Gopi S et al. International Journal of Recent Research Aspects ISSN: 2349-7688, Special Issue: Conscientious Computing Technologies, April 2018, pp. 40-47

Re-engineered beam design & evaluation to sustain high Impact for mid -size four wheeler's using finite element analysis: A case-study

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Abstract- **Objective of this research paper is to replace the current car door side impact beam with re-engineered design and use 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 which in turn reduces injuries of the occupant during fatalities. The usage of high strength impact beam on the car door has been implemented and its effect in the reduction of intrusion of the door structure has been evaluated.**

Keywords: Re-engineered design, Impact Beam, High Strength Steel, Yield Stress, Intrusion.

INTRODUCTION

India has the highest number of road accidental deaths in the world. Statistics say that there were 105,725 deaths reported as per the recent data provided by the World Health Organization (WHO), in the year 2013-14. Plot-1 shows the total number of road accidents, persons injured and persons killed from 2000 to 2013.Therefore to reduce the accidental fatalities, safety regulations of passenger cars have a major role in the automotive industry. Gov't of India has keenly taken up this issue and legislations have been passed and notified to the manufacturers. These industries have to meet the needs of a particular crashworthiness standard by manufacturing the nearest dimension design change in the vehicle structure and by implementing necessary structural parts that suit the overall design requirements. This research starts with the design modification of the door side impact beam, then comparing current steel beam with the newly designed steel beam, for the capability of total energy absorption. The material of the newly designed beam is replaced from low strength steel to high strength steel. Effect of the current side door impact beam and newly designed high strength steel beam are studied by finding the intrusion, acceleration and displacement at the central node of the beam, by incorporating them into the FE model of a car door and tested as per the new FMVSS214regulation.

To reduce the accidental risk of occupants in the event of side impact crash, the car doors are manufactured with impact beams. The major objective of the side door intrusion beam is to reduce injuries to the occupants by providing high strength to car door structure. Car door impact beam is mounted to the car side door inner structural part in three locations which is shown in the above figure. The door frame and three beams are designed in such a way that it minimizes the door intrusion in the event of side crash.
The resistance to the force per unit deformation of the material plays a major role in the optimization of car door structure design. The effect of the intrusion by the car door structure should be a little possible and the force developed on the car door structure during the side impact crash must be equally divided in such a way that the occupants in the car are minimally affected. In regard to these safety precautions FMVSS 214 of American standards is one of the regulations which should be taken into consideration at the time of designing the side closures.

Several studies have been carried out by many researchers in order to analyze and modify side impact beams. Harijono Djojodihardjo[1], 2010 compared results by considering steel and composite material and found 5.71% weight reduction and 57.2% increased energy absorption in composite beam. Černiauskas,A. Keršys,V. Lukoševičius and J. Sapragonas[2] Presented a paper on anti impact beams in 2010 by considering the old FMVSS 214 regulation. They analyzed impact beams by considering different cross sections and different grades of steel material. They also explained the importance of analyzing individual parts rather than complete vehicle.

Divakara H Basavaraju [6], 2005 compared the energy absorption and displacement of a side impact beam by considering carbon fiber composite material and steel., Final conclusions were that the weight has been reduced considerably, deformational energy absorption capability of composite material impact beam is more, composite materials can be used where high stiffness and strength are needed, but the cost to manufacture the composite material beam is very high. Hence it cannot match the lower end priced cars. Martin J Wilson[8], 2003 presented a thesis on applications of glass reinforced thermoplastic composites for structural automotive components. He considered side impact beam and performed both implicit and explicit analysis to develop and validate predictive models for the intra-laminar damage behavior of long glass fiber reinforced polypropylene matrix composites.

Tom Gibson[9], 2001 on improved side impact protection explained recent developments on side impact protection. He discussed in detail the severity of accidents during side impact crashes and the extent and patterns of injuries to occupant. Taking real time accident data from the year 1989 to 1997 in the whole state of Victoria for real time crash vehicle analysis he took data from National Accident Analysis Sample (NAAS) and provided injury details of side impact crashes .From the literature review it has been found that the researchers have not concentrated on reducing the intrusion. Also there are no evidences of re-engineered design to reduce intrusion and increase its effectuality. It is in this context that this research has been carried out.

