ISSN 2395-1621

Analysis of Energy Absorption Capacity of Crash Box

#1S. S. Bhosale, #2G. S. Waghmare

[1]shubhangib2000@gmail.com

#12Department of Mechanical Engineering
Sinhgad Institute of Technology and Science, Narhe, Pune-41.

ABSTRACT

Crash box is a device mounted between front bumper and main frame of car to absorb energy during collision. It buckles when axial compressive force exceeds limit. Energy is absorbed during buckling and damage to main frame is avoided. Recently, it has been strictly required to satisfy both reduction of body weight and improvement of crash worthiness in the design and thus, regarding crash box, it is required to ensure high energy absorption. This paper is aimed to investigate the most suitable structure of crash box with different materials at conceptual design stage. The various structures of Crash Box such as Square, triangle and hexagonal were analyzed with Aluminium, Epoxy and carbon Fiber materials.

Keywords: Crash box, crushing load, energy absorption, FEA, ANSYS.

ARTICLE INFO

Article History

Received: 8th July 2019

Received in revised form :

8th May 2019

Accepted: 12th July 2019

Published online :

12th July 2019

I. INTRODUCTION

Naturally, there is an increase in the number of vehicles on the road with increase in the populace. The rate of motor vehicle accidents globally is alarming. The trend in the rate of road accidents is the same in many countries and it is growing. It is estimated that 1.2 million people are killed in road crashes and nearly 50 million are injured worldwide every year. In order to ensure the driver's safety in case of high-speed crashes, special impact structures are designed to absorb the race car's kinetic energy and limit the deceleration acting on the human body. These energy absorbing structures are made of laminated composite sandwich materials - like the whole monocoque chassis - and have to meet defined crash test requirements specified by the Formula SAE Rules and Regulations. This study covers the crash behavior of the front impact structure of crash box for maximum energy absorption and minimum critical deformation. When the body of occupant is moving (say at 55 kmph), it has a certain amount of kinetic energy. After the crash, when it comes to a complete stop, it will have zero kinetic energy. To minimize risk of injury, removing the kinetic energy as slowly Crash Box with which a car is equipped at the front end of its front side frame, is one of the most important automotive parts for crash energy absorption. Generated energy of the vehicle collided have been absorbed mainly by the plastic deformation of crash box.Position and structure of the crash box in the body structure as shown in Fig. 1.In order to make crash box absorb the entire energy in the low-speed collision, it requires that the impact force is evenly distributed, and the force value is not more than the value of permits to protect other structures from damage, and all the Kinetic Energy were absorbed.

Shape Selection: -In previous research papers, the study is done for circular, square, Hexagon Sections. The impact test results are obtained. In this paper, Triangular section, Rectangular Section, Hexagonal Section are analyzed and manufacturing of Crash Box for weight optimization is proposed. Using this cross section, we are also analyzing another set of geometry for Crash Box.

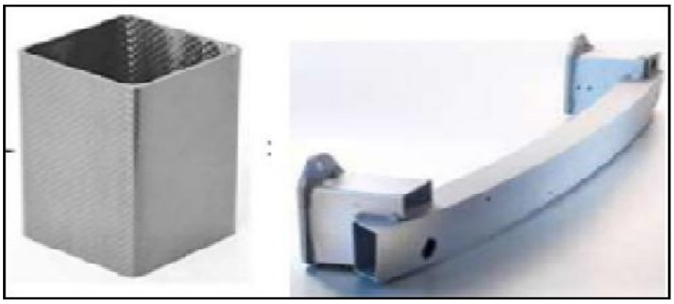

FIGURE. 1 Crash Box and Crash Box Assembly

Material Selection: -

Previously, most of the crash boxes are made of steel. However, in mid-80's the application of polymer composite material has been introduced to replace conventional material such as plastic, aluminum, and metal. There are many past research have been conducted using polymer composite where it can offer low weight, easier to produce complex shape, and high impact energy absorption capacity. The use of composite has been introduced to replace the use of conventional materials because it has an advantage of low density, high specific strength and stiffness.

