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Parameters of Side Intrusion Beam Affecting on Crash Force Efficiency During Impact

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Abstract*: Occupants safety is one of the most important criteria in car design. Due to the less space between occupant and side door, the scope of energy absorption is less. Hence in a case of side impact, the strength of side door is plays crucial role. A side intrusion beam is mount inside the side door and is also called side impact beam. During side impact, side intrusion beam gets deformed and it absorb the highest amount of energy compare to others parts of side door. And also for smooth bending during the impact, nearly equal amount of force should absorb during the whole bending process. So design of side intrusion beam is important part of vehicle door design. The various parameters of intrusion beam like, material of intrusion beam, shape of intrusion beam, dimensions, mounting of beam inside the door etc. are affected on the strength of side door. In present work using finite elements analysis the effect of important parameters of hollow circular cross section side intrusion beam on Crash Force Efficiency (CFE) is studied. The ABAQUS software is used to perform various finite element simulation. In the first part of this work most influential parameter is determine by Design of Experiments and ANOVA analysis, in a second part of this work relative effect of this influential parameter on crashworthiness of side intrusion beam is studied.

***Keywords*: Side intrusion beam, Side impact beam, vehicle side door, Taguchi method; ANOVA, crashworthiness of side door, crash force efficiency**

I. INTRODUCTION

Road accidents is a one of most critical issue in India. In every year many deaths, injuries courses in road accidents. During the years 2014 to 2018, India had 24, 03,429 road accidents. Out of this road accidents 24,28,770 were severely injured and 7,35,919 occupants were dead [1]. This data shows in India per day 1317 road accidents occurred and 403 peoples died. Due to such alarming numbers it is need to work all aspect related to road accident. Data also shows in 2014 to 2018 years 2,14,958 accidents were side impact collisions. As the space between occupants and vehicle door is less compere to frontal impact the chances of injuries is more in side impact. In a case of side impact only vehicle side door is in between external object and occupant. In a side door the intrusion beam is absorb maximum amount of impact energy hence, due to all this design of side intrusion beam is important. [2-5].

The vehicle side impact is study by various crashworthiness indicators like Energy absorption (EA), average crash force (F_{avg}), Specific Energy Absorption (SEA) and Crash Force Indicator (CFE) [6-7]. This indicators are also used for comparative study of various intrusion beam those having various cross section, dimension, material etc.

In a side impact process, force verses displacement diagram is used to calculate crashworthiness indicator. The area under the force displacement diagram is the Energy Absorption (EA) capacity of beam. Higher value of EA is indicate the higher energy absorption capacity of beam, it can be calculated by

$$EA = \int_0^{\delta} F(z)\, dz \qquad (1)$$

Where F(z) is crash force of bending, δ is deformation of beam. F_{avg} is average value of crash force during whole bending process and can be calculated as by equation,

$$F_{avg} = \frac{EA}{\delta} \qquad (2)$$

As the weight of vehicle is much important in design of vehicle so, SEA indicator is used to shows efficiency of structure, SEA is the energy absorb per unit mass of the impact beam, it is calculated by equation 3,

$$SEA = \frac{EA}{mass \quad of \quad beam} \qquad (3)$$

In a side impact for smooth bending process side intrusion beam should be deformed steadily. For steadily deformation, the bending force should be almost same during the whole bending process.

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This is indict by dimensionless number CFE. The value of CFE lies between 0 and 1. If energy absorption is decrease gradually as deformation of beam increase, in a such cases CFE indicator value is closer to 0. Similarly if energy absorb is almost same during the whole bending process, in a cases CFE value is closer to 1. CFE is calculated from equation 4

$$CFE = \frac{F_{avg}}{F_{\max}} \qquad (4)$$

Where, F_{max} is the maximum value of crash force in force displacement diagram [3-7].

In the present work CFE of hollow circular cross section side intrusion beam is study. Various parameters of intrusion beam like material, geometry, dimension, mounting inside a side door etc. are affected on CFE of beam [10,11]. In this work thickness, diameter, angle of mounting inside the beam are study. Material is kept same, due to cost and weight aspect of beam. Comparative study of various intrusion beam is done by finite element simulation on ABAQUS software. The validation of finite element simulation model is done by comparing the current simulation results with available literature results. In the first part of work most influence parameter out of above said parameter is determined by Design of Experiment (DoE). The DoE is performed using Taguchi L_9 orthogonal array, followed by ANOVA analysis. In the second part of this work individual effect of this parameters on CFE and other crashworthiness indictor is studied.