Fig1. Side impact beams on mid-size car door

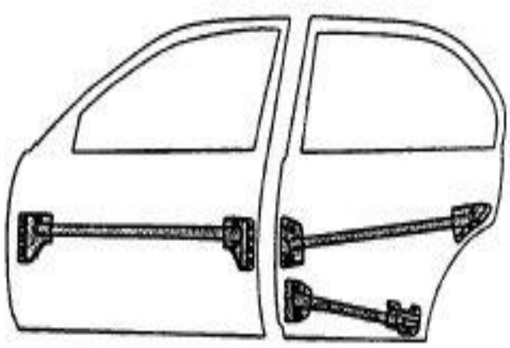
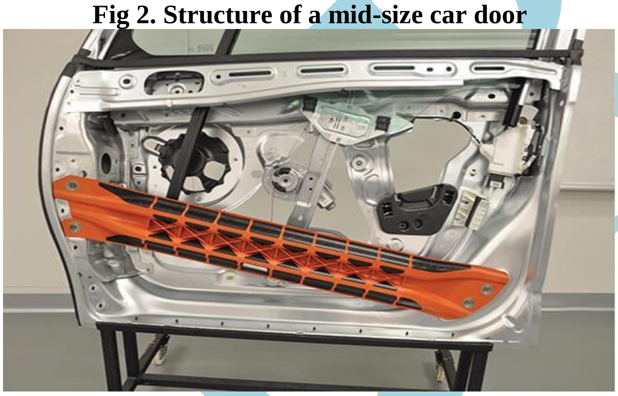


Fig 2. Structure of a mid-size car door



II. PROBLEM STATEMENT:

India has the highest number of road accidental fatalities in the world. From year 2000 to 2013 105,725 people have died due to road accidents, In that 37% of the fatalities were due to side impact crashes as per the recent report submitted by the World Health Organization (WHO)., Hence it is very critical to take necessary precautions to avoid fatalities during the event of a side impact crash. Objective of this research work is to re-engineer the current car door impact beam with modified design and use high strength steel of yield stress 1.2 GPa instead of low strength steel of yield stress 0.366 GPa in order to reduce intrusion of side closure structure and hence reduce injury to the occupant. The usage of the high strength impact beam on the car door has been implemented and its effectiveness in reduction of intrusion of the door structure has been evaluated.

Plot-1. Persons injured and killed (WHO)

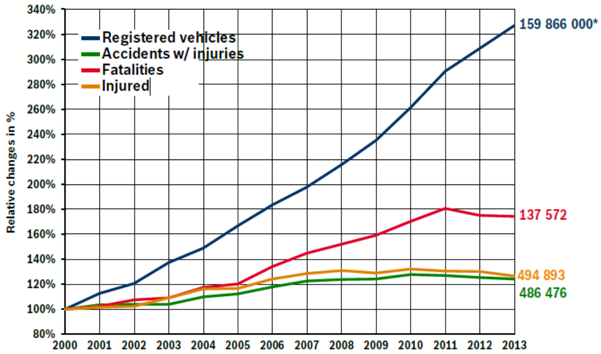


Fig 3. Simulated side impact crash (source: Ford crash test centre)

RESEARCH METHODOLOGY:

This research work starts with the re-engineered design modification of the door side impact beam, followed by comparing current steel beam with the newly designed steel beam, for the capability of total energy absorption. The material of the newly designed beam is replaced from low strength steel to high strength steel. Effectiveness of the current side door impact beam and newly designed high strength steel beam are compared by finding the intrusion, acceleration and displacement at the central node of the beam, and by incorporating them into the FE model of a car door and tested as per the new FMVSS214 regulation.

A.Finite Element model development, Simulation & Analysis

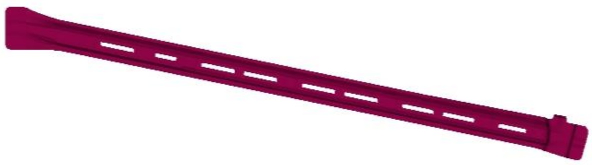
Finite Element (FE) model building of a side car door is performed by using pre processing software HYPERMESH. The physical model is described in European Commission. The simulations were performed using LS-DYNA version 971 R4.2.1. The calibration requirements of a car door, specified by the regulation FMVSS 214 are compared with results obtained from the FE model. The FE model demonstrates good agreement with the calibration specifications.

