ANALYSIS AND DEVELOPMENT OF ENERGY ABSORBING CRASH BOX

Dhananjay D.Desai[1], Prof.M.A.Kadam[2]
[1] *Student, M.Tech CAD-CAM, Bharati Vidyapeeth Deemed University College of Engineering Pune, Maharashtra, India.*
[2]*Associate Professor, Department of Mechanical Engg. Bharati Vidyapeeth Deemed University College of Engineering Pune, Maharashtra, India.*

ABSTRACT

Crash box is a separate component in vehicle which is mounted in between main frame of the car and front bumper. At the time of the accident it deforms axially and absorbs accidental energy. Crash box structure provides comfort to the passenger at the time of impact. It works as safe guard for the costly components behind the bumper like engine hood and cooling system. In this report plane crash box geometry is studied for the energy absorption. Study is based on analytical, experimental and numerical work. Various parameters like width, thickness, taper which affects on the crash box performance are studied by using Design of experiments in Minitab 17. Crash box crushing behavior is analyzed by using quasi static method. Experimental test is performed on UTM machine. Quasi-static simulation is performed using ANSYS Explicit Dynamic workbench with its Auto-Dyna solver. Good agreement obtained in the results of analytical, experimental and numerical method. By varying the parameters and application of beads different designs are proposed and simulated for the maximum energy absorption. Application of various positioned beads show good influence on the energy absorption.

Keyword: - *Crash box, Energy absorption, FEA and ANSYS.*

1. INTRODUCTION

Nowadays thin walled structures have become very popular as energy absorbers because of their desirable energy absorption capacity, quite light weight and low cost. They are widely used in automobile, aerospace, defense and other industries. In the automobile design it has become very important to reduce the occurrence and consequences of accidents and to take effective precautions to minimize the damage. In the accidental impact when automobile is travelling with velocity equal to or less than 15 km/hr , insurance companies required that the damage of the vehicle should be as small as possible so that repairing cost of automobile can be reduced also insurance fee can be reduced.
The insurance company's requirements are like engine hood and headlights should be undamaged after the accident. Other than the frontal components should not get damage in a frontal crash at low speed. The parts of vehicle that are allowed to damage in a low velocity impact are the bumper and the crash-box. The length of these parts varies with the length of vehicle. We can vary the material properties and sheet thickness to improve the performance of the vehicle at the crash impact. As crash box is separate component it can be varied singly of other components of vehicle. Therefore it is useful to utilize mathematical optimization by varying the material properties, geometry of the crash-box to improve the performance. Purpose of this paper is to find out an optimum design of crash box for maximizing energy absorption capacity, minimizing critical buckling load (first peak load) and weight reduction.

Design of crash box should meet following essential condition.

1. Critical buckling force (first maximum peak load) need to be low so that the force dispatched to vehicle frame can be minimized.
2. Energy absorption in crash box deformation should be high.
3. Crash box should be light weight as its weight influences on vehicles weight.

2. DESIGN OF EXPERIMENTS

2.1 DOE with Analysis of factorial design:

Design of experiment is the branch of applied science that deals with evaluating factors that controls the value of parameter or group of parameters by planning, conducting, analyzing and interpreting tests. Planned executed experiments provide large amount of important data regarding what is the effect of one or more factors on the response variable. In many experiments some variables are constant and other factors influence the value of output variable independently or by interaction.
Well performed DOE provide important information as follows

1. What are key factors in the process?
2. What are key, main and interaction effects in the process?
3. Provide Input output relationship in the form of equation.
4. Provide range of factors interactions for the required output (response).
5. Provide optimum setting for the best output.

Table -1: Factors and levels

		Levels	
	Factors	Low (-)	High(+)
1	Width (a)	60mm	75mm
2	Thickness (t)	1mm	2mm
3	Angle (Q)	0^o	5^o

For 8 numbers of runs Energy is calculated by performing quasi-static analysis using ANSYS-Explicit dynamic simulation which is briefly explained in the chapter no. 5.

Table-2: 2^3 FF experiment

Runs	Width a	Thickness t	Angle Q	Energy E
1	-	-	-	2088.00
2	+	-	-	2142.70
3	-	+	-	2933.90
4	+	+	-	2971.90
5	-	-	+	2018.00
6	+	-	+	2067.04
7	-	+	+	2866.90
8	+	+	+	2901.102

In the Pareto chart position of the red line give idea of significant factors. First statistically significant factor is width a. Second and third statistically significant factors are angle and thickness. The last statistically significant factor is combination of width and thickness. Normal plot also provides same result for significant factors.
Regression Equation in Uncoded Units:-
Energy E = 2498.69 + 21.992 Width a + 419.757 Thickness t - 35.432 Angle Q - 3.942 Width a* Thickness t.

