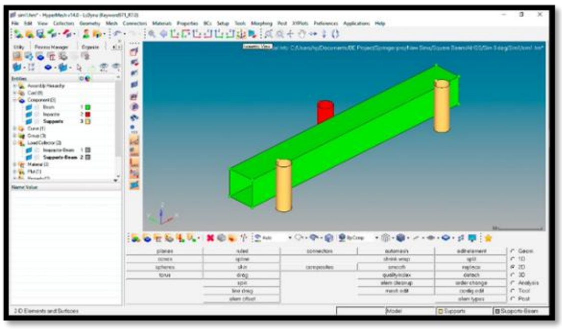

Fig. 4Square beam geometry

V. MESHING

A quad type mesh was used to mesh the impactor, beam and supports. The mesh size was taken as 1mm for the beam and 2mm for the impactor and supports.

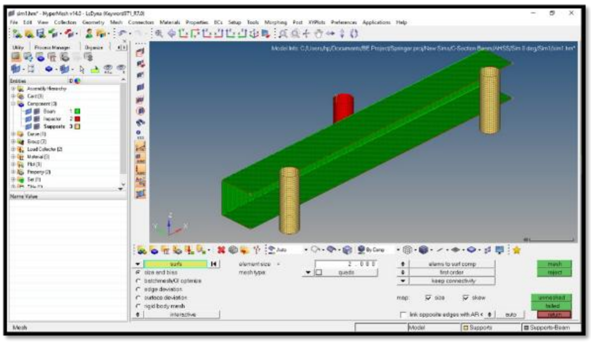

Fig. 5C-section hollow beam meshing

VI. RESULTS

The circular beam mounted at an angle of 0 degrees, showed great agreement with the results of the paper [1]. Hence the methodology used was validated. Using the same methodology simulations were run for both the materials for beams with square and c type cross section.

The results for circular beam made of AHSS mounted at 0-degree orientation are shown in figure 6.