All components are modeled with shell elements. Constrained nodal rigid body elements, spherical joint and revolute joint are used to connect between the parts. The door is constrained in five locations by using single point constraint element assuming door is fixed to car's A and B pillar.

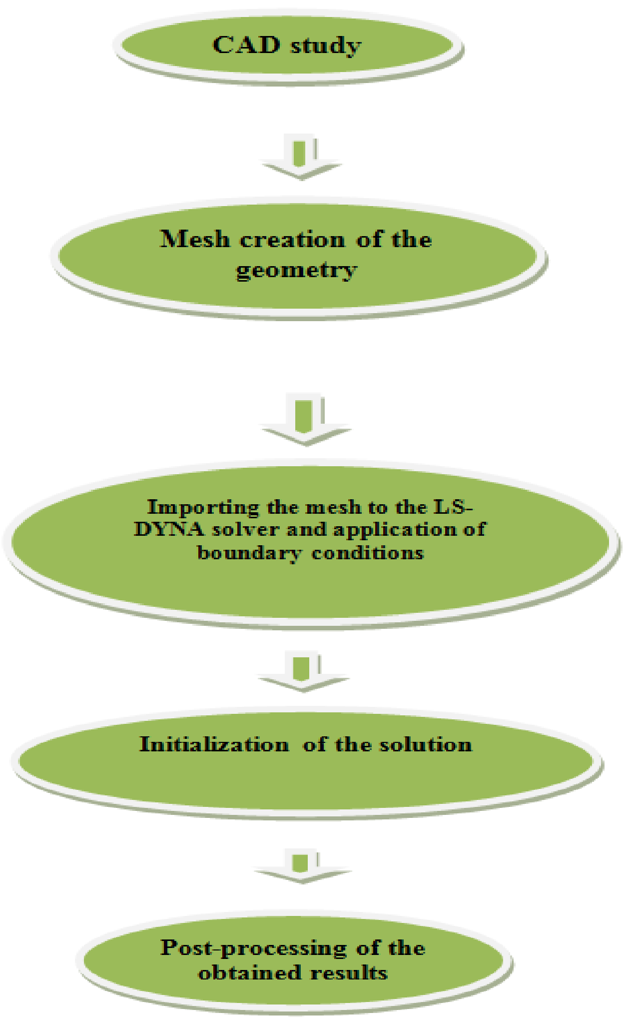
Table: FE MODEL DESCRIPTION

Element size	5mm
Number of nodes	116376
Number of elements	116002

Fig 4 Current beam



Flow Chart 1: Steps in simulation.



B. Description of pole used in simulation.

The pole is considered as an analytically rigid body with mechanical properties of steel. The diameter of the pole is 254mm and the height is 945mm. the rigid pole is a course FE modeled with the element size of 10mm, since it is a rigid body, the number of nodes does not depend on the solution time. The total mass of the pole is 20kg.

Fig 5 .pole

Table.II FE MODEL DESCRIPTION OF THE POLE

Element size	10mm
Number of Nodes	7760
Number of elements	7680

Units Used:

Table III.UNITS

Length	Time	Mass	Force
mm	millisecond	kg	Kilo Newton

Materials Models and Properties:

Table IV. MATERIAL PROPERTIES OF STRUCTURAL PARTS

Material card	MAT 24
Mass density	7.85e-06
Young's Modulus	210 GPa
Poison's ratio	0.3
Yield stress	0.19

Table V. MATERIAL PROPERTIES OF THE IMPACT BEAM

Material card	MAT 24
Mass density	7.85e-06
Young's Modulus	207GPa
Poison's ratio	0.29

Yield stress	0.366

Table VI. MATERIAL PROPERTIES OF THE GLASS

Material card	MAT 32
Mass density	2.50e-06
Young's Modulus	73GPa
Poison's ratio	0.20
Yield stress	0.0412

Table VII. MATERIAL PROPERTIES OF THE POLE

Material card	MAT 20
Mass density	7.85e-06
Young's Modulus	210GPa
Poison's ratio	0.3