2.1 Contour Plot:

1. In the contour plots the values for two variables are represented on the x and y axes and the values for the response are represented by shaded region.
2. Blue colour represents less energy absorption regions while Green colour represents high energy absorption regions. So our focus will be on only Green shaded regions.
3. In fig 1 dark-green region shows large energy absorption at the right bottom corner of the graph. That is high level of width with low level of angle provide maximum Energy.

4. In fig 2 dark-green region shows large energy absorption at the top side of the graph. That is level of thickness has great impact on the energy than width but the slight slope suggest high level of width provide good effect.

From the analysis we come to conclusion that the run that provide maximum Energy is.
Width=75mm, Thickness=2mm, Angle=0^{0}. Energy absorbed=2971.90J.

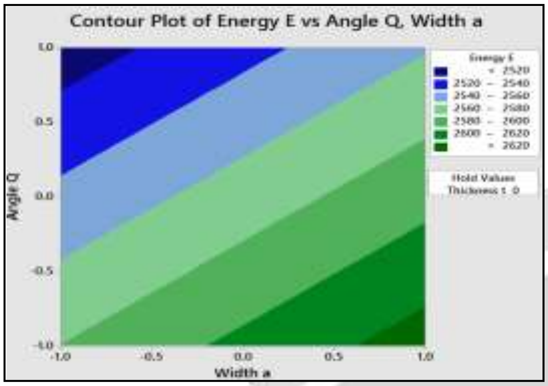

Fig -1: Contour plot (Energy vs. Q,a)

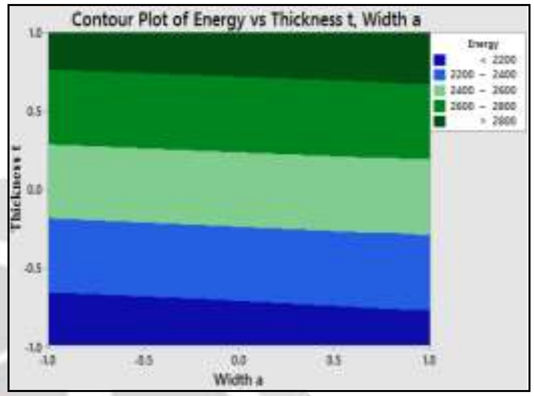

Fig -2: Contour plot (Energy vs. t,a)

3. ANALYTICAL ANALYSIS :

3.1 Absorbed energy:

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

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

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

P_m – Mean crushing load,
E - Absorbed energy,
δmax - Total displacement.

3.2 Equation 1:

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

$$P_m = K\sigma_0 b^{\frac{1}{3}} t^{\frac{5}{3}}$$

Where, Pm, b and t are mean crushing load, width and thickness respectively. σ_0 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 Pm expressed in N, yield stress σ_0 in MPa, and all dimensions are in mm).[1]

4. EXPERIMENTAL ANALYSIS

4.1 Material :

1. Density of Aluminium is around three times less than that of steel. This directly gives us idea that Aluminium is three times lighter than the steel. So use of Aluminium can reduce the weight by three times if compared with steel crash box.

2. Modulus of elasticity of Aluminium is three times less than that of Steel. This directly gives us idea that Aluminium is three times flexible than that of steel. As the crash box material is need to be flexible; it can absorb

maximum amount of energy by maximum deformation.
Aluminium has low stiffness so it has high weight- stiffness ratio, that's why it is widely used in energy absorbing components.
Specimen: Specimen used in experimental analysis is made up of Aluminium alloy AA2028A and has cross-section of '75x75' mm, 120 mm length and thickness of 2 mm. Finishing of specimen is performed on numerical control milling machine.

4.2 Test set up:

1000kN Computer control Universal Testing Machine (FIE-UTES100) is used to test two specimen. Loading accuracy of machine is ± 1%. Machine is connected to the Printer & PC graphs which are enabling to study the behavior of the materials. Compressive force is recorded during crushing, together with crosshead displacement, giving a load– displacement curve. Quasi-static tests are stopped after reaching a specified distance, which is approximately 65 mm. All tests are conducted at ambient temperature. Velocity of top compression plate is 50 mm/min. Due to very small velocity kinetic energy during application of load is negligible.

