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Optimization Of Side Door Intrusion Beam For Automotive Safety

[1]Girish M. Patil, [2]Akash Belkhede, [3]Kiran C. More

[1]Master Student, Mechanical Engineering Department, DYPIET, Ambi, [2]Assistant Professor, Mechanical Engineering Department, DYPIET, Ambi, [3]Associate Professor, Mechanical Engineering Department, DYPIET, Ambi
[1]D.Y.Patil Institute of Engineering and Technology Ambi, Pune, India

Abstract *:* Front and Side collision are the major cause of passenger's injuries in car accidents. Passenger's safety is the important criteria while designing the automotive structure (Body in White). The Side Door Intrusion Beam is a protective part assembled in the vehicle and designed to enhance passenger's safety in the event of a side collision. This structure's role is to absorb the maximum amount of impact energy and reduce the depth of door intrusion through an elasto-plastic deformation. This study focuses on comparative study of three different cross-sectional profiles, three different materials and three different thicknesses for side door intrusion beam. The side door intrusion beams designs are analyzed to check their energy absorbing characteristics in the static and dynamic analysis in FEM software to prevent the occupant from the side collision. Taguchi method is used to determine the optimized design parameter. Optimum design of side door intrusion beam with maximum energy absorbing capacity and resistance force is cross validated on three point bending physical test and full vehicle side impact simulation.

Index Terms – Body-In-White, Side Door Intrusion Beam, Elasto-plastic deformation, FEM

1. INTRODUCTION

Road accidents is global concern related to human life protection. As per World Health Organization (WHO) Report-2015, 1.25 million people dies in road accident across the world. Road accidents can be categorized into front impact, side impact, rear impact, roll-over etc [1].

"Crashworthiness" provided a measure of the ability of a structure and any of its components to protect the occupants in survivable crashes [2]. Passenger cabin and the doors structure of the vehicle should absorb any kind of direct impacts and protect the passengers. Real world vehicle collisions are unique dynamic events where the vehicle may collide with another vehicle of similar or different shape, stiffness and mass or it may collide with different stationary object such as a tree, utility pole. To assure the passengers safety, different vehicle regulatory standards are been set across the world. Side impact case considered in this study. Side door-intrusion beams, designed to save passengers from side impact while strange object intrudes into the cabin space, are mounted within internal door cavity of a vehicle at external plane and fixed to door supports. These beams are bent outward slightly – thus impact deformation energy absorbed firstly is directed to door sides which rest on the body struts. Designing of these elements is considerably complex. Unlike front and rear deformation zones, it is rather complex to arrange in body sides components, able to deform hardly while absorbing energy. Designing is difficult due to dual purpose of these elements – apart from protection against side impact they are used to stiffen the door in order to dissipate impact energy more effectively, in front crash and rear impact. Designing is inconvenient as well, because there are no completely determined requirements for energy absorbing components. Investigators in their works analyze side impacts of three types: Static door strength, car to car, and car to pole. In the first static door strength is tested to avoid the intrusion in the cabin [3]. In the second case, impact of a vehicle moving straight or at some angle are tested with stationary vehicle are analyzed [4]. In the third case the tested vehicle side impact against stationary fixed pole, imitating tree, lighting pole or other obstacle is analyzed [5]. To improve occupant safety means in the case of side impact, side impact test Federal Motor Vehicles Safety Standard No.214 (FMVSS 214) has been developed by National Highways Traffic Safety Authority (NHTSA)[3]. According to directive FMVSS No.214 in USA quasi-static and dynamic side impact tests have been performed. During quasi-static test the reaction of rigid body intruding into passenger cabin space of the vehicle is determined. The Resistance force of the door should be more than 10KN for passenger vehicles. The test is performed with a stiff 450 mm cylinder of diameter 300 mm being pushed at constant speed of 0.03 m/s to car doors [3]. During side impact against a pole (Fig.1) a car is fixed on the special carriage and is pushed against stationary fixed pole at the speed of 32 km/h [5].