II. VALIDATION OF SIMULATION MODEL

Validation of simulation model is important before doing the further study on it. In this work geometry of intrusion beam, its material and simulation setup is adopted from available literature [13]. Below Fig. 1 and Table I are shows the simulation setup and simulation parameters of finite element model. Where, 'D', 't' and 'L' is the diameter, thickness and length of intrusion beam respectively. In the Fig. 1 intrusion beam is supported on two numbers of cylindrical support of diameter 'R2', span of this support this is denoted by 's'. 'R1' and 'm' and 'v' is denoted the diameter, mass and velocity of impactor respectively. Material of intrusion beam is AISI1080, the properties of this material are shown in Table II.

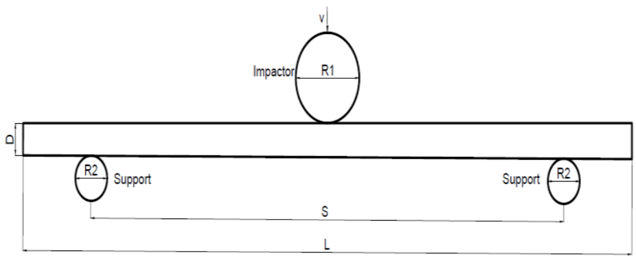


Fig. 1. Simulation setup for validation

Table-I: Value of Simulation and geometry parameters

D (mm)	t (mm)	L (mm)	s (mm)	R1 (mm)	R2 (mm)	m (kg)	v (m/s)
40	1.7	960	745	100	50	200	5.8

Table-II: Material Properties

Material	Densit y (kg/m^3)	Yield stress (MPa)	Poison's ratio (μ)	Young's Modulus (GPa)	Tangent Modulus
AISI100	7860	869	0.28	205	5669

In ABAQUS model is done on explicit dynamic module. The impactor and cylindrical support are considered as rigid body in simulation model. Coefficient of friction between all surfaces is taken 0.3. Mesh size of simulation model is 1.5 and impactor displacement 200 mm is considered for validation. ABAQUS simulation model and deformed shape of intrusion beam is shown in Fig. 2 and Fig. 3 respectively.

Fig. 2. ABAQUS simulation model

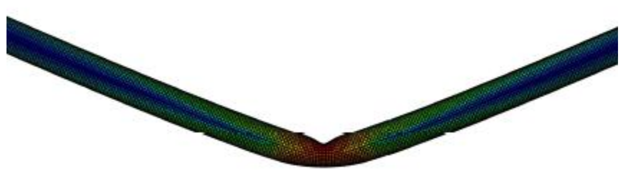
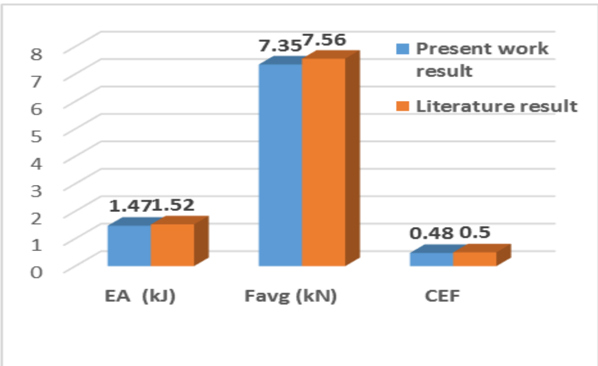


Fig. 3. Deformed shape of intrusion beam



From simulation the force displacement diagram of bending process is draw and using the equation 1, 2 and 4 crashworthiness indicators EA, Favg and CFE is calculated respectively. The obtained result of EA, Favg and CFE is compare with reported result in literature [13]. Fig 4 is shows the comparison of current simulation results and literature results.

Fig. 4. Comparison of results

From Fig. 4 it is clear that absolute error between current simulation results and results reported in literature is less than 5%, hence above simulation model is considered for further work.

III. DESIGN OF EXPERIMENT FOR PARAMETER STUDY

To study the effect of intrusion beam parameters on CFE design of Experiment methodology is used. Where intrusion beam parameters like thickness, diameter and angle of mounting inside the door are input parameters while CFE is the output parameter. Considering the space availability of side intrusion beam inside the side door, parameters levels are decided. The parameters and its levels is tabulated in Table III.

Table-III. Parameters and their levels

Sr. No.	Circular beam parameter	Parameters value at each level		
		1	2	3
1	Diameter (mm)	20	25	30
2	Thickness (mm)	1.62	2	2.65
3	Angle of orientation (degree)	0	10	20

A. Taguchi design of Experiment

For optimized the number of simulation Taguchi design of experiments method is considered this work. For three parameters and three levels of each parameters Taguchi L_9 orthogonal array is selected 14-15]. Number of simulations are carry out by taken the level of parameters mentioned in Table IV.

