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Design and Analysis of Compatibility of Crash Box with Trigger and Thickness Variation for Vehicle Frontal Part During Low Velocity Collision

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***Abstract*- The frontal impact as per the statistics is the most common means of phenomena when it comes to collision and thereby results in several injuries and fatalities. Therefore the design of crashbox has become an important area of focus for vehicle structure to deform and absorb the impact energy during collsion. The crash box deforms by absorbing the force and reduces the force acted on the longitudinal members there by preventing the collision force intrusion to passenger cabin. Triggers can be implemented in the design of crash box to help in achieving sequential deformation pattern. The crashbox is tested at 15 kmph based on RCAR (Research Council for Automobile Repairs) regulation. A crashbox of a Sedan has been measured and designed to been taken as a benchmark. A hexagonal crashbox has been designed with trigger holes and trigger thickness variations and is compared with the benchmark Sedan crashbox to determine its deformation characterisitcs. The main objective is to design a crash box with trigger and thickness variation to aid the longitudinal members using Creo 2.0 software and analyse the overall behaviour & characteristics using the ANSYS software.**

***Keywords*- Crashbox, Triggers, ANSYS.**

I. INTRODUCTION

Now a days, accidents involving passenger vehicle account for total road accidents which causes increased number of injuries and fatality. Therefore it is necessary to improve the crashworthiness of passenger vehicles and so, the design and optimization of crash box in M1 category vehicle is one of the important considerations to improve the crashworthiness of vehicle. The crashworthiness is the subject that deals with the concept of optimizing the vehicle structure to actuate controlled deformation maintaining sufficient space so that the impact force can be managed by the restraint systems to minimize crash loads transfer to the vehicle occupants.

For a head on collision which is most common among passenger vehicles the frontal structure needs to be strong and absorb sufficient energy to prevent the impact force from getting into passenger cabin. For the development in this where the Crashbox comes into play.

Vehicle safety has become predominant with the implementation of various crash regulations in different regions which require the vehicle to satisfy certain criteria for securing good ratings in the crash tests, which forces the manufacturers to make safer cars. But there is always a need for manufacturers to decrease the weight and cost of the automobile by reducing the mass of the vehicle. So even though a single component is optimized and if there is reduction in the weight of the component and performs near to the component it replaces it's a good alternative.

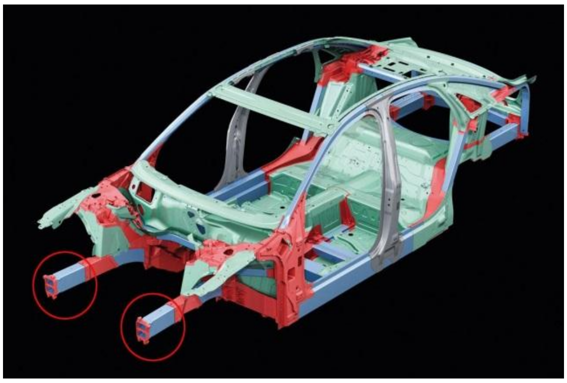

Fig 1. Vehicle Exoskeleton.

From the above Fig 1 it can be seen that Crash box is a device mounted between front bumper and main frame of car to absorb impact energy during collision. It tends to buckles when axial compressive force exceeds limit to execute sequential deformation and energy is absorbed during buckling and damage to mainframe or the longitudinal members are avoided. Vehicle safety has become predominant with the implementation of various crash regulations in different regions which require the vehicle to satisfy certain criteria for securing good ratings in the crash tests, which forces the manufacturers to make safer cars. But there is always a need for manufacturers to decrease the weight and cost of the automobile by reducing the mass of the vehicle. So even though a single component is optimized and if there is reduction in the weight of the component and performs near to the component it replaces it's a good alternative.

This analysis is also done to study the effect of each trigger configurations on the energy absorption of crash boxes in low velocity impact, based on the 'Research Council for Automobile Repairs' test popularly known as the 'RCAR' test [1].

This study focuses on the implementation of trigger holes and thickness variation triggers on the Crashbox to determine the behaviour during low velocity frontal collision. Triggers can be implemented in the design of crash box to help in achieving desired deformation pattern without abrupt deformation. Progressive triggering through variable pattern formulation effectively triggers and initiates a more stable collapse.