In the past, study is done circular, square section, Hexagonal Sections with Aluminium and composite materials. The objective of this paper is to study & compare on Triangular section, Rectangular Section and Hexagonal Sections with Aluminium alloy, Glass Epoxy, Carbon Fiber for maximum energy absorption.

II. METHODOLGY

- Literature survey for current research regarding crash box analysis.
- Collection of Data
- CATIA design
- FEA Testing
- Experimental testing
- Comparison & Results

III. LITERATURE REVIEW

N.S.B. Yusof et.al [1] describes design of geometry profiles and the crash box material advancements, both geometry and material properties would influence the efficiency of kinetic energy absorption during collision.its benefits both academics and corporate sector as it outlines major lines of research in the crash box design. It discusses the results from 3D simulations up to laboratory experiments of crash box specimen and the effect of material selection to the characteristic of crash box device.

Yanjie LIU et.al [2] studied for the Finite Element (FE) method is applied to model the structure and material of the crash-box.Carbon steel with aluminum alloy material pipe is another method of construction. A feasible transversal surface shape of the pipe was seen to give the best 'crash worthiness' in a collision. Five types of transversal surfaces are presented and contrasted. The result in the repair cost of the pipe was shown to be the best when employing aluminum alloy square cross section.

B A Constantin et al.[3] describes the present paper focuses on the low speed urban impact, offering an overview over the actual state, the load configuration, the applicable regulation, the challenging requirements of a modern front structure, which the modern bumper has to comply with and the finite element simulation of this kind of test.

F. N. Habib1 et al.[4] describes the effect of unit cell geometry on the in plane compressive response and energy absorption behavior of honeycombs using full-scale non-linear numerical simulations. The effect of cell shape and its arrangement on the selection of honeycombs for energy absorption application is discussed and a methodology is proposed to balance the energy absorption with maximum transmitted stress.

L. Peroni & M. Avalle et al. [4] describes the behavior of square box bonded columns subjected to axial crushing was investigated.

K. Elavarasan et al.[5] this paper concluded that Thus, the automotive bumper beam was successfully analyzed using FEA- software. Finally, I-shape bumper beam is proposing to concept deign. From the analyzed results it is being concluded that the epoxy polymer/ Glass fiber can be chosen as a suitable material for making automotive bumper beam.

Omkar Garud et al. [6] studied analytical, experimental and numerical work. Various parameters like width, thickness, filler material which affects the crash box performance are studied by using Design of experiments.

Tie Wang [7] studied bumper beam by changing the material and thickness to improve the crash worthiness performance in low-velocity impact. The steel can be replaced by the carbon

Gabriel Jigaa[8] describes influence of the crash box material in order to reduce the side member permanent deformations and identified the influence of the velocity upon the crash box behavior.

IV. COLLECTION OF DATA

Mechanical properties for selected materials as shown below

Table 1 Properties of material

Parameter	Al Alloy	Glass epoxy	Carbon fiber
Young's Modulus (MPa)	7.1×104	12×103	70×103
Poisson's Ratio	0.33	0.35	0.10
Density (kg/m^3)	2770	1900	1600
Ultimate tensile strength (MPa)	310	490	600
Yield Strength(MPa)	280	65	228

V. ANALYSIS RESULTS

To check various parameters such as energy absorption capacity, various stress induced we have done some FEA simulation on the ANSYS software for the crash box designed in Catia software for Triangular, Rectangular and Hexagonal Sections models and below is total deformation results.

