Investigation of Energy Absorption Capacity of Crash Boxes With Analytical, Experimental and Numerical Methods

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Abstract—*Crash box is a device mounted between the front bumper and the main frame of a car in order to absorb energy during collision. In this study the crash box of plane square tube is studied, to check the accuracy achieved by numerical (FEA) methods over analytical, experimental methods for the energy absorption capacity. In this study the crushing behavior of crash boxes determined at quasi-static deformation velocities. The quasi-static crushing of the boxes was simulated using the LS-Dyna. The amount of energy absorbed by plane boxes were predicted as function of box wall thickness between 1 and 1.5 mm, using the analytical equations developed in the reference, for the mean crushing loads and the experimental values are taken from experimentation of same crash box design.*

Keywords: -Crash box, Crushing load, Energy absorption, FEA, LS-Dyna

I. INTRODUCTION

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.Typically crash box buckles when the axial compressive force exceeds limit. The formation of the buckling pattern absorbs energy, and therefore damage to the main frame is avoided. Crash box design should meet the following requirements. First, the critical buckling force has to be low so no excessive force is transmitted to the main frame. Second, the amount of Energy absorbed due to plastic deformation after buckling needs to be high, and finally the cost has to be low as they get destroyed during a collision**.** In case of frontal accident damage of the main cabin frame is minimized and passengers are saved their lives. Recently, it has been strictly required to satisfy both reduction of body weight and improvement of crash worthiness and thus, regarding crash box, it is required to ensure high energy absorption. It is difficult to acquire required maximum energy absorption by analytical and experimental method as cost and time involved in this method is more, then as alternative and reliable method numerical method can be used for effective use of man, machine, and materials. For basic crash box shape comparative study of all analytical, experimental, numerical (FEA) is done in current study to check the accuracy of numerical method for design and optimization of crash box.

II. ANALYTICAL ANALYSIS OF CRASH-BOX

The interest in this study is the mean crushing load Pm and the energy absorption E. The mean crash load is defined by,

$$P_m = \frac{1}{\delta \max}\int_0^{\delta \max} P(\partial)\, d(\partial)$$

Where P (∂) is the instantaneous crash load corresponding to the instantaneous crash displacement d (∂). The area under the crash load–displacement curve gives the absorbed energy. As in [2]

The empty square box mean load was previously given as

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

Where, P_m, b and t are the empty box mean load, width and thickness.$\sigma_0$is yield stress. The value of b is taken as the mean of box widths and K is a dimensionless constant. The value of K is proposed to be 13.06. This value of K shows a good correlation with experimental and simulation mean load values for plane crash boxes. As in [1]

III. FINITE ELEMENT ANALYSIS OF CRASH-BOX

Finite Element Analysis is a simulationtechnique which evaluates the behavior of components,equipment and structures for various loading conditionsincluding applied forces, pressures and temperatures.Thus, a complex engineering problem with non-standardshape and geometry can be solved using finite elementanalysis where a closed form solution is not available. Thefinite element analysis methods provide results of stressdistribution, displacements and reaction loads at supportsetc. for the model. As in [1], [2], [3], [4].

General procedure of FEA can be described as follows.

1. Select suitable field variables and the elements.
2. Discretization of continuous geometry
3. Assemble element properties to get global properties.
4. Impose the boundary conditions.
5. Solve the system to get the nodal unknowns results of stressdistribution, displacements and reaction loads at supportsetc.
6. Evaluate the results based on the experimental results.

A. *Geometric Modelling*

Geometry was created in part design module in software Catia V5 R20. The outer dimensions of crash box section are modeled as 50 × 50 mm and height 150 mm width edge fillet of 3mm radius. 1mm, 1.5mm thickness of parts are modeled.

