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Energy Absorption of Thin Walled Rectangular Aluminium Sections

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Abstract: - **In this research, Quasi-static axial compression test is conducted on empty aluminium tubes of rectangular cross-section in order to analyze its energy absorption capacity under different modes of collapse. This test was carried out keeping in mind the cases for aluminium tubes as an energy absorber, when subjected to dynamic forces during accidents or sudden impacts. The process of this experiment was initialized by attaining stress strain curve from the tensile testing of aluminium specimen, which was further used in finite element code ABAQUS for 3D modeling and simulation purpose. Finite element analysis was adopted in this research due to its problem solving vast approaches. Simulations were done on ABAQUS to obtain the results deduced by axial compression of rectangular section. Similar test were performed practically on compression testing machine to verify the observations of computational tests for axial compression and it was found that practical results were is good venture with those of computational. Beside this, efficiency of finite element code was also notified and finite element analysis was proved to be good at identifying the modes of collapse for structures.**

Index Terms: - Axial compression, Finite element code, Thin walled section.

I. INTRODUCTION

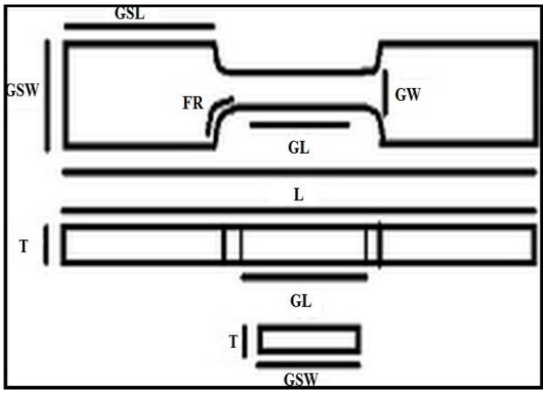
In today's era vehicle has been a piece of affordability, appealing features are not only the primary need of customer but quality dimensions are also a huge consideration beside aesthetics. In this research similar cases are opted for crash boxes which are installed in vehicle for the purpose of resisting sudden dynamic shocks that are exerted on the vehicle during accidents or collapse, but they are usually capable of performing their work up to a certain extent above which they crash due to inefficiency towards plastic deformation. The actual purpose of energy absorber is to provide a safeguard to the vehicle and thereby to the user by its feature of resisting the kinetic energy and occupying the place in plastic deformation region[7]. An actual energy absorber should be good at retaining its stiffness and strength in crucial places this helps in not only implying a safety features to automobile but also act as part of aesthetics.

An appropriate manufacturing of energy absorption devices can be attained using thin walled structures which had been profusely used in automobile field and studied in several reviews, among majority of which were usually concerned with the manipulation of the geometry of tubes while there have been several researches in the field of crashworthiness identical to this paper, but there were rare concerning the modified shape of energy absorbers. Quite a few researchers have gone through the use of composite material for the purpose of enhancing the stiffness and energy absorbing capacity by impinging external agent (i.e. wood saw dust, polymeric foam, and plain foam) into the shell and sections. Ref. [5] reviewed the similar case of foam filed tube by multi design optimization method to obtain an empty tube having maximum load carrying capacity at optimum weight. Some of the researchers have studied different patterns capable of absorption, apart from square, rectangular or circular. Ref. [6] have gone through the modifications on the surface of square tubes which had a mass increase of 5% but contributed to an enhanced energy absorption of 10-32.5% in comparison to the conventional square tubes.

This paper adopts a conventional rectangular shape of sections for testing under axial loading. Aluminium has been used as a working material for energy absorber throughout the research because of its property of good tensile strength, higher energy absorbing characteristics, ductility and the most favourable is formability which makes it a flexible material for such purposes. Ref. [10] has derived an equation for the specific absorbed energy which proves that an aluminium section have more specific absorption capacity than even brazen tubes. Beside this reason, aluminium has been used since late 30's for such kind of purposes and after Second World War it was greatly flourished due to the scarcity of steel [1]. Experiments of this research were conducted on rectangular geometry of L/t ratio 36.62, 48.83, 51.56, and 108.85. Parameters of length and thickness were taken, as experiment conducted in Ref. [4] has notified that modes of crush were dependent proportionally on the T/D and L/D ratios for tailor made tubes, remarkable result were also seen in modelling as well as analysis of crashes and maximum load carrying capacity of the section. Along with this Ref. [8] has also observed the effect dimensions on the modes of collapse for square, rectangular and circular sections. These parameters also facilitate in easy designing of 3D deformable models of rectangular sections. The test carried out in this paper was under quasi static conditions because it was quite difficult to obtain results of compression in dynamic stages and it requires a sum of precautions in the experimental setup to be robust enough to exert the dynamic forces of compression on rectangular aluminium specimens.

II. STRESS STRAIN CURVE DETAILS

Stress strain curve was obtained from tensile testing performed on universal testing machine of 400kN capacity. In order to carry out the test, dumbbell shaped specimen of aluminium material was designed with gauge parameters as gauge width (GW) of 0.0063m, fillet radius (FR) of 0.0063m, overall length (OL) of 0.1m, gauge length (GL) of 0.025m, width of grip section (GSW) as 0.0095m, length of grip section (GSL) as 0.01875m and thickness (T) of 0.0008m, which are illustrated in figure 1(a) and (b).