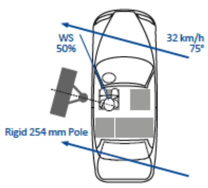

Fig.1: Side Pole Impact [5]

Side door intrusion beams are constructive responding doors parts, protecting passengers during an accident with side obstacle, but there are no separate regulations or standards for beams testing. During experimental or computational-simulations side impact researches the interaction of side safety bags, passenger head and central strut and dynamic of the passenger on rear seat cross moving is analyzed, but stiffness or strength of side door components is not analyzed separately. Vehicles safety is characterized by different regulations, but none of them defines strength characteristics of side doors anti-intrusion beams. To determine the anti-intrusion behavior of the side door beam, a static load test is to be performed as shown in Fig-2

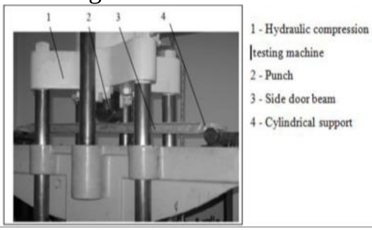

Fig.2: 3-point Bend Test on UTM [6]

A 3-point bending test of the side-door beam punched with a rigid pole was set up. The numerical simulation were carried out by using LS-DYNA software. The design variables are material, cross section, gauge of the side door beam. Attention was focused upon finding an optimum design of the beam in order to improve the energy absorption characteristic.

Different researchers tried different combination of the side door intrusion sections, materials to improve the energy absorbing capacity but few have used the combination of section, material and gauge.

Avinash Pawar et al., studies the side door intrusion beam by using composite materials (Glass filed epoxy composite) and thermoplastic polymers (PEEK). Study shows that the composites door beam reduces the door intrusions and eventually reduces the occupant injury. Disadvantage for composites are high in material cost, manufacturing cost as compared to traditional steels and composite beams fails by buckling during impact loading. [1]

E. Černiauskas, et al. This study shows analysis of impact beams by considering different cross sections and different grade steel material. Door beam is analyzed on 3-point bending test. FEA analysis of side doors anti-intrusion beams shows effectiveness of door beam is influenced by material mechanical characteristics. [6]

Raghvendra Krishana et al. studied the effectiveness of door beam for SUV in side impact. Two different section-circular and rectangular with same material is tested by using 3-point bending method in FEA software and compared back with physical test.

As per study shows that the rectangular sections beam has more energy absorption capacity as compared to circular section beams.[7]

Pavan K. et al. studied the three different section –circular, M-shape and HAT section is analyzed in this study by using FEA software. Different combination of shape, thickness were studied. Comparative study shows Hat shape cross-sectional is optimum for door beam which gives better energy absorption with comparatively less weight. Gap in this studied was Material variable was not taken into account. [8]

Yogesh K. Nichit et al. Analyzed four different cross section and thickness of the side impact beam by using three point bending test by using FEM simulation for component test and concluded as square shape and I-shape cross section beams require higher bending force as compared to the traditional used circular cross section beams. [9]

Sarang C. Saraf et al. studied the side door intrusion beam with circular cross section and high strength steel. Comparative study is done with square section with different concrete filler material inside. As compared normal concrete, rubberized concrete absorbs more force with minimum deformation. By using rubberized concrete in circular sections shows significant improvement in flexural strength of the solid beam with minimal deformation. [10]

Dhaneesh K. P. et al. study shows the FEA tool is used to demonstrate the effectiveness of the side door intrusion beam with different section and high strength material to enhance the energy absorbing capability. High strength material & M-shape section can gives significant increase in energy absorption. Side door intrusion beam is tested on full vehicle simulation as per FMVSS214. [11]

Radha Krishna Nemani et al. Analyzed door intrusion beam is tested by using 3-point bending test by using FEA tool. Taguchi method is used to optimize the door intrusion beam. In this work variables are used as cross sections (Circular, M-shape, HAT-section), different punch displacement (100, 125, 150mm) and different punch location on the beam relative to fixing (300, 375, 450mm). M-Shape & Hat section intrusion beam gives better performance compared to circular section. [12]