Table-IV. Parameters and their levels

Experiment number	Diameter of beam	Thickness of beam	Angle of orientation
a	1	1	1
b	1	2	2
c	1	3	3
d	2	1	2
e	2	2	3
f	2	3	1
g	3	1	3
h	3	2	1
i	3	3	2

The simulation model is same as shown in Fig. 1 Table 1. Similarly, intrusion beam mesh size, friction between the surfaces and simulation procedure is kept same and describe in validation section. TWIP 750/1000 most common material used for intrusion beam so, for further simulation this material is taken. The properties of this material are taken from literature [17] and they are shown in Table V.

Table-V. Properties of TWIP 750/1000 material

Name of material	Density (kg/m3)	Yield stress (MPa)	Young's modulus E (GPa)	Poison's ratio	Elongation at break in percentage
TWIP 750/1000	8000	750	210	0.3	37

As per mentioned in Table IV all experiments are performed. By using the similar methodology discussed in validation section EA and CFE for all experiments is determined. Fig. 5 is shows force displacement diagram of all experiments in Table IV. Intrusion beam EA and CFE value of all experiment is shown in Fig. 6 (a) and Fig. 6 (b) respectively.

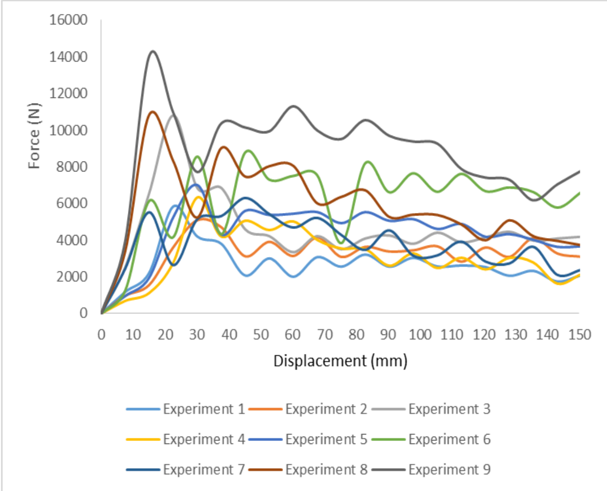
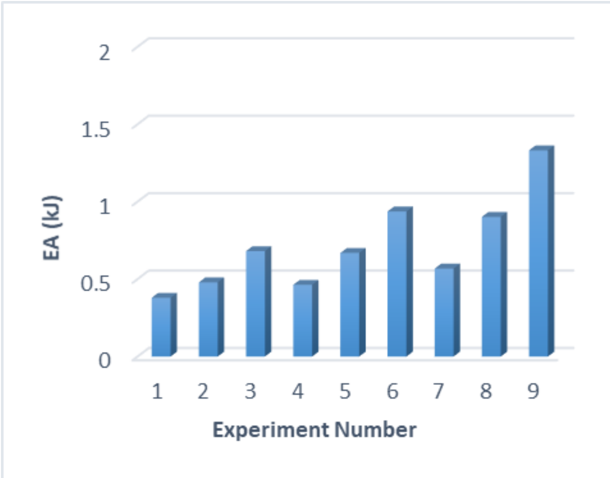
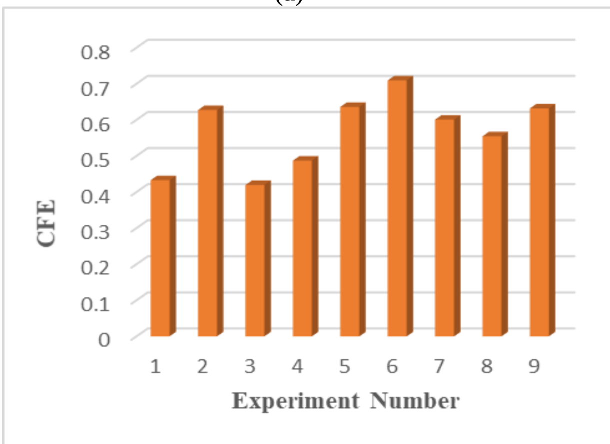


Fig.5. Force versus Displacement curves of experiments



(a)



(b)

To determine the most influence parameter on CFE among the diameter, thickness and angle of mounting of intrusion beam ANOVA analysis has been performed. As mentioned earlier CFE value should be closer to 1. Hence 'largest is better' type objective characteristics is selected for signal to noise ratio (S/N) [19-20]. According to equation 5 S/N ratio of all experiment is calculated and it is shown in Table VI.