Fig -3: Undeformed and deformed crash box specimen 1 and 2

5. FINITE ELEMENT ANALYSIS

Finite Element Analysis is widely used numerical methods for solving the various types of engineering problems. In FEA, result is calculated for the specific points called as finite elements and then the result is interpolated for the entire domain. FEA has reduced the testing requirement in industries. Software based FEA has 3 steps Pre-processing, solution and post-processing. FEA is used for solving various types of analysis like dynamic, fatigue, buckling, static, thermal, linear and non linear analysis.

5.1 Quasi-Static Simulation Using ANSYS Explicit Dynamic:

Quasi-static process is slow process which converts one equilibrium state into another equilibrium state. Load in quasi static process depends on time but application of load is very slow. In other words, kinetic energy during application of load is almost zero and can be neglected. In experimental setup, same loading is used, by applying velocity to top compression plate. Explicit Dynamic analysis is used to simulate high-speed impact events. Application of Explicit Dynamic to model quasi-static events needs special conditions to be satisfied. Simulating the model in natural time will be computationally inconvenient. If we simulate it to natural time period then run time will be very high. Increasing loading rates artificially reduces time of simulation. Condition of quasi-static simulation is total kinetic energy of the model should be negligible or close to zero. Total energy should be almost equal to internal energy. It shows total work is converted into internal energy. Material used =General non-linear material-Aluminium alloy NL, Density=2.81 g/cm^3, Young's modulus=74330 MPa, Poisson's ratio= 0.33, Yield Strength=240MPa.Behaviour provided to the crash box is flexible while for the top and bottom plates is rigid.

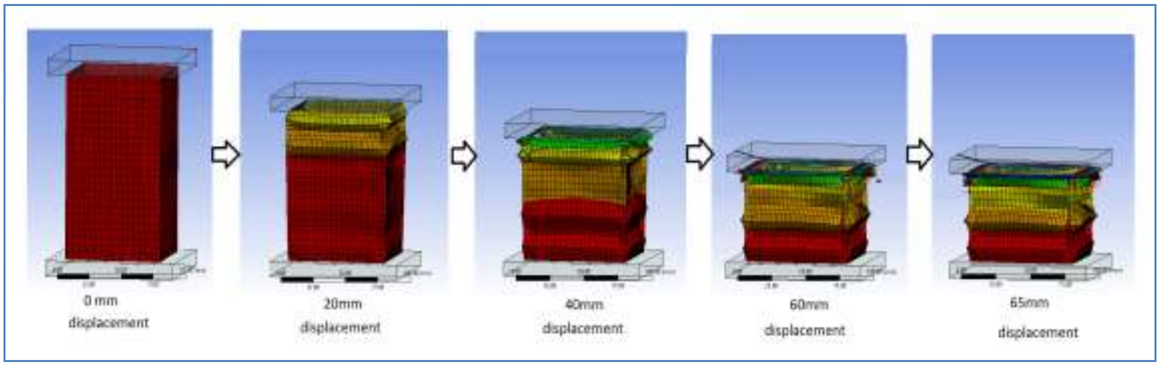

Fig -4: Deformation of Plane crash box.

6. RESULT COMPARISON:

Results comparison of experimental and FEA shows good agreement. Values given by analytical equation are comparable with those given by experimental ones. Also buckling pattern observed in FEA is similar to that in experimental.

Table -3: Result comparison

Test	Mean crushing load (kN)	Energy absorbed (Joule)	Critical Buckling load (kN)	Lowest crushing load (kN)	Difference in absorbed energy compare to experimental average(J)
Equation 1	41.965	2727.75	-	-	-152.2
FEA	58	2971.901	123.96	26.996	91.95
Experimental average	45.36	2879.95	111	24.895	-