Teng T.L et al. study shows the comparative study between side door with intrusion beam and without intrusion beam. Study clearly shows the dummy injuries reduced with side door intrusion beam incorporated when tested under FMVSS214 specification. Effectiveness of the side door intrusion beam is influenced by shape, material and placement of beam. [13]

2. ANALYTICAL METHOD

The 3-point bending load-case simulation set up done in LS-Dyna explicit solver format to determine performance of side door intrusion beam:

1. The side door beam is rigidly constrained in all DOF on two ends which is represented by rigid cylinder supports of dia. 40 mm.
2. A punch of diameter 300 mm is used, which intrudes into the side door beam. It is fully constrained in other 5 degrees of freedom. 3. Surface to surface contact is defined between
   i. ‘Punch’ and ‘Side door beam’
   ii. ‘Cylinder supports’ and ‘Side door beam’

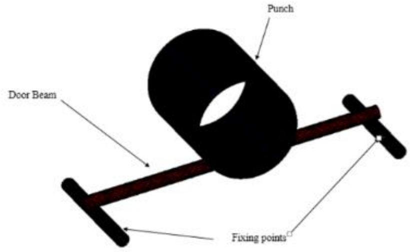

Fig.3: 3-point Bend Test simulation up

3. PHYSICAL EXPERIMENTS

Physical experiments are done as below

a. Material procurement
b. Sample preparation
c. Test set-up
d. Component testing

Material procurement is done on very initial stage material procurement done. Hollow circular sections and panel type sections were procured from existing on-road vehicles. Optimized door design is tested on universal testing machine (tensile testing machine or tensile tester) with a 3 point bend fixtures.

4.EXPERIMENTATION

4.1 Materials

A door impact beam should absorb impact energy when a car is subjected to a side impact without increase in the mass. Recent development in the metallurgy, efforts have also been carried out to improve the strength of a steel material such as Ultra High Strength Steel (UHSS) with over 780MPa in tensile strength similarly recently produced to have about 1000-2000 MPa in tensile strength is known as Advanced High Strength Steel (AHSS) to improve the safety characteristics of a vehicle.

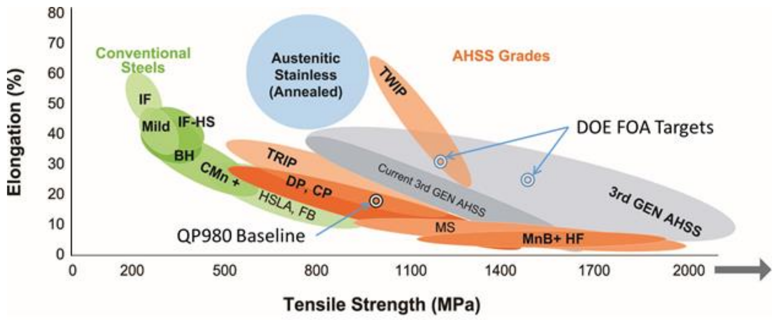

Fig.4: Global formability diagram for today's AHSS steel grades [14]

While comparing the mechanical properties of different materials stands when it comes to comparing costs with weight reduction. Aluminum and composites are the alternative to steel. Still alternative materials are not widely used in the industry is due to their high development and raw material costs which is mainly used in high cost vehicle like sports car.

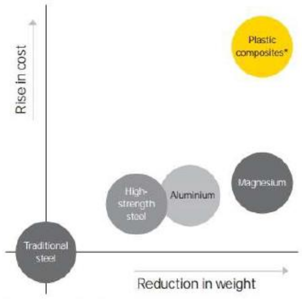

Fig.5: Material Cost Vs. weight reduction [15]

For the proposed work, door beam is made up of the different high strength steels material to give cost effective solution mentioned below

.

Table 4.1 Material details of The Door Beam in Proposed Work [16]

MATERIAL	Young's Modulus, GPa	Poisson's Ratio	Density Kg/m3	Yield Strength, MPa
AISI 1080	200	0.3	7890	800
AISI1010	210	0.3	7850	1050
BORON Steel,1500-AS	210	0.3	7780	1250

4.2 Door Beam Sections

Based on different literature review it is observed that panel sections are more effective for door beam than the tubular sections. So for proposed worked below mentioned sections are considered.