FEA Boundary conditions

The Velocity generated from the action of bumping velocity are applied at the region where top of the section are touching to Bumper. Assume the velocity 33330 mm/s as a worst loading scenario. For the stimulation any model in CAE software, it is necessary to provide some boundary conditions which probable in the actual model for the accurate results. This relates to the practical uses of the model.

a) Aluminium

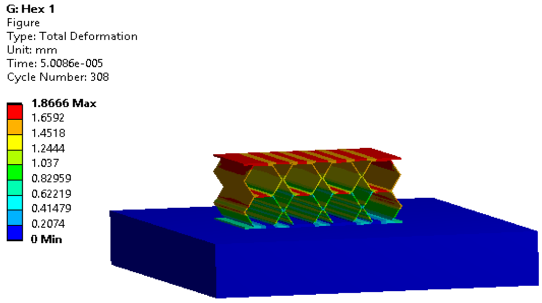

FIGURE 2. Deformed Hexagonal Section

b) Glass epoxy

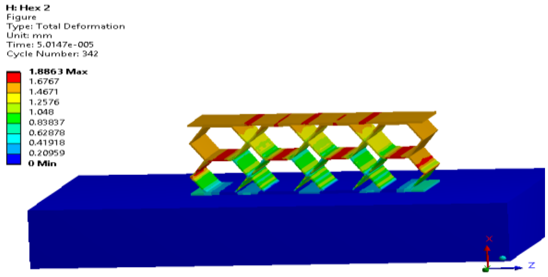

FIGURE 3. Deformed Hexagonal Section

c) Carbon fiber

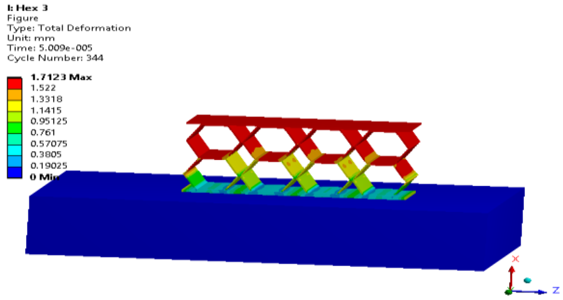

FIGURE 4. Deformed Hexagonal Section

d) Aluminium

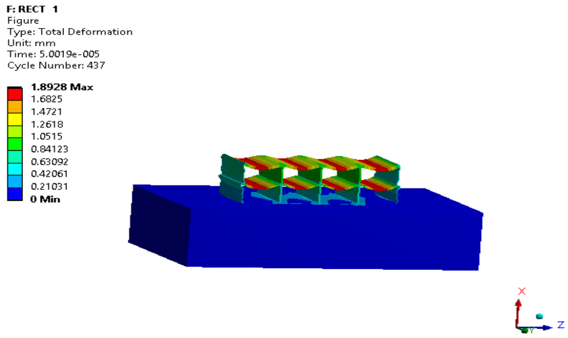

FIGURE 5. Deformed Rectangular Section

e) Glass epoxy

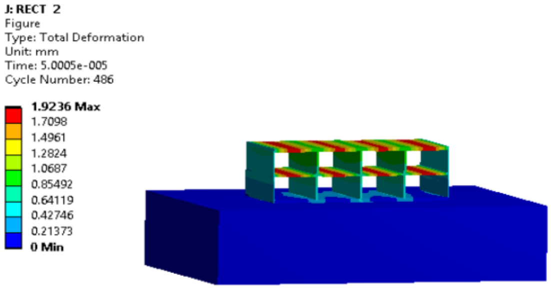

FIGURE 6. Deformed Rectangular Section

f) Carbon fiber