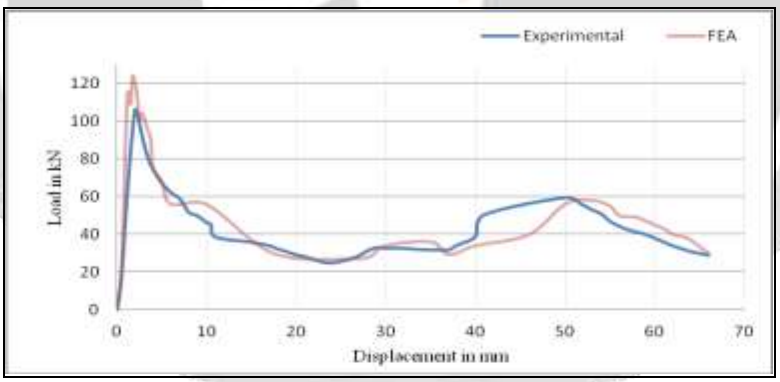

Chart -1: FEA and Experimental graph comparison

7. DESIGN AND OPTIMIZATION:

7.1 Designs and Description: Four successive designs with different combinations of beads are proposed for the required energy objective.

Table -4: Name of the Table

Design	Description
A1	Beads on One Pair of Opposite Faces
B1	Continuous Bead along Perimeter
D1	All Small Beads Inside
G1	All Small Beads Inside With Eight Sides