Table 4.2 Door Beam Cross-sections in Proposed Work

Cross sections		
Circular Shape	HAT Shape	M-SHAPE

4.3 Door Beam Dimensions

Proposed work dimensions are selected from available data from literature review and engineering judgment.

Table 4.3 Dimensions of the Door Beam in Proposed Work

Parameter	**Dimension**
Length of Door Beam	900mm

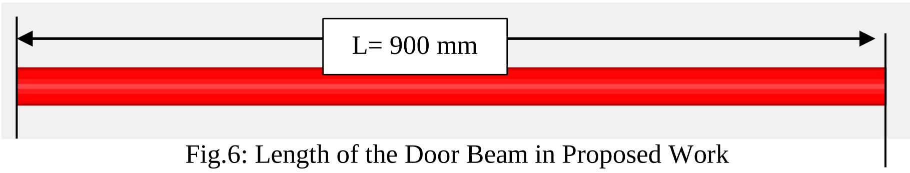

Fig.6: Length of the Door Beam in Proposed Work

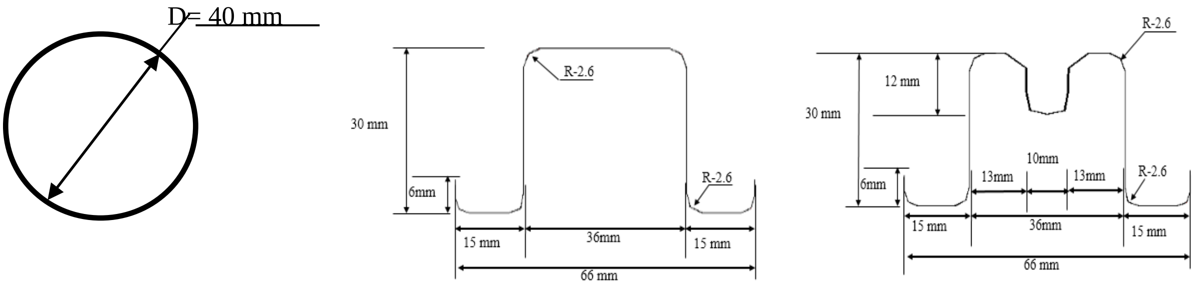

Fig.7: Circular, HAT-section & M-section of the Door Beam in Proposed Work

4.4 Door Beam Thickness

Table 4.4 Thickness of the Door Beam in Proposed Work

Thickness (mm)		
1.6	1.8	2.0

4.5 Mathematical Model

The goal for this work is to obtain the Force, displacement relation for the door beam. Side impact beam in the vehicle are subjected to lateral loading in a side impact. Theoretically it can be simplified by assuming the beam as a simply supported beam with central loading.

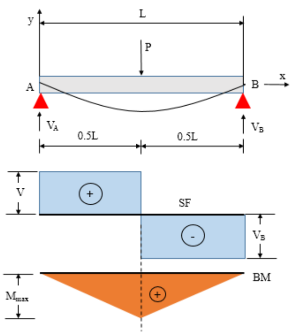

Fig.8: FBD of Side Door Beam

Maximum bending moment,

$$BM = \frac{P*L}{4} \quad (4.1)$$

$$Maximum\ Shear\ force = \frac{P}{2} \quad (4.2)$$

Bending Equation is given by,

$$\frac{M}{I} = \frac{\sigma}{Y} = \frac{E}{R} \quad (4.3)$$

Flexural strength of the beam can be derive from above equation,

$$P = \frac{I*\sigma*4}{y*L} \quad (4.4)$$

5. DESIGN OF EXPERIMENTS BY USING TAGUCHI METHOD

Taguchi has introduced a new method of conducting the design of experiments which are based on well-defined guidelines, which is depends on a special set of arrays called orthogonal arrays. Standard arrays helps for conducting the minimum number of experiments which could give the full information of all the factors that affect the performance parameter