Fig 6 : Effective plastic strain

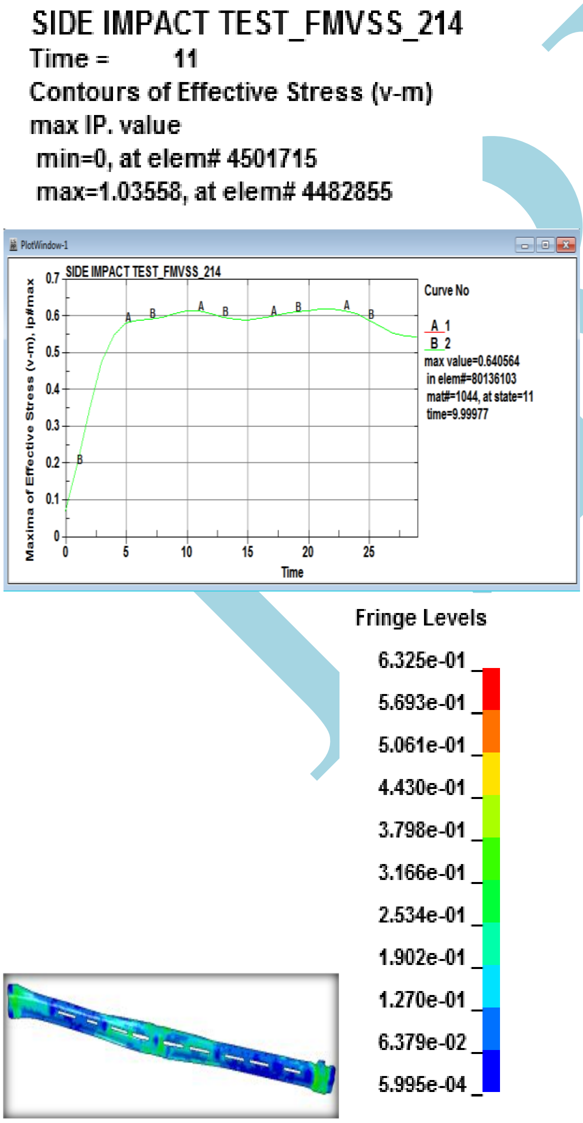
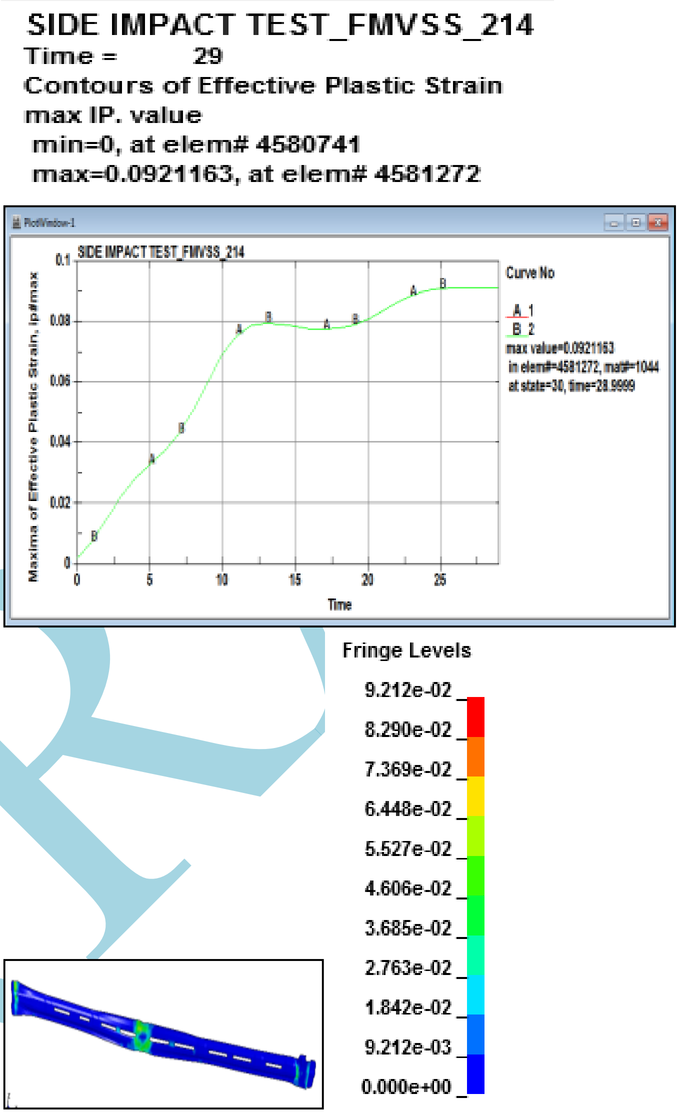