(a)

(b)

Figure1. Tensile testing specimen: (a) Demonstration of dimensions for test specimens, (b) Actual dumbbell shaped test pieces

Drafting of gauge parameter was done so as to observe the necking due to fracture at gauge width. Beside this semi circular fixtures were also designed so as to facilitate the specimen into the jaws of universal testing machine as shown in figure 2, having one end grooved and other half semi circular in order to make it clamp into the jaws.

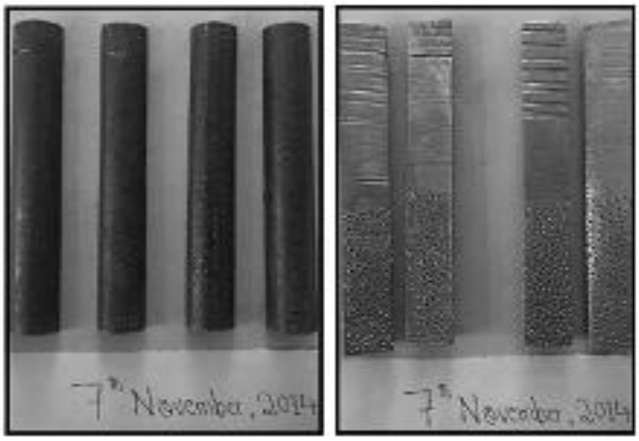


Figure2. Top and bottom surface of semi-circular fixtures

Figure2 Demonstrates the complete assembly of specimen clamped in the jaws of universal testing machine.

Figure3. Tensile testing specimen within the jaws of crosshead

Tensile testing facilitated in obtaining the stress train curve for aluminium specimen, these values were used for further calculating the True stress strain for the same test piece from the following Equations:-

$$\sigma = s\,(1+e) \qquad (1)$$

$$\epsilon = \ln\,(1+e) \qquad (2)$$

Where,
σ - True Stress
ϵ - True Strain
s – Engineering Stress
e – Engineering Strain

Figure 4 illustrated the necked gauge width of dumbbell shaped specimen after the successful completion of tensile test.

Figure4. Necked gauge width of fractured tensile test specimen

True stress and True strain points were used to obtain the material properties per unit change in area of cross section. The curve plotted between true stress and true strain was further compared with the ideal curve adopted for tensile testing for aluminium material [8], figure 5 demonstrated the graph between practical and ideal curve which showed the ultimate true stress point as 210MPa for aluminium material.

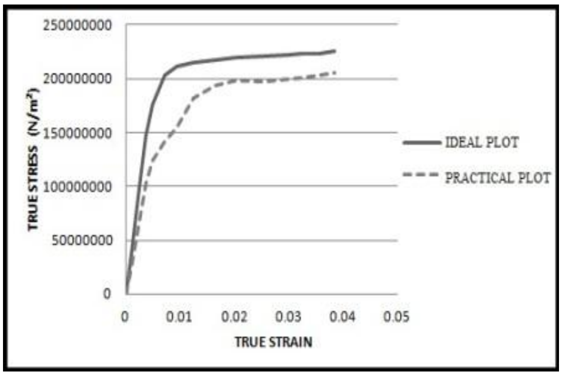


Figure5. Plot between true stress and true strain for tensile testing of aluminium

III. Computational Specifications

A. *Finite Element Method*

Finite Element Method was used for the computational analysis of compression testing on rectangular aluminium specimens by finite element code ABAQUS. The main reason to employ this method was that finite element method was capable of solving hundreds and thousands of constraints with accuracy which was quite a difficult task for human, beside this finite element method was preferred when dealing with the cases like that of structure analysis, heat and mass transfer, static and dynamic test, etc which made it more appreciable to be used for compression testing of aluminium sections.

B. *Modelling and Simulation*

3D Axis symmetric modelling and simulation are the well known attributes of finite code ABAQUS. In this analysis modelling was succeeded by simulations for aluminium sections. At initial stage aluminium tubes of rectangular shapes were modelled with dimensions as mentioned in table 1 illustrating L/t ratios along with the two circular plates which were analytical rigid in order to make them act as compression plates for our system.

Table1. Dimensions for Modelling of Specimen

Specimen	L (m)	W (m)	T (m)	D (m)	L/T
SP1	0.063	0.038	0.00057	0.1	108.89
SP2	0.075	0.026	0.00095	0.1	78.95
SP3	0.049	0.025	0.00080	0.1	61.88
SP4	0.050	0.025	0.00102	0.1	48.82
SP5	0.038	0.025	0.00102	0.1	36.62
SP6	0.025	0.036	0.00158	0.1	15.73

There were certain constraints on which modelling depended, including the properties for the section as mentioned in table 2.

Table2. Properties for Modelling of specimens

Density (Kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
2700	68.9	0.33

These properties were adopted from the past researches conducted in this field [2]. Implementation of properties makes the solution realistic. True stress and true strain values which were obtained from tensile testing were also included in material properties for modelling purpose. Then we moved on to the assembly of designed parts