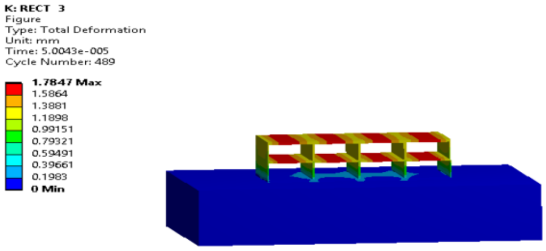

FIGURE 7. Deformed Rectangular Section

g) Aluminium

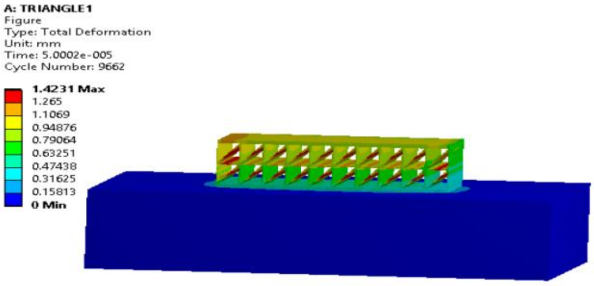

FIGURE 8. Deformed Triangular Section

h) Glass epoxy

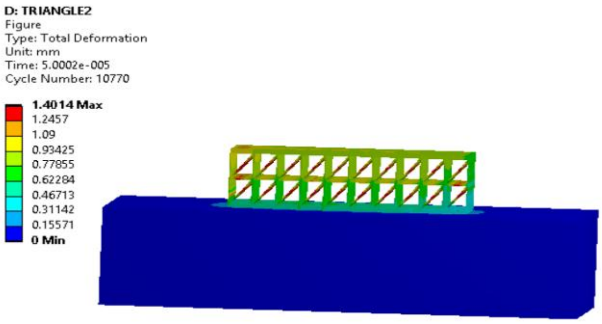

FIGURE 9. Deformed Triangular Section

i) Carbon fiber

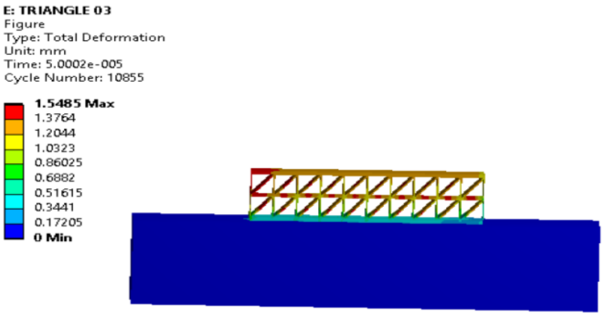

FIGURE 10. Deformed Triangular Section

FEA Results:

Currently, automotive industry relies on finite element analysis (FEA) in development of product. Analyzing the energy absorption in real impact is quite complicated and depends on different parameters. The influence of design parameters on the weight, costs or functional properties of new car models can be determined using the FEA. FEA is a suitable method to analyze the energy absorption during impact to determine the approximate deflection behavior during an impact. Weight and impact behavior parameter were compared for composite and aluminum material.