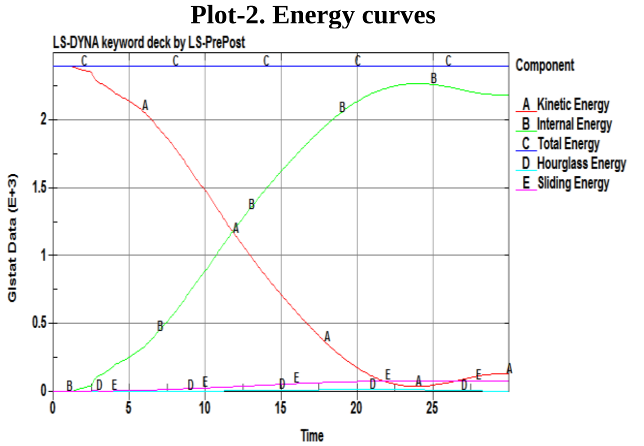
Fig. 7. Effective plastic strain



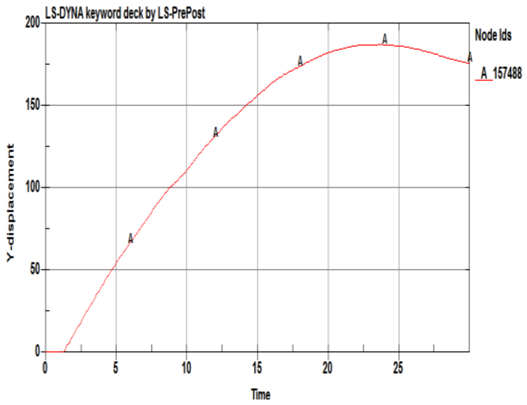
C.Results

Below figures show the energy curves for the FE model. The kinetic energy developed due to velocity of the pole is 28 x E3 KJ. The kinetic energy is minimized by internal energy developed due to material strength. Finally according to law of conservation of energy, the total energy remains constant.

Plot-2. Energy curves

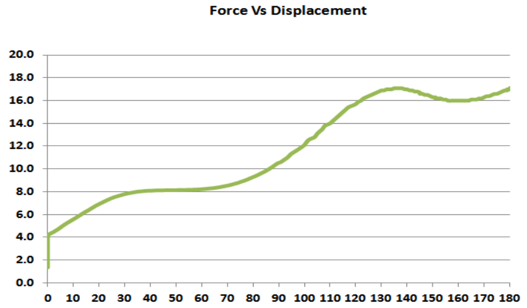


Plot-3. Maximum displacement of intrusion beam



Plot shows displacement of impact beam at its center location. The maximum displacement is at 180 mm. Acceptable value for FMVSS 214 regulation is 154 mm. Hence, it is very essential to increase the strength of the beam to reduce the intrusion of the car door.

Plot-4.Displacement v\s force curve



Above graph shows the displacement v/s force curve. The maximum displacement was noticed at 180mm mid location of the beam.

D. Re-engineered Design of Impact Beam.

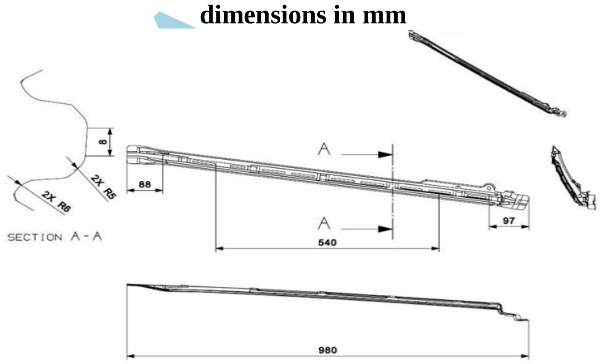
The energy absorbing ability of the material depends on section modulus. Z=Section modulus, can be written as

$$Z = I/Y \quad (1)$$

where, I = Moment of Inertia, Y max = distance from neutral axis.