$$S/N = -10\log\left(\frac{\sum y_i^2}{n}\right) \qquad (5)$$

Table VI

S/N ratio of CFE

Experiment No.	CFE	S/N ration
1	0.433	-7.27162
2	0.627	-4.05058
3	0.42	-7.54257
4	0.487	-6.24541
5	0.636	-3.93244
6	0.709	-2.98123
7	0.601	-4.42588
8	0.554	-5.12233
9	0.632	-3.98862

Further in ANOVA analysis, k value is calculated as per equation 6, where i is number of same level of parameter occurs in orthogonal array. k_1, k_2 and k_3 value of each parameter are shown in Table VII. The difference between maximum and minimum value of k_1, k_2 and k_3 of each parameter is also shown in below table and as per ANOVA technique it should be same value for all parameters.

$$k = -\sum S/N_i \qquad (6)$$

Table VII
Summation of S/N ratio

Parameters	Diameter	Thickness	Angle of orientation
k1	18.865	17.943	15.375
k2	13.159	13.105	14.285
k3	13.537	14.512	15.901
Differences	5.706	4.838	1.616
Total	45.561	45.561	45.561

$$S = \sum\left(\frac{S}{N}\right)^2 - C_f \qquad (7)$$

$$C_f = \left(\frac{\sum\left(\frac{S}{N}\right)^2}{n}\right) \qquad (8)$$

$$S_k = \left(\sum \frac{k_i^2}{m_i}\right) - C_f \qquad (9)$$

$$V = \left(\frac{S_k}{m-1}\right) \qquad (10)$$

$$Percentage \quad Contribution = \left(\frac{veriation \quad due \quad to \quad parameter}{total \quad veriation} X100\right) \qquad (11)$$

Table VIII

ANOVA analysis for CFE

Parameters	S	DoF	V	F	Percent contrib	Rank
Diameter	6.787	2	3.394	3.394	59.704	1
Thickness	4.128	2	2.064	2.064	36.310	2
Angle of Orientation	0.453	2	0.227	0.227	3.986	3
Error	0		0	0		
Total	11.368		5.684	5.684	100	

To calculate percentage of contribution of each parameter on CFE, using equation 7, 8, 9 and 10 total variances S, correction factor C_f, Sk and variances V is calculated respectively. In equation 9, m-1 is the total degree of freedom of each parameter those is 2 here for all parameters. From equation 11 percentage contribution of each parameter is calculated. All above value are tabulated in Table VIII.

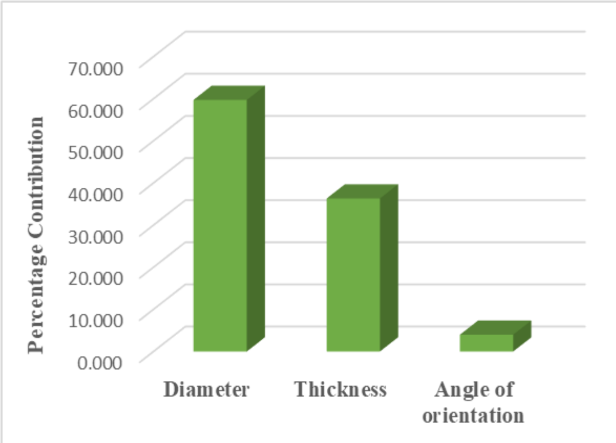


Fig.7. Contribution of impact beam parameters on CFE

From Fig. 7 is it is seen that, in case of CFE of hollow circular cross section intrusion beam, diameter parameter is more influence compare to thickness and angle of mounting parameters of beam. Contribution of diameter on CFE indicator is 56.06% and is maximum, followed by intrusion beam thickness and angle of mounting 36.31% and 3.98% respectively.

IV. Effect of Diameter Parameter on CFE

In the second part of this work effect diameter parameters of intrusion beam on CFE indicator is studied. For that various simulation are performed as per table IX, where level of diameter parameters are vary from 1 to 3 and other parameters level are kept constant.

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Table-IX Simulations for thickness analysis

Experiment number	Parameters level		
	Diameter (mm)	*Thickness (mm)*	*Angle of orientation (degree)*
1	1	1	1
2	2	1	1
3	3	1	1

The force displacement graph of all simulations is shown in Fig. 8 and using the similar methodology discussed in validation section the crashworthiness indicator EA, SEA and CFE are calculated and shown in Fig.9 (a), (b) and (c) respectively.