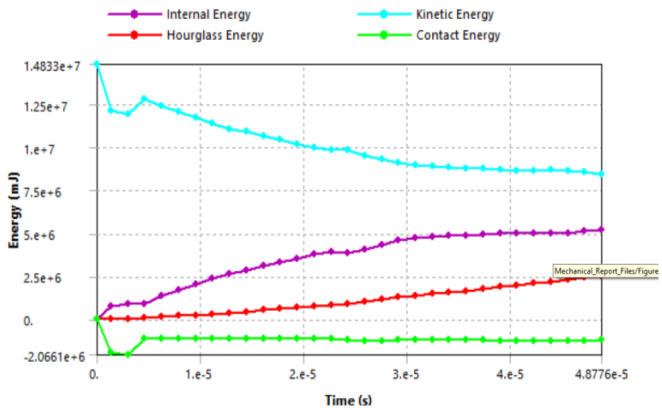

FIGURE 11. Energy graph for Hexagonal section

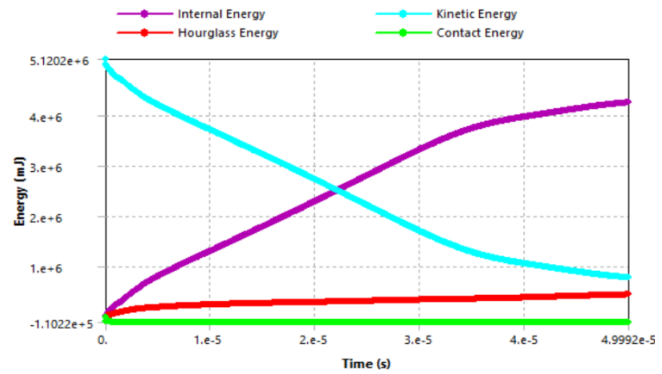

FIGURE 12. Energy graph for Rectangular section

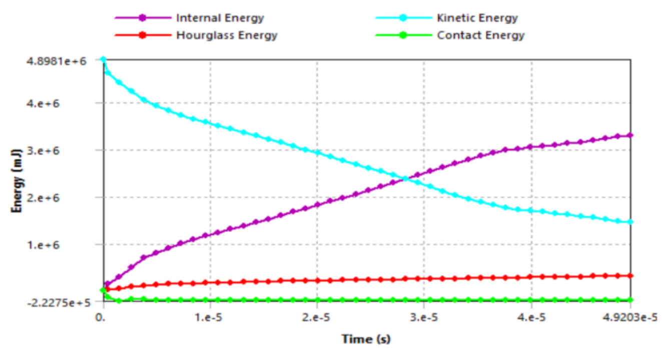

FIGURE 13. Energy graph for Triangular section

The above energy graphs we can see that the conservation of energy is substantiated. It is observed from the graphical values that the kinetic energy of the entire system drops upon collision due to sudden drop in the velocity of moving car. It is observed by the deforming structural components, increases simultaneously, thus keeping the total energy constant.

Below table show the FEA results for all threes shapes with all three materials considered.

TABLE 2: FEA Results

Shape	Material	Mass (kg)	Deflection(mm)	Von-Mises stress (M Pa)
Hexagonal Section	Aluminium alloy	2.11	1.866	1217.4
	Glass Epoxy	2.0461	1.8863	1458.8
	Carbon Fiber	2.0581	1.7123	484.98
Rectangular Section	Aluminium alloy	0.6145	1.8928	1560.4
	Glass Epoxy	0.5934	1.9236	1775.8
	Carbon Fiber	0.5969	1.7847	506.63
Triangular Section	Aluminium alloy	0.139	1.4231	1595.6
	Glass Epoxy	0.1342	1.4014	2933.2
	Carbon Fiber	0.135	1.5486	514.52

Table 3: Impact Test results

Material	Impact strength (kJ/m^2)
Al	1579
Composite Material	252.79

VI. ANALYTICAL ANALYSIS

Absorbed energy: Absorbed energy is energy absorbed by component during its plastic deformation. Are a under load–displacement curve is absorbed energy.

$$E = \int_0^{\delta_{max}} P(\delta)d(\delta)$$

$$P_m = \frac{E}{\delta_{max}}$$

P_m – Mean crushing load,
E - Absorbed energy,
δ_{max} - Total displacement.

This Equation is derived by equating large number of experimental data. Mean crushing load is evaluated by means of following formula:

$$P_m = K\sigma_o b^{\frac{1}{3}} t^{\frac{5}{3}}$$

Where, P_m, b and t are mean crushing load, width and thickness respectively. σ_o is yield stress. Value of b is taken as mean of box widths and K is a dimensionless constant. Value of K is proposed to be 13.06. (load P_m expressed in N, yield stress σ_0 in MPa, and all dimensions are in mm).

VII.RESULTS & DISCUSSION

By comparing FEA results, it is clear that Hexagonal section having better energy absorption capacity than Rectangular & Triangular section by considering Aluminium, Glass Epoxy and carbon fiber. From analysis results, it is observed that the Hexagonal shaped crash box can store more energy than Rectangular & triangular shaped crash box. Since from the results, Aluminium shows better energy absorption characteristics, it is recommended that the frontal rails of an automobile passenger car be produced with Aluminium material. Along with the above said benefits, the Aluminium also boasts of being considerably lighter, thus gaining advantage on better acceleration and speed of the car. Added to it is the advantage of better fuel economy which is the playing card in today's competitive passenger vehicle market. Also, with hybrid technology and electric vehicles paving the way for future, where weight reduction is a prime motive to aid the added weight of the extra drive mechanisms, Aluminium structured vehicles are the future of cost effective automobile passenger cars.

VIII. CONCLUSION

This analysis work for different shapes Triangle, Rectangle and hexagon with different material AL, Epoxy Glass, Carbon fiber were investigated for crash box. The following conclusions are drawn:

1. Crush box components absorbing energy are studied through basic types of different cross sections.
2. Triangular and Rectangular profile have significant Lower energy absorption than the other profiles.
3. More study on different composite materials and improvements in additional can achieve more improvement on deformation and energy absorption.