Hussain et.al. paper showed that triggers can be placed near the region which is impacted by the impactor, so that due to presence of trigger there is a local deformation in that region and then the component can deform in a sequential manner rather than deforming catastrophically. Therefore a benchmark sedan crashbox is take and developed using the CREO software and an hexagonal crashbox with trigger holes and thickness variation is also designed and compared for its characteristics behaviour with respect to the benchmark crashbox on its deformation and internal energy characteristics.

II. LITERATURE SURVEY

There are various crashworthiness requirements like deformable, yet stiff, front structure with crumple zones to absorb the crash, properly designed side structures, strong roof structure, properly designed restraint systems, etc. Out of all the above requirements, one option is that the vehicle front structure should be deformable to absorb energy. This can be effectively done with the help of crash box [1].

Deformable,yet stiff, front structure with crumple zones to absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and prevent intrusion into the occupant compartment, especially in case of offset crashes and collisions with narrow objects such as trees. Deformable rear structure to maintain integrity of the rear passenger compartment and protect the fuel tank. Properly designed side structures and doors to minimize intrusion in side impact and prevent doors from opening due to crash loads. Strong roof structure for rollover protection. Properly designed restraint systems that work in harmony with the vehicle structure to provide the occupant with optimal ride down and protection in different interior spaces and trims. Accommodate various chassis designs for different power train locations and drive configurations. Automotive structures, however, must meet all previously mentioned service load requirement, plus it must deform plastically in a short period of time (milliseconds) to absorb the crash energy in a controllable manner.

It must be light and able to be economically mass-produced. Further, the structural stiffness must be tuned for ride and handling, NVH and must be compatible with other vehicles on the road, so it is not too soft or too aggressive [5]. Therefore the Crashbox designed is based on structural steel material and is benchmarked with a Sedan Crashbox to understand its deformation and energy absorption characteristics.

Vehicle safety has become more important with the implementation of various crash regulations in different countries which require the vehicle to satisfy certain criteria for obtaining good ratings in the crash test, thus forcing the manufacturer to make safer cars. But there is always an urge for manufacturers to decrease the weight and cost of the automobile by reducing the mass of the vehicle.

Due to need of reduction in weight of vehicle automobile parts are made of thin metal sheets, thus making it more difficult for the automobile structural components to absorb sufficient energy in the event of a crash [1]. In this study, the effect of the compatability of a trigger and thickness variation optimized crashbox is designed and analysed for low speed frontal collision of passenger vehicles.

Hussain et.al [1], highlighted the effect of triggers on crashworthiness of GFRP crashboxes made of various cross sections and also on the energy and force variation; with the variation of cross section of the crash boxes. The parameter focused in this study was S.E.A as it reveals the energy absorption characteristic for a component considering its mass. Triggers can be placed near the region which is impacted by the impactor, so that due to presence of trigger there is a local deformation in that region and then the component can deform in a sequential manner rather than deforming catastrophically.

Hence, the objective and takeaway of this study is to highlight the effect of triggers on crash boxes made of various cross sections and also to showcase the relative effect of each trigger configuration on the energy and force level achieved with the variation of cross sections of the crash boxes.

Mizuno et.al [2], article focuses on the effectiveness and evaluation of SEAS investigated by frontal offset crash tests. The SUVs, with and without the SEAS, were impacted against a small car. it was demonstrated that the

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SEAS of an SUV was effective for improving structural interaction in crashes into a small car even though there was a lateral mismatch between the SUV's SEAS and the small car's longitudinal structural member. In this crash type, the SEAS engaged the front wheel of the small car and the deformation for the small car was reduced due to the energy absorption by the additional energy absorber.

From this, the take away for the mini project is the area of collision , at the crashbox structure where this project also travels, for reducing effect of low speed collision at frontal part of the car focussing on sedans and hatchbacks. From the paper, the energy absorber also focuses on the reduction of the deformation on the smaller vehicle, and therefore the crashbox has to withstand the similar scenario but at low speed collision.

The RCAR test procedure to assess a vehicle's damageability and reparability. Research Council for Automobile Repair (RCAR) front crash test is performed at 15 kmph. The RCAR test applies to passenger cars, pickups and SUVs. The RCAR bumper test encourages vehicle manufacturers to produce effective bumper systems that feature tall energy absorbing beams and crash boxes that are fitted at common heights and can effectively protect the vehicle in low speed crashes.