5.1 Designing of Experiments by using Taguchi Method

5.1 Independent design variables considered

X1-Materials variable: Three Materials were selected

Table 5.1 Material as Independent design variables

MATERIAL		
I	II	III
AISI 1080	AISI1010	BORON Steel, 1500-AS

X2-Section variable: Three beam section were selected

Table 5.2 Door Beam section as design variables

Beam Section		
I	II	III
Circular	HAT-Section	M-Section

X3-Thickness variable: Three beam thickness were selected

Table 5.3 Door Beam section as design variables

Beam Thickness		
I	II	III
1.6mm	1.8mm	2mm

Table 5.4 Orthogonal Array formulations: (3^3) [12]

	Independent Variable						
	Variable 1	Variable 2	Variable 3	P1(Kg)	P2 (J)	P3 (J/Kg)	P4 (KN)
EX No	Material	Cross Section	Thickness	Weight	Energy absorption	Specific Energy absorption	Resistance Force
A1	1	1	1	1.42	988.3	696	29
A2	1	2	2	1.85	2493.4	1348	80
A3	1	3	3	2.51	3664.1	1460	136
A4	2	1	2	1.6	2403.8	1502	75
A5	2	2	3	2.01	2648.6	1318	90
A6	2	3	1	2.01	2709.3	1348	91
A7	3	1	3	1.77	2558	1445	81
A8	3	2	1	1.6	1973	1233	64
A9	3	3	2	2.25	2909	1293	103

Von Mises Stress Plot:

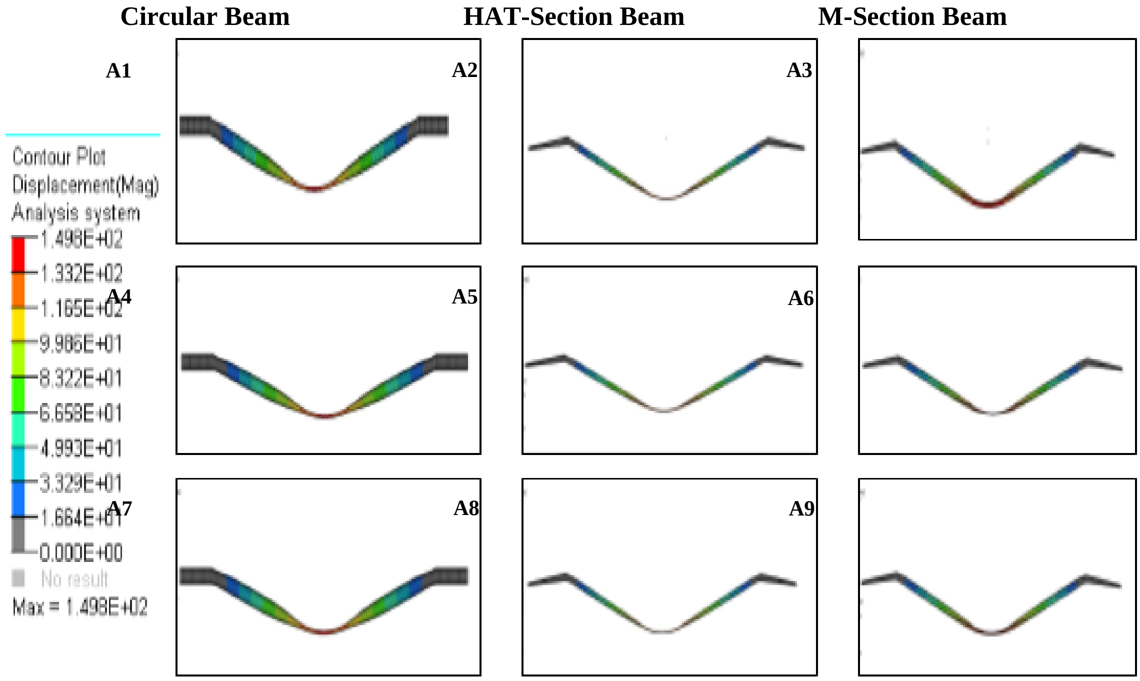

Fig.9: Von Mises Stress Plot of Circular, HAT-section & M-section (EX-A1 to A9)