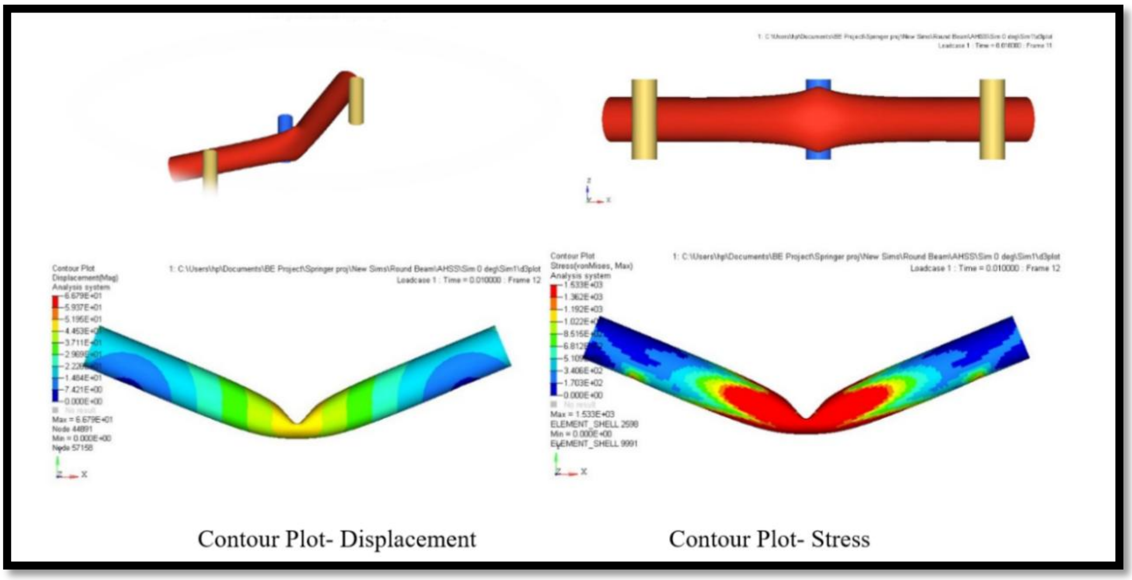

Fig. 6 Results for Circular beam / AHSS / 0 degrees

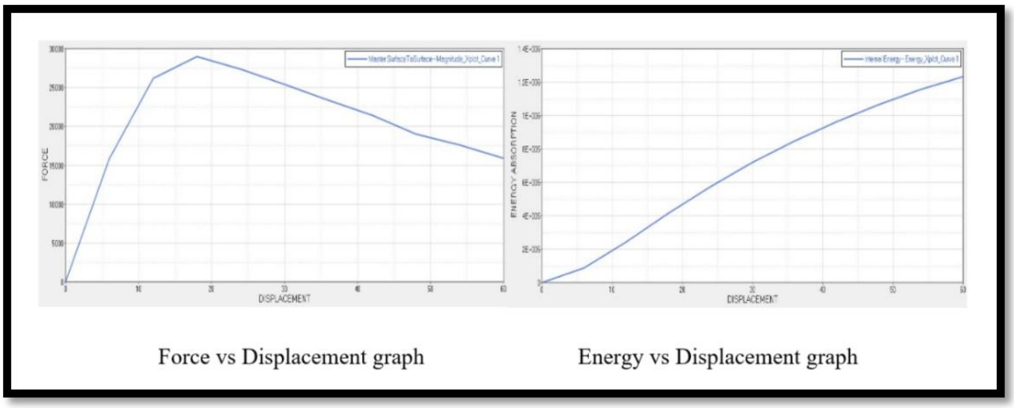

Fig. 7Graphs for Circular beam / AHSS / 0 degrees

TABLE 3

RESULTS OF CIRCULAR HOLLOW BEAM

	PEAK FORCE (N)	ENERGY ABSORBED (J)	
AHSS	29013.3	1232.39	**0 DEG**
	29147.2	1242.36	**10 DEG**
	29526.4	1268.4	**20 DEG**
	30342.5	1329.38	**30 DEG**
6061	11808.6	560.079	**0 DEG**
	11892.4	565.57	**10 DEG**
	12110.9	582.2	**20 DEG**
	12573.9	616.924	**30 DEG**

TABLE 4

RESULTS OF SQUARE HOLLOW BEAM

	PEAK FORCE (N)	ENERGY ABSORBED (J)	
AHSS	106257	5251.01	**0 DEG**
	107496	5289.46	**10 DEG**
	111371	5465.04	**20 DEG**
	118417	5730.14	**30 DEG**
6061	25854.3	1325.44	**0 DEG**
	26016.6	1340.65	**10 DEG**
	26947.7	1383.01	**20 DEG**
	28715.7	1446.31	**30 DEG**

TABLE 5

RESULTS OF C-SECTION BEAM

	PEAK FORCE (N)	ENERGY ABSORBED (J)	
AHSS	80198.2	3086.75	**0 DEG**
	80939.2	3204.74	**10 DEG**
	82873.3	3354.59	**20 DEG**
	87224.8	3633.81	**30 DEG**
6061	19702.9	820.014	**0 DEG**
	19938.2	831.447	**10 DEG**
	20397.8	867.408	**20 DEG**
	21193	945.616	**30 DEG**

AHSS and 6061T6 tubes did not fracture in any of the tests, which were conducted up to a maximum impactor displacement of 60mm. However, the rate of load decrease after reaching the peak force was more for AHSS beams, while the 6061T6 beams showed a much lower rate of load decrease. The higher rate of load decrease in AHSS beams could be due to thinner wall thickness compared to other beams. Beams mounted at an angle of 30 degrees showed the highest energy absorption in circular, square and C type cross-section beams.

Advanced High Strength Steel (AHSS) beams showed considerably higher energy absorption than 6061T6. On comparing the energy absorbed on the basis of cross-section it was seen that the square hollow beam gave maximum energy absorption of 5730.14 J, followed by a C-section beam which gave an energy absorption of 3633.81 J. And lastly circular hollow beam absorbed 1329.98 J energy.

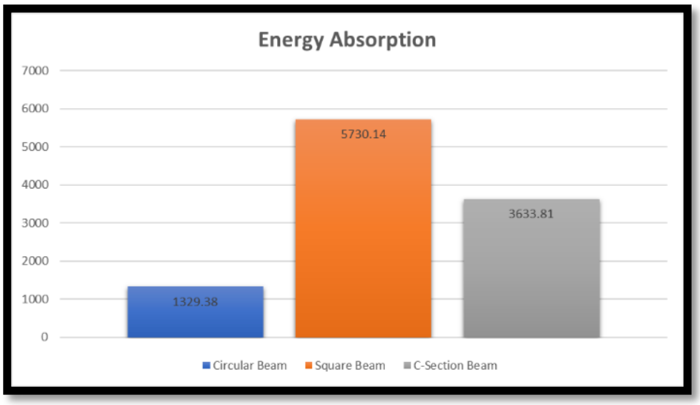

Fig. 8Maximum Energy Absorption classified according to cross-section of beam

VII. CONCLUSION

From this review and experimental study, we concluded the following.

- The energy absorbed by the beam is dependent on the beam orientation. We observed that the energy absorption goes on increasing as the angle at which the beam is mounted is increased. We varied the beam orientation between 0 to 30 degrees and observed and concluded that the 30degree orientation was optimum as the energy absorption at this particular orientation was maximum.
- The Advanced High Strength Steel (AHSS) beams showed the highest energy absorption. The energy absorption in AHSS beams was more than twice that of Aluminum alloy 6061T6 beams. Thus, we can conclude that AHSS has great strength which would prove useful during an impact and enhance the passenger safety. On the other hand, the Aluminum alloy 6061T6 shows lower energy absorption as compared to AHSS but is an extremely lightweight material and hence is useful in bringing down the weight of the vehicle.
- None of the beams fractured during the testing and hence showed ideal plastic deformation.
- It was observed that the square hollow beams showed the most energy absorption, followed by the C type cross-section beams and the Circular hollow beams showed the least energy absorption among the three.

Observations of this experimental study can be used as a guiding factor for optimum beam selection while designing the side door.

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