There is one impact into a non-deformable barrier. The front face of the barrier is perpendicular to the direction of travel of the test vehicle. The mass of the barrier exceeds twice that of the test vehicle

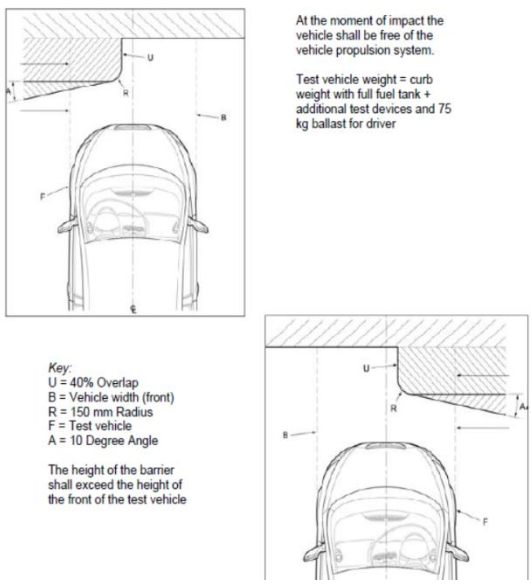

Fig 2. RCAR Frontal Impact.

The assessment as in Fig 2 includes an estimation of the vehicle damage (physical damage and repair cost) in two impacts: A 15 km/h frontal impact into a rigid barrier and a rigid-faced mobile barrier striking the rear of the stationary vehicle at 15 km/h RCAR implemented two 15 km/h crash tests in order to encourage vehicle designers to limit unnecessary damage to the structure of passenger vehicles in low speed front and rear crashes.

The barrier may be secured to a rigid weight or anchored directly to the floor in such a way that it cannot move during impact. From the RCAR regulation the Frontal impact at 15kmph is considered to test the compatibility of the hexagonal Crashbox in this study.

III. DESIGN OF CRASHBOX

Based on literature and benchmarking, a crash box of passenger vehicle is selected to improve the crashworthiness of vehicle. The Benchmarking crashbox is taken from a sedan to make sure the dimensions with which the optimised crashbox is developed actually syncs in with the real world scenario to avoid false designing. The benchmark crashbox has a rectangular shape of 110mm×80mm.

The dimensions of the benchmark Crashbox are given in the table 4.1, with its indentation at a distance of 50mm,95mm and 145mm from the top of the crashbox. The addition of a newer crashbox has to be analysed for the its length and trigger configurations, as the increase in length of the crashbox can cause a considerable increase in the length of the vehicle and thats the reason Benchmarking is done with a standard sedan Crashbox. The design of the benchmark crashbox was done in Creo 2.0 modelling software.

Table 1. Benchmark Crashbox dimensions.

Length	110mm
Height	200mm
Width	80mm
Hole Diameter	5mm
Thickness	3mm

Table 2. Indentation dimensions.

Diameter	20mm
Depth	10mm

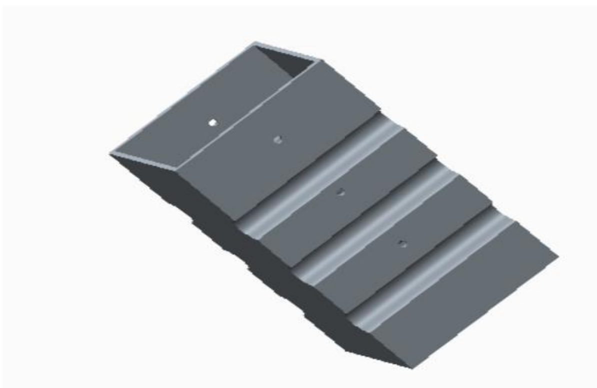

Fig 3. Designed Benchmark Crashbox.

The Test crastbox i.e The hexagonal Crashbox is the Optimized crashbox with trigger an thickness variation modifications which is analysed in this study and is compared for its characteristics during low velocity frontal impacts at 15kmph based on RCAR regulations. The hexagonal crashbox is considered due to its better energy absorbing Characteristics based on the Hussain et.al, wherein he showed the effect of triggers on crashworthiness of GFRP crashboxes made of various cross sections that includes Hexagon Crashbox.

The Optimized Crashbox is designed in Creo 2.0 modelling software by considering the Benchmark Crashbox so as to abide by the standards. The Hexagon Crashbox is inscribed inside a circle of radius 36mm and The trigger slots and thickness variation are adopted as per Hussan et.al. [1]. The Trigger slots allows for a sequential deformation of the crashbox prevent its from abrupt Collapsing. The thickness variation triggers (Highlighted Green) parts are placed at a distance of 70 mm and 130 mm from the top of the crashbox.