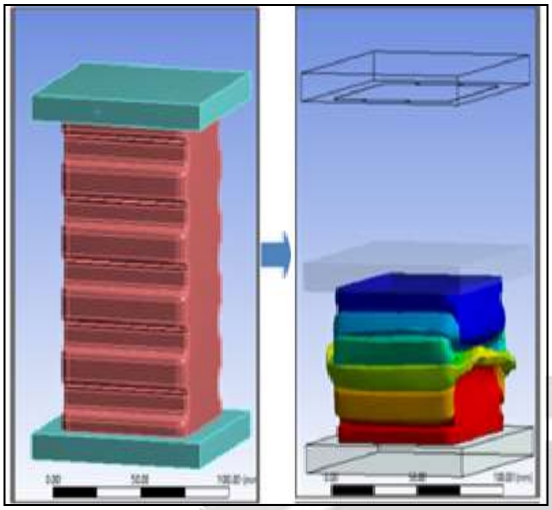

Fig 5- Design D1

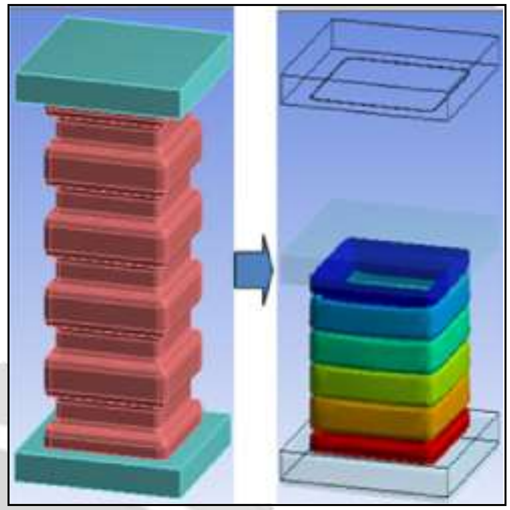

Fig 6-Design B1

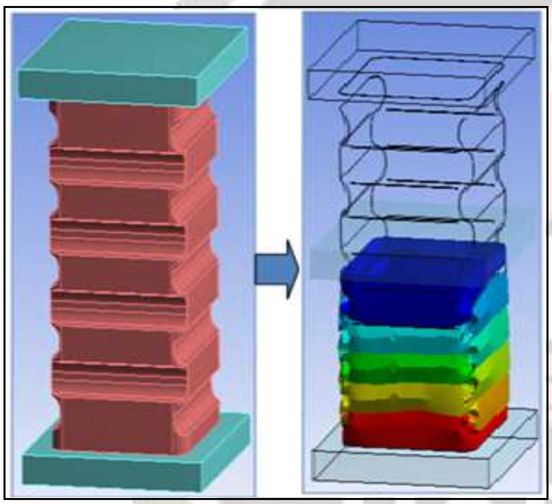

Fig7- Design D1

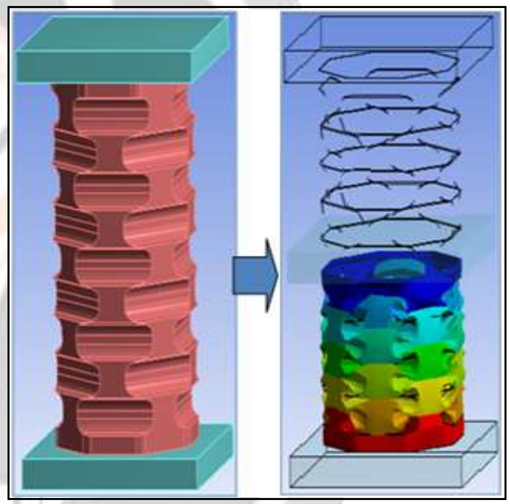

Fig 8- Design G1

7.2 Result Comparison for designs:

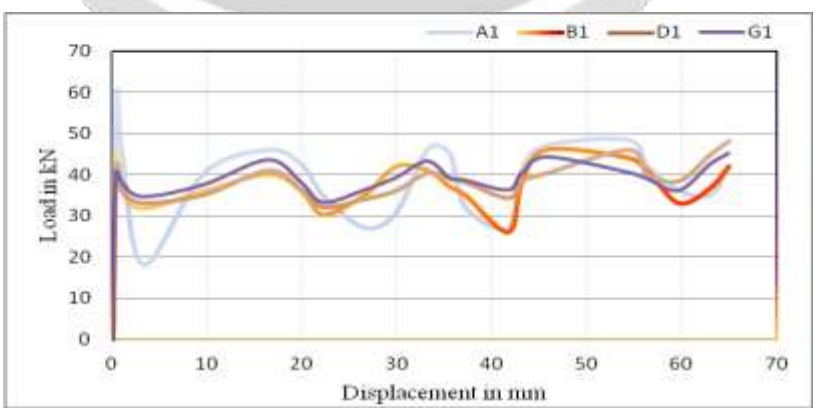

Chart -2: Comparison of result of design A1,B1,D1,G1

Table -5: Results of Design A1, Design B1, Design D1 and Design G1

Design	Mean crushing load (kN)	Energy absorbed (Joule)	Critical Buckling load (kN)	Lowest crushing load (kN)
A1	37.1292	2505.36	59.025	18.266
B1	37.178	2430.57	62.026	18.025
D1	36.009	2402.615	45.125	30.125
G1	37.442	2537.93	40.489	33.265

1. Design D1 offer lowest mean crushing load while Design G1 presents highest mean crushing load.
2. Design G1 has highest energy absorption. Energy absorption of Design D1 is less than that of Design A1 and Design B1.
3. Critical buckling load offered by Design G1 is very less. It is 35% less if compared to Design B1. Critical buckling load offered by Design B1 is very high.
4. Lowest crushing load given by Design B1 is small and of Design G1 is high.

It is seen that Design G1 is best design in all condition. This geometric design can be improved further providing holes and can be used for efficient crash energy absorption.

8. CONCLUSION

Experimental and numerical simulation by using ANSYS Explicit Dynamic analysis is performed on plane crash box. Good agreement found out in between analytical, experimental and numerical analysis result. In the crash box there is increase in mean crushing load, lowest crushing load and absorbed energy. We got drop in critical buckling load. The crash box profile is improved and can fulfill the required objectives. Also we come to the conclusion that absorbed energy increases with increase in thickness and with reduction in taper angle. Also increase in number of sides of box affects significantly on the energy absorption. Design G1 is evaluated as best design as it has high energy absorption with low critical buckling load.

REFERENCES

[1]. A.K. Toksoy, M. Guden, "Partial Al foam filling of commercial 1050H14 Al crash boxes: effect of box column thickness and foam relative density on energy absorption",Thin walled structures 48(2010) 482-494

[2].Yoshiaki Nakazawa, Kenji Tamura , Michitaka Yoshida, Katsutoshi Takagi And Mitsutoshi Kano," Development of crash-box for passenger car with high capability for energy absorption", VIII International Conference on Computational Plasticity COMPLAS VIII E. Oñate and D. R. J. Owen (Eds) CIMNE, Barcelona, 2005.

[3]. S. Santosa , T. Wierzbicki, "Crash behavior of box columns filled with aluminum foam", Computers and Structures 68 (1998) 343±367

[4]. B.P. DiPaolo, P.J.M. Monteiro, R. Gronsky s ,"Quasi-static axial crush response of a thin-wall, stainless steel box component", Solids and Structures – 2004 Elsevier.

[5]. Mihail Daniel Iozsa, Dan Alexandru Micu, Gheorghe Frățilă, Florin-Cristian Antonache, "Influence of Crash Box on Automotive Crashworthiness", ISBN: 978-960-474-403-9.