5.2 Design Variable Effects On Energy Absorption Of Door Beam:

Calculation of Factor Averages

$$Average\ effect\ of\ Factor = \frac{Sum\ of\ all\ results\ containing\ the\ effect\ of\ the\ factor}{Number\ of\ results\ included\ in\ the\ sum} \qquad (5.2)$$

Factor averages of the 3 variables are denoted by 'Vij', where, 'i' is variable number, and 'j' is variable level

From Table-5.2 the result P3 for experiments A1 to A9 be denoted by Y1, to Y9

Calculations of 'Variable 1' (Material) factor averages,

V11 = (Y1+Y2 + Y3) / 3 = (696 + 1348+ 1460) / 3 = 1168
V12 = (Y4+ Y5 + Y6) / 3 = (1502+ 1318+ 1348) / 3 = 1389
V13 = (Y7+ Y8 + Y9) / 3 = (1445+ 1233+ 1293) / 3 = 1324

Calculations of 'Variable 2' (Beam cross section) factor averages,

V21 = (Y1+ Y4 + Y7) / 3 = (696+ 1502+ 1445) / 3 = 1214
V22 = (Y2+ Y5 + Y8) / 3 = (1348+ 1318+ 1233) / 3 = 1300
V23 = (Y3+ Y6 + Y9) / 3 = (1460+ 1348+ 1293) / 3 = 1367

Calculations of 'Variable 3' (Beam Thickness) factor averages,

V31 = (Y1+Y6+Y8) / 3 = (696+ 1348+ 1233) / 3 = 1092
V32 = (Y2+Y4+ Y9) / 3 = (1348+ 1502+ 1293) / 3 = 1381
V33 = (Y3+Y5+Y7) / 3 = (1460+ 1318+ 1445) / 3 = 1408

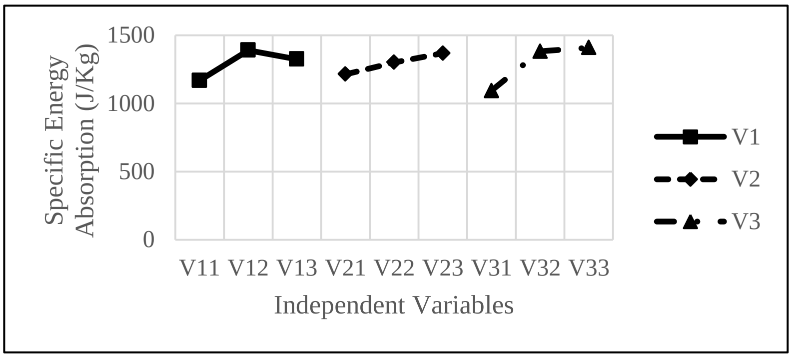

Fig.10: Plot of Specific Energy Absorption vs. Independent Variables

Plot of Factor Average Effects: The graph shows the 'Factor average effects' of the three independent variables.

Variable 1 (V1) – Material Cross-section of beam,
Variable 2 (V2) - Cross-section of beam,
Variable 3 (V3) – Thickness of the beam

6. RESULTS AND DISCUSSION

From graph shown in figure-12, the following conclusions are made:

1. 'M-Section Shape' and 'H-Shape' cross section beams have higher 'Specific energy absorption' compared to the 'Circular shaped' beams.
2. Specific Energy absorption increase with increase in door beam thickness.
3. 'M-Hat Shape' cross section beam has the best energy absorption characteristics and resistance force.
4. Minimum absorption of energy by circular side impact beam is observed with 1mm gauge and with AISI1080 material.
5. Above all door beam sections are passing the static door intrusion resistance force criteria of 10KN.
6. Optimal door beam design is concluded as M-Shape section, 2.0 mm gauge and AISI1080 as material considering the maximum energy absorption and maximum resistance force.

FUTURE SCOPE:

1. Optimal door beam performance need to checked physically validate on 3-point bending test
2. Optimal door beam performance need to verify on full vehicle side pole impact simulation.

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