The triggers can be placed near the region which is impacted by the impactor, so that due to presence of trigger there is a local deformation in that region and then the component can deform in a sequential manner rather than deforming catastrophically. Hussain et.al and Sarage et.al Showed the characteristics of Crashbox with respect to trigger slots and thickness variation and ribbing slots respectively.

This study focuses on the combined performance of trigger slots and thickness variation within a single crashbox during low velocity impact with respect to the benchmark crashbox. The constructional dimensions of the hexagon crashbox are given in the table 3.

Table 3. Hexagon crashbox dimensions.

LENGTH	72mm
HEIGHT	200mm
THICKNESS	1.8mm
TRIGGER THICKNESS (Highlighted green)	1.9mm
HOLE DIAMETER	10mm

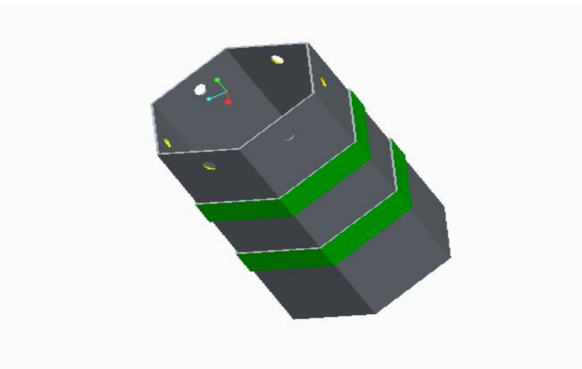

Fig 4. Hexagon Crashbox with Triggers.

So this the constraints with which the Hexagon crashbox is designed using the trigger slots and thickness variation in its structure for better deformation and energy absorbing characteristics during low velocity frontal collisions. The material used here is Structural Steel, in simple words consist of varying composition of 0.565%C, 1.8% Si, 0.7% Mn, 0.045% P and 0.045% S.

Table 4. Material Properties.

Structural Steel Properties	
Young's Modulus(Mpa)	200×10^3
Poissons' Ratio	0.3
Mass Density (Kg/M^3)	7850
Tensile Yield Strength(Mpa)	250
Tensile Ultimate Strength(Mpa)	460

IV. METHODOLOGY

The hexagonal crashbox and Benchmark crashbox are to be analysed for their crashworthiness during low speed front impact.The analysis is to be done in Explicit dynamics division of the ANSYS at 15kmph as per RCAR for low velocity frontal collisions.The materials with which the crashboxes are analysed is Structural steel.

The bumper along with the crashbox is fixed at the non impact face. The end of the crashbox is fixed and on the opposite side a velocity of 15kmph is applied as per sarage et.al.The total deformation, equivalent stress is to be analysed for explicit dynamics.

The Static structural analysis is also done to determine the deformation and stress acting on the crashbox. The Boundary condtions are set as per Sarage et.al for analysing the crasboxes at low velocity frontal impact based on the RCAR regulations. For numerical analysis, the model is prepared as shown in figure 5 and simulation is carried out using ANSYS explicit dynamics tool.

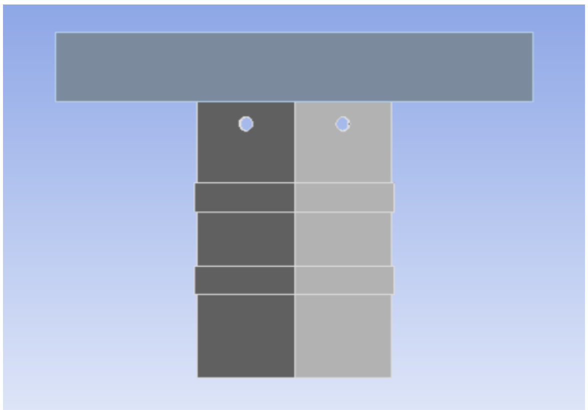

Fig 5. Analysis Setup.

The benchmark Crashbox is analysed to set the values as a standard value to be compared with the hexagon crashbox for its anlaysis .The models created in Creo 2.0 modelling

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software is designed with a bumper like structure with 50mm thickness for analysis. The materials are taken as Structural steel with its properties as mentioned in table 4. The part models are then imported on to the workbench window in the design modeller.

The meshing charcateristcs are kept at 5mm for better accuracy. The velocity and the fixed portion is set as per the boundary conditions given in the table 5. The Crashboxes are analysed for its characteristics based on the total deformation and equivalent stress. The internal energy characteristics are also determined followed by the specific energy absorption is calculated based on the analysis .