C sections, circular tubes, and rectangular tubes are the different cross sections used for impact beams. In all of the above sections resistance to deformation can be enhanced by increasing its thickness. The mounting location of the re-engineered beam has not been changed. The re-engineered beam contains curve type side wings which provide additional resistance to deformation, causing a considerable reduction in displacement. Some portion of the impact beam is under compression and some under tension, so one can expect an increase in spring back effect on the entire cross section. When the material gets deformed in its plastic state, the largest portion of the energy is absorbed by the side wings. Under the application of load it is expected that the curved side wings will fold inwards. Smooth flow in the fillet region ensures that high stress concentration factor is avoided. The total length of the impact beam is 991 mm. The highest displacement is expected in the mid location of the beam and it is identified to be 570 mm long (mid span) and was chosen according to the applied load position. The impact beam c/s section is like the shape of the English letter M. It is 41 mm wide at the widest section. The thickness of the beam is 1.6 mm. The total mass of the beam is 0.80 kg.

Fig 8 Re-engineered beam design CAD model, all dimensions in mm



E. Finite element Model of the Re-engineered beam:

The geometry creation of side impact beam is done by using NX and all the necessary preprocessing functions are performed by using hyper mesh. To get close results we have modeled 5 mm global size. The re-engineered designed beam replaced by current beam to the car door.

Fig 9 FE model of the new beam

Fig 10 .Von misses stress

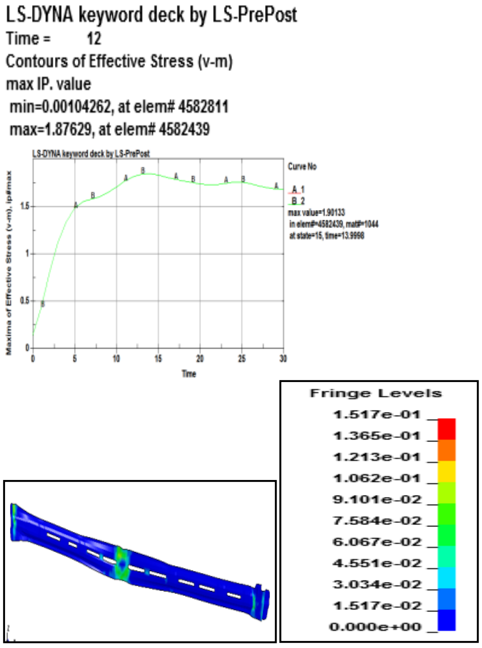
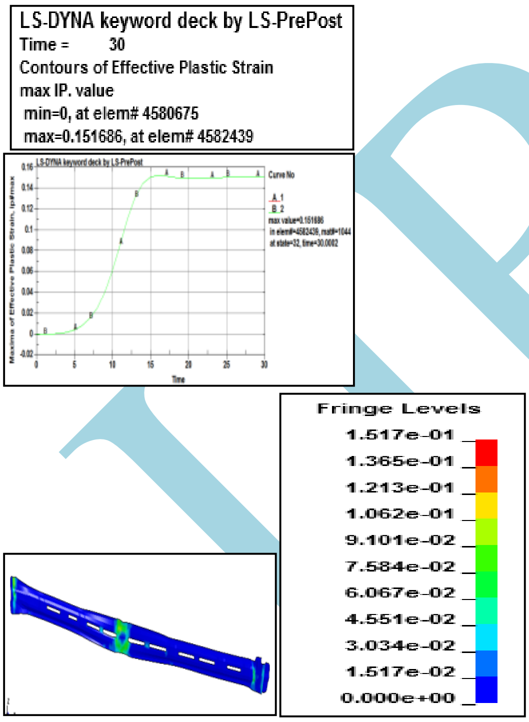


Fig11. Effective plastic strain



F.Analysis& Results

Plot-5, 6, 7 shows the displacement of the impact beam for three cases.

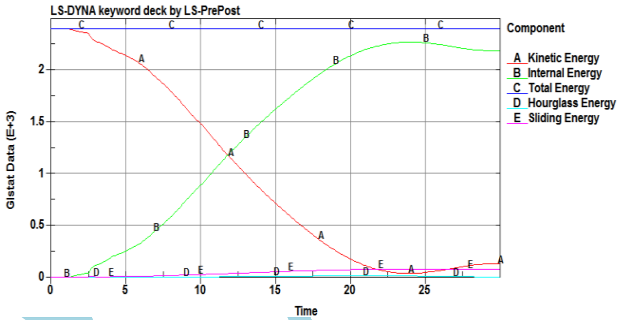
Case 1: The maximum displacement was identified at 188 mm for the current beam.