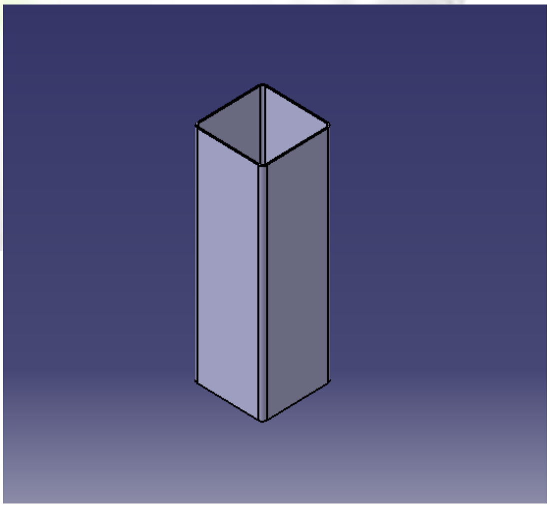

Fig. 3.1: "3D" drawing of the CAD model

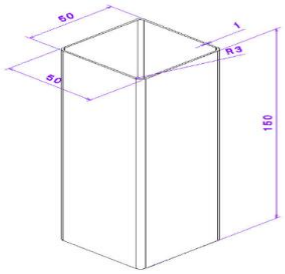

Fig. 3.2: "3D"wireframe drawing of the CAD model

B. Element Selection and Meshing

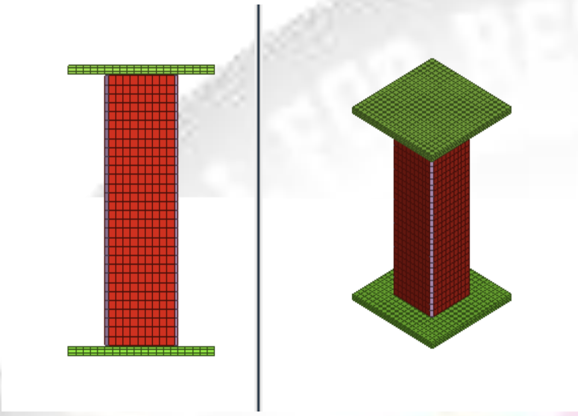

Fig. 3.3: Meshed Model of Plane Crash box

For the 3D quasi-static analysis of the crash box, LS-Dyna V971 R4 solver is used, 2D elastic element with six degrees of freedom at each node are modeled. Meshing is done by using ANSA preprocessor where the material properties, geometrical properties, boundary condition and loading conditions are assigned. The file is exported to LS-Dyna for further analysis.

C. Material Model

The mechanical properties of AISI 202 steel sheet alloy determined through tensile testing in accord with ASTM E8 standard as in [18]. The material properties of AISI 202 are modeled by using tensile test experimentation done on the UTM the average of true stress vs strain graph is used to model non-linearity of the material given as nonlinear isotropic with Young's modulus of 205000 MPa and Poisson's ratio of 0.3. and density of 7850 Kg/M^3 The yield value of material is 410MPa and ultimate tensile strength is 619MPaand the maximum effective plastic strain is 16%. In MAT24_PIECEWISE_LINEAR_PLASTICITY material card, the mechanical properties are characterized by the material yield strength, Young's modulus and effective plastic stress vs. effective plastic strain curve. As in [1],[2]

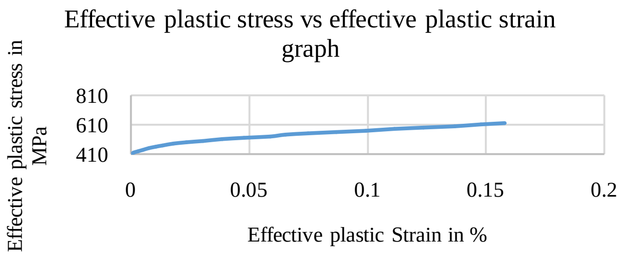

Fig. 3.4Effective plastic stress vs. effective plastic strain graph of AISI 202 modeled in software

Table 3.1 AISI 202

Direction	**Young's modulus E (MPa)**	**Yield strength $s_{0.2}$ (MPa)**	**Ultimate tensile strength s_u (MPa)**	**Poison ratio n**	**Failure effective plastic strain (%)**
Parallel to extrusion direction	205000	410	619	0.30	16

D. Modelling Crash box

Modeling the crash box consists of meshing and the modelbuild up of crash box. The crash box was modeled using element formulation 16 fully integrated elements, one point integration in the plane and five in the thickness direction, Top and bottom montage plates using 5 mm thick layer of solid elements. In the model, the translation and rotation of the bottom montage plate were restricted. The self-contacting crush zone surfaces (folds) were modeled using automatic single surface contact algorithm in the LS-DYNA. The contact between box and montage plates was modeled with automatic nodes to surface contact algorithm. The static and dynamic friction coefficients were taken to be 0.3 and 0.2, respectively. In quasi-static simulation two conditions must be satisfied. The total kinetic energy must be very small compared to total internal energy and the load-displacement curves must be independent of the deformation rate.Above conditions were found to be satisfied in the quasi-static simulations. In the simulations of the dynamic crushing tests, the velocity of the top compression plate was 300mm/s as in[1],[2]