Table 5. Boundary Condition.

PARAMETER	VELOCITY
Frontal part	15kmph
Crashbox (Backend)	fixed

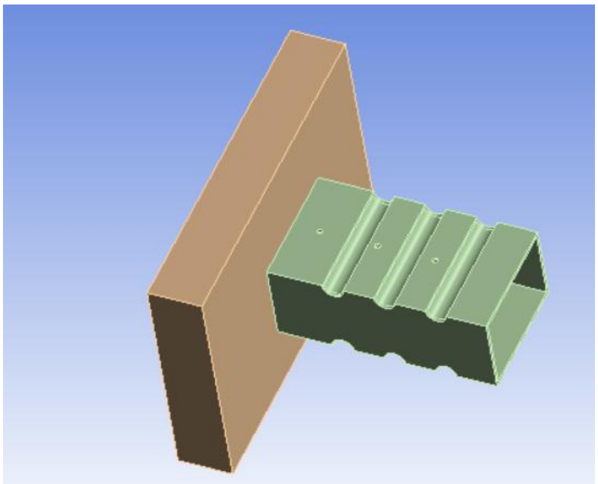

Fig 6. Benchmark Crashbox Analysis Condition.

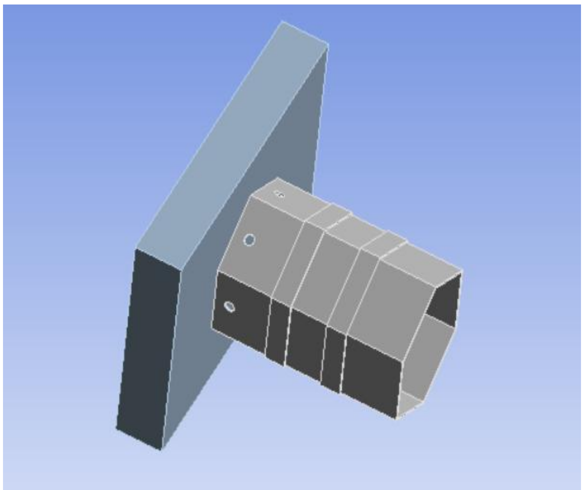

Fig 7. Hexagon Crashbox Analysis Condition.

The Explicit dynamics analysis in ANSYS is carried out on the Benchmark crashbox and the Hexagonal Crashbox for low velocity frontal collision at 15kmph as per RCAR regulation and the energy summary graphs are Determined and studied. The graphs gives the variation of the Kinetic and internal energy of the Crashboxes during the collision. The Total Deformation and the equivalent Stress of the crashbox is taken as the output result analysis.

V. ANALYSIS RESULTS

1. Benchmark Crashbox:

The analysed graphs for energy summary, Total Deformation and the Equivalent stress of the Crashboxes are being studied onto.

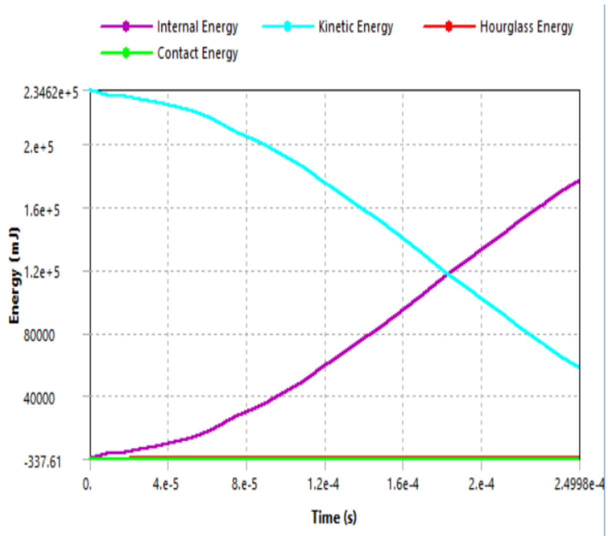

Fig 8. Benchmark Energy Summary.