REFERENCES

[1] N.S.B. Yusofa,b, S.M. Sapuana,c,* M.T.H. Sultand ,M. Jawaida , M.A. Malequee, "Design and materials development of automotive crash box: a review",*ScienceDirect*29(2017),129-144

[2] Yanjie LIU, Lin DING "A Study of using Different Crash Box Types in Automobile Frontal Collision", *IJSSST.*

[3] B A Constantin1,D Iozsa2 and G Fratila,"Studies about the Behavior of the Crash Boxes of a Car Body",*International Engineering Research and Innovation Symposium,*160 (2016).

[4] F. N. Habib1 & P. Iovenitti1 & S. H. Masood1 & M. Nikzad1,"Cell geometry effect on in-plane energy absorption of periodic honeycomb structures",*Springer,*September 2017.

[5] L. Peroni & M. Avalle "Experimental investigation of the energy absorption capability of bonded crash boxes",*WIT Transactions on The Built Environment*, Vol 87,2006.

[6] K. Elavarasan, D. Gopinath, T. Rajendiran, T.G. Sakthivel and M. Ganesh ,"Design and Analysis of Automotive Bumper Beam Using Polymer Matrix Composite",*Middle-East Journal of Scientific Research*,24 (S1): 415-418, 2016.

[7] Omkar Garud1, Krishna S. Pawar2, Prashant K. Thorat3, Amit M. Waghmare4, Sagar P. Chopade5, "Analysis and Experimental Validation of Crash Box for the Energy Absorption Capacity" *International Journal for Research in Applied Science & Engineering Technology (IJRASET)* 1(6), January-2018

[8] Tie Wang and Yonggang Li, "Design and analysis of automotive carbon fiber composite bumper beam based on finite element analysis", *Advances in Mechanical Engineering*, Vol. 7(6) (2015).

[9] Gabriel Jigaa,*,Ştefan Staminb, Gabriela Dinua, Daniel VlăsceanuaDorina Popovicic"Material and shape crash-box influence on the evaluation of the impact energy absorption capacity during a vehicle collision",*ScienceDirect*,28 (2016) 67–72

[10] Prof. F B Sayyad and A D Deshmukh, "Deploying CAE with Explicit Solver for Simulating the Phenomenon of Crash while Improving the Design of Bumper", *International Journal of Research in Mechanical Engineering*, 1(1), July-September, 2013, pp. 34-43.

[11] Yanjie LIU, Lin DING "A Study of using Different Crash Box Types in Automobile Frontal Collision", *IJSSST.*

[12] F. B. Sayyad, Abhaysingh Diliprao Deshmukh, "Crash Analysis of Bumper Assembly with Solver to Improvise the Design for Impact Tests", *International Journal of Engineering Research & Technology (IJERT)* ,2 (6), June – 2013.

[13] Anjali Solanki1, Gaurav Nirman1, Pramendra Kumar Bajpai," Modelling of car bumper developed by polymer composite material", *International Journal of Advance Research in Science and Engineering*, 06(02),December 2017.

[14] Lande P.R1,Patil R.V. 2 ,"Analysis of Bumper Beam in Frontal collision", *International Journal of Innovative Research in Science, Engineering and Technology* ,04(05),May 2015

[15] Mohammed Rasool Naji ,Girish Narayanrao Kotwal, "Design and Analysis of Honeycomb Sandwich Panel for Automobile Bumper-Review", *International Journal of Science Technology & Engineering*,03(12),June 2017.

[16] A.T. Beyenea, E.G. Korichob, G. Belingardib*, B. Martoranac,"Design and manufacturing issues in the development of lightweight solution for a vehicle frontal bumper",*Elsevier, 2014.*

[17] Belingardi G., Beyene A..T, Koricho E.G., Martorana B., Crashworthiness of integrated crash-box and beam made of die forming composite Seville, Spain, 22-26 June 2014.