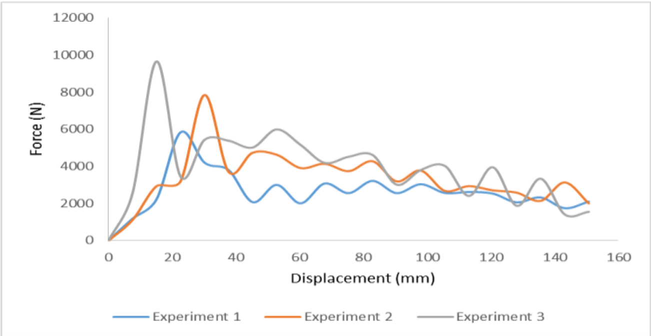
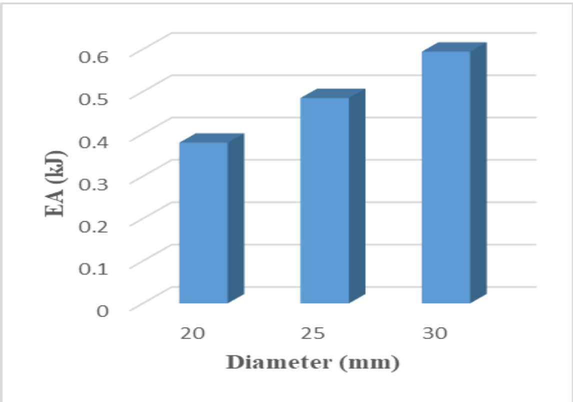
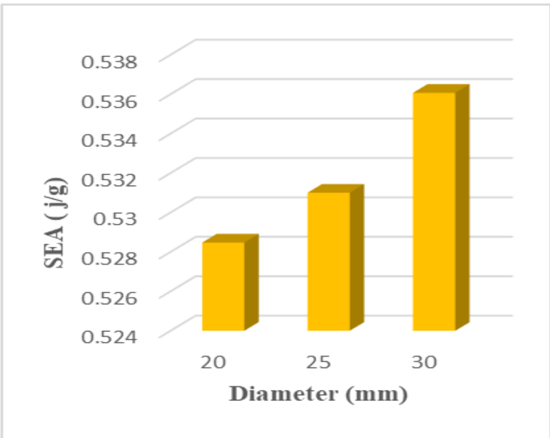


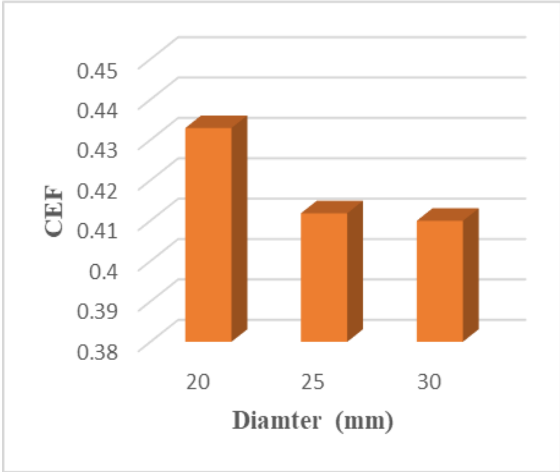
Fig.8. Force versus Displacement curves of experiments for diameter analysis



(a) EA



(b) SEA



(c) CFE

Fig. 9. Experiments results of thickness on (a) EA and (b) SEA and (c) CFE

It can be observer from Fig. 9 that, as the diameter parameter of the intrusion beam is increased from 20mm to 30mm the EA and SEA capacity of intrusion beam is increased and at same time the CFE indicator decreases with increase in diameter. From Fig. 8 it can also be clearly seen that, as diameter increase crash force increases and is maximum for 30mm diameter also area under force displacement curve increase from diameter 20mm to 30mm, and it leads to greater EA capacity. Similarly, it can be observer that after the crash force reaches maximum value, it starts to show a non-steadier response with increase in diameter during the bending of intrusion beam. Hence, it indicates that the CFE indicator decreases with increase in diameter of beam.

V. C ONCLUSIONE

In the present work, the effect of thickness, diameter and angle of mounting parameters of intrusion beam on CFE indicator is studied. Using the DoE and ANOVA analysis most influence parameter on CFE indictor is determined. From this study it can be concluded that, the diameter parameter of intrusion beam is shows more effect on CFE indicator which is 56.06%.

In the present work various simulation are also done to insight the effect of diameter parameters on CFE. From this experiments it is concluded that, if the diameter of intrusion beam is increased and after reaching the maximum crash force value the crash force starts to show a non-steadier response. Hence, CFE indicator decreases with increase in diameter of intrusion beam. It is also analyzed that, those beam having comparative higher diameter will have smaller value of CFE indicator.

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