Case 2: The maximum displacement is identified at 171 mm for the new beam without changing the material.

Case 3: The maximum displacement is identified at 140 mm for the newly designed beam with high strength steel.

According to the new FMVSS 214 regulation, the max displacement should not be more than 154 mm. In case 2, re-engineered beam noticed a displacement of 171 mm. By performing a number of iterations optimized the design and finally updated the material. The maximum displacement in case 3 is 140 mm which is less than upper limit value of FMVSS 214 new regulation. Comparing the current beam and new high strength steel beam, nearly 20% of displacement has been reduced.

Plot-5. Energy curves



Plot-6. Maximum displacement

Plot-7. Force v/s displacement curve

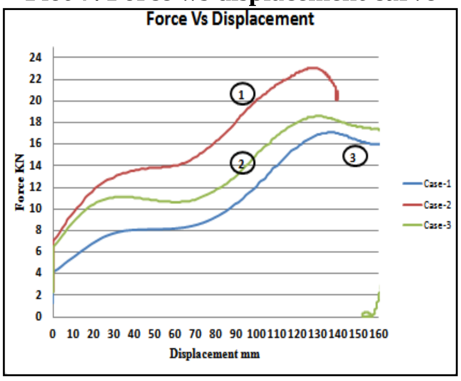
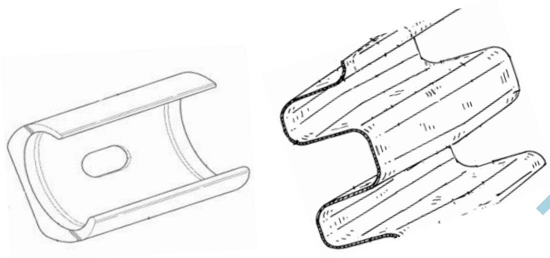


Table VIII. COMPARISON OF CURRENT BEAM WITH RE-ENGINEERED BEAM

Parameter	Current beam	Re-engineered beam

Cross Section	C type cross section.	M type cross section.
Width	Uniform width along its length.	Wider in the middle to improve strength.
Edges	Cornered edges along its length; this affects its force distribution.	Round edges; this facilitates smooth distribution of force.

C/s of current beam   C/s of Re-engineered beam



VI. SELECTION OF MATERIAL

Material selected is DOCOL-1200, which is a high strength steel. All material properties have been optimized and selected referring to paper "High strength and ultra high strength steels for weight reduction in structural and safety related applications" by Jan-Olof Sperle and Kennet Olsson SSAB Tunnplåt AB, Borlänge, Sweden

TableIX. MATERIAL DESCRIPTION OF HIGH STRENGTH STEEL

Mass density	7.85E-06 kg/mm^3
Young's modulus	210 GPa
Poisons ratio	0.3
Yield strength	1.2 GPa

V. CONCLUSION

Effectiveness of the current side impact beam with current materials compared with the re-engineered impact beam with steel of high strength, by testing the beams according to FMVSS-214 regulation on Re-engineered designed side impact beam, There is a considerable reduction in the intrusion of the side door structure, which leads to decrease in injuries due to side impact crashes. By analyzing and comparing the computational results of the current impact beam and the re-engineered high strength steel beam it can be concluded that there is a noticeable reduction in the deformation of impact beam by nearly 25%. By using new high strength steel beam, it is identified that there is an increase in total energy absorption by 40 %. High strength steel is more effective for the new FMVSS 214 regulation. The manufacturer can manipulate the mechanical properties of the high strength steel material by using heat treatment processes. High strength steel material is preferred when high stiffness and high strength are needed.

VI. SCOPE OF RESEARCH

Experimental tests need to be conducted before practical implementation of the high strength steel door impact beam in car door. By investigating the occupant injury parameters, one can verify the effectiveness of the new side impact beam with high strength steel using test dummies in LS-DYNA. The energy absorbing capability of the impact beam can be enhanced by using different cross sections.

VII.REFERENCES

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