E. Loads and Boundary Conditions

The FEA crash box placed centrally in the top and bottom compression plate, without any further support, material of both plates modeled with rigid, Top and bottom montage plates using shell elements. In the model, the translation and rotation of the bottom montage plate were restricted. In the simulations of the quasi-static crushing tests, the velocity of the top compression plate was 300 mm/s. The compressive force was recorded during crushing, together with the crosshead displacement, giving a load–displacement curve of the crushing process. As in [1],[2]

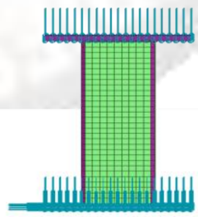

Fig. 3.5 Boundary Conditions and loading conditions Crash part

IV. EXPERIMENTAL ANALYSIS OF CRASH-BOX

A. Introduction

Experimental analysis using the computerised universal testing machine is a popular technique for a comparative experiment such as current study. Main advantage of this method is that the accuracy of process is high and the readings of experiment are recorded more frequently by computreised synchronization and the manual error can de avoided

B. *Specimen*

Specimen used in experimental analysis is having same imentions as shown in figure 3.2 material of specimen is AISI 202 as it is widely available in market and it has good mechanical properties.

C. *Test Setup and Specifications*

The setup consists of 200 kN computer control and data acquisition systems universal testing machine at "Shri Savitribai Phule Polytechinc Pune". The samples were placed centrally in the test machine, without any further support, and between two very hard steel end plates, which were bolted to the crossheads of the testing machine. The testing mode was displacement control with the top plate of the machine being moved vertically downward to load the tube specimens in compression The compressive force was recorded during crushing, together with the crosshead displacement, giving a load–displacement curve of the crushing process The quasi-static tests were stopped after reaching a prescribed crushing distance which was approximately 90 mm. All tests were conducted at ambient temperature. As in [1],[3],[5],[6]

Fig. 4.1: 200 kN computer control and data acquisition systems universal testing machine (Strength of material Laboratory, Department of Civil Engineering, Shri Savitribai Phule Polytechinc Pune)

V. Comparison Of Analytical Experimental And Fea Results

Average of 3 experimental tests for each 1mm, 1.5mm specimen is considered for comparing with numerical analysis results. In analytical method average value of load is calculated and further using that value the amount of absorbed energy is calculated. Average load is average value of experimental and numerical method's load during the crushing process. Absorbed energy is calculated by displacement value of specimen which is considered up to 90mm. Highest and lowest resistance values are high and low resistance load values observed during crushing process. In case of analytical method the high and low values are unknown due to limitation of analytical method.

A. *Comparison of 1 mm thickness Analytical, FEA and Experimental results*

Table 5.1

Test	Average Load of FEA test kN	Energy absorbed in "Jules"	Highest resistance "kN"	Lowest resistance "kN"
1 mm thickness Analytical	19.73	1775.38	-	-
1mm_thickness FEA	18.20	1637.84	62.18	8.05
1 mm thickness Experiment average	18.78	1690.46	51.91	10.41

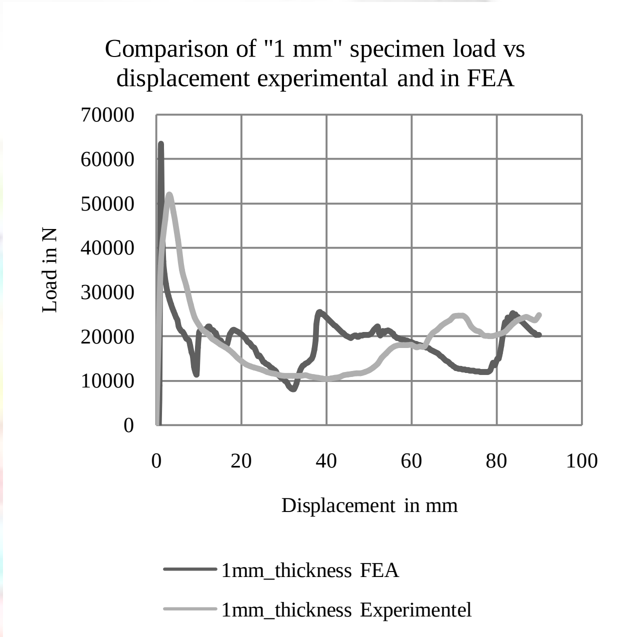

Fig. 5.1:

B. *Comparison of 1.5 mm thickness Analytical, FEA and Experimental results*

Table 5.2

Test	Average Load of FEA test kN	Energy absorbed in "Jules"	Highest resistance "kN"	Lowest resistance "kN"
1.5 mm thickness Analytical	38.77	3489.62	-	-
1.5mm_thickness FEA	38.07	3426.57	123.00	19.74
1.5 mm thickness Experiment Average	37.19	3347.70	114.06	18.07

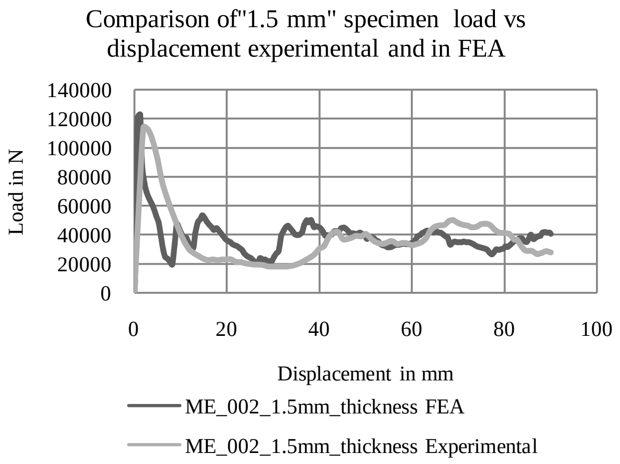

Fig. 5.2:

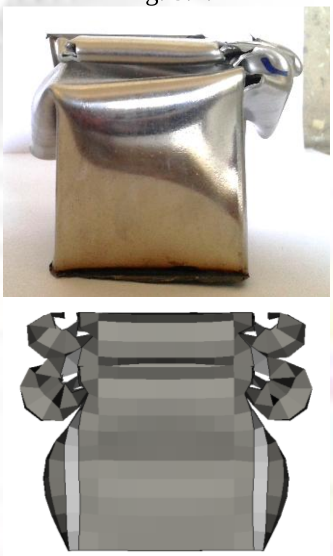

Fig. 5.3: 1 mm thickness specimen experimental, numerical result

Fig. 5.4:1.5 mm thickness specimen experimental, numerical result

Comparing Analytical, FEA and Experimental results, of average load, amount of energy absorbed and load vs displacement values following is studied,.

1. The average load value of analytical, FEA and experimental, is significantly matching. Good amount of co-relation is observed in this values in table V-1,V-2
2. As amount of energy absorption is depend on the amount of deformation for all crash boxes the tests are done upto 90 mm deformation hence the absorbed energy is also matching significantly.
3. If we observe figure 5.1,5.2 and the FEA and experimental load vs. displacement is compared then it is observed that the experimental curve is slightly smoother than the FEA curve as it is average of three experiments.
4. The load vs. displacement curve is also similar for FEA and the experimental observations in figure 5.1,5.2
5. Slight difference in results is observed in experimental may be due to some small differences in test, instrumental errors. In FEA due to the factors like element length, contracts and loading condition,and in analytical method slight approximations like round-off, caused slight differences in results.

VI. Conclusion

In this study, we examined the collapse characteristics of square crash box subjected to axial crushing, analytically the values of average crushing load is calculated, experimentally the crash performances of same crash boxes are determined. And also crash performance of same crash box is calculated using numerical method with the help of LS-DYNA explicit finite element code to reveal greater detail about the crash process, and to simulate the behavior of the tubes.

The comparison of analytical, experimental and numerical results shows that the numerical method using LS-DYNA explicit finite element code can predict the energy absorption of the crash box very accurately. Main objective of the work was to demonstrate the advantages of using numerical method in structures subjected to crash, and very accurate results with very miner differences can be obtained. From the comparison presented above, it is evident that the FEA results are significantly matching with analytical and experimental results and can be trusted for further studies.

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