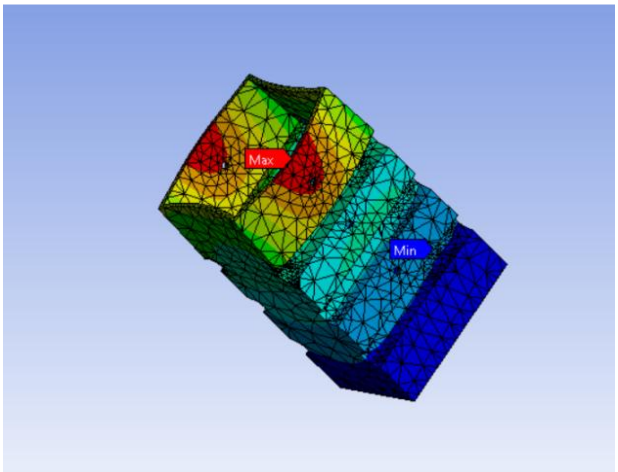

Fig 9. Benchmark Crashbox Deformed.

The deformation and the energy variation of the Benchmark Crashbox is shown above and these characteristics are compared with the modified Hexagonal Crashbox to determine how the optimized crashbox is efficient During the low speed frontal impact pf the passeneger vehicles. The Characterisitcs results of the Hexagon Crashbox are given below.

2. Hexagon Crashbox:

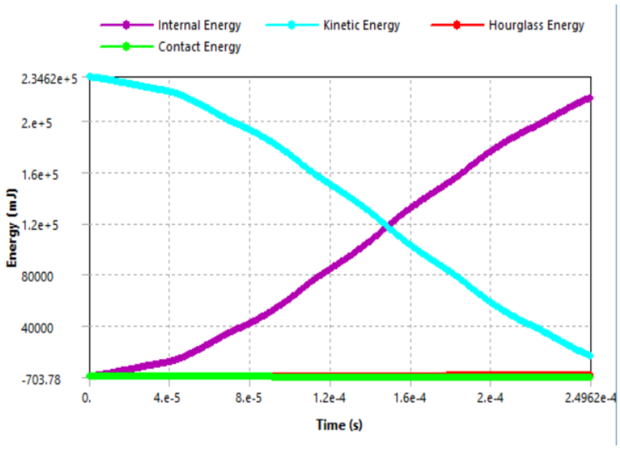

Fig 10. Hexagon Energy Summary.

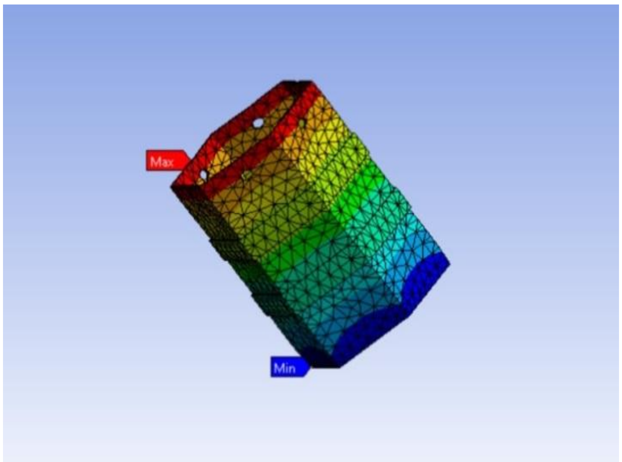

Fig 11. Hexagon Crashbox Deformed.

3. Observed Results:

Table 6. Analysis Results of Crashboxes.

Properties	Benchmark	Hexagon
Mass	1.4761Kg	1.442 Kg
Velocity	15 KMPH	15 KMPH
Internal Energy	180 J	215 J
Specific Energy Absorption	122 J/Kg	150 J/Kg
Total Deformation	0.83mm	0.71mm
Equivalent Stress	436MPa	395MPa

From the above results its shown that the the hexagonal crashbox has better characteristics in terms of energy absorption with respect to the Benchmark crashbox. The hexagonal crashbox with further optimisation can be of a better alternative compared to the standard benchmark crashbox in the constructional and low speed velocity impacts related aspects.

VI. CONCLUSION

The hexagonal crashbox has a combined performance of trigger holes and thickness variation. The deformation of the hexagon crashbox is less than the benchmark crashbox as per the analysed values. The overall weight of the hexagon crash box is reduced by 2% with respect to benchmark crashbox.

The internal energy of the hexagon crashbox is 19% higher when compared to the benchmark sedan crashbox. The specific energy absorption of the hexagonal crashbox is 22% higher than the benchmarked sedan crashbox. Therefore the percentage increase in the internal energy and specific energy absorption depicts that the Hexagon crashbox can perform better and on further optimisation in future analysis with static structural, hexagon will make for a better alternative.

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