[18] Ince F., et al. "Experimental And Numerical Study On Impact Behavior Of Box Structure" *Elsevier Science Direct* 2011.

[19] Kim H.C., etal ."crash worthiness of aluminum/CFRP square hollow section beam under axial impact loading for crash box application" Elsevier Science Direct www.elsevier.com ,5 February 2014.

[20] Brad E. Padena, ∗, Paraic M. Kellyb, Jacob A. Hinesc, David Bothmana, Ciaran Simmsd, "On the feasibility of life-saving locomotive bumpers", *Accident Analysis and Prevention Elsevier Science Direct* www.elsevier.com , 8 February 2016.

[21] A.T. Beyene, E.G. Koricho, G. Belingardi, B. Martorana, "Design and manufacturing issues in the development of lightweight solution for a vehicle frontal bumper", *Science Direct, Procedia Engineering*, 88, 2014, pp. 77 – 84.

[22] Dnyaneshwar B. Kahane, K.V. Chandratre, "Experimental and Analytical Investigation for Impact Behavior of Different Shapes of Crash Box", *International Conference on Ideas, Impact and Innovation in Mechanical Engineering*, 2017, 5 (6).

[23] Ajay D. Katore, Prof. Sachin Jain, "Deploying FEA for simulating the phenomenon of impact while improving the Design of Bumper*", International Journal of Engineering and Technical Research, 3* (7), July 2015.

[24] Sagar P Dhamone, Dr Arun kumar P, "Advance Robotics Technology on Crash Analysis of Automobile Bumper by Varying Suitable Input Parameter in Order to Control Energy Absorption for Improve Passenger Car Safety Aspect", *International Research Journal of Engineering and Technology (IRJET)* ,5 (7), July 2018.

[25] Brad E. Paden, Paraic M. Kelly, Jacob A. Hines, David Bothman, Ciaran Simms, "On the feasibility of life-saving locomotive bumpers" *, Science Direct, Accident Analysis and Prevention,* 89 ,2016,pp. 103–110 .

[26] Lande P.R, Patil R.V, "Analysis of Bumper Beam in Frontal collision", *International Journal of Innovative Research in Science, Engineering and Technology*, 4, (5), May 2015.

[27] Mohammed Rasool Naji, Girish Narayan Rao Kotwal, "Design and Analysis of Honeycomb Sandwich Panel for Automobile Bumper-Review", *IJSTE - International Journal of Science Technology & Engineering*, 3(12), June 2017.

[28] M. Sudheer, Pradyoth K. R, Shashiraj Somayaji, "Analytical and Numerical Validation of Epoxy/Glass Structural Composites for Elastic Models", *American Journal of Materials Science* 2015, 5(3), pp. 162-168.

[29] Wasim Akram, Sachin Kumar Chaturvedi, Syed Mazhar Ali, "Comparative Study of Mechanical Properties Of E-Glass/Epoxy Composite Materials With Al2O3, CaCo3, SiO2 AND PBO Fillers", *International Journal of Engineering Research & Technology*, 2(7), July – 2013.

[30] Xiaosong Huang, "Fabrication and Properties of Carbon Fibers", *Materials 2009*, 2, 2369-2403; doi:10.3390/ma2042369.

[31] Arun Kumar D T, "Study of Mechanical Properties of Carbon Fiber Reinforced Polypropylene", *International Journal of Engineering Research & Technology (IJERT)*. 4(10), October-2015.

[32] F. İncea, H.S. Türkmena*, Z. Mecitoğlua, N. Uludağb, İ. Durgunb, E. Altınokb, H. Örenelb*," * A numerical and experimental study on the impact behavior of box structures*", Elsevier* ,Procedia Engineering 10 (2011*).*

[33] Modeling and Analysis of Honeycomb Impact Attenuator, *Altair University*.

[34] Shaik.Nazeer ,Shaik Allabakshu, "Design and Analysis of Honey Comb Structures with Different Cases" , *International Journal of Engineering Development and Research*, Vol 3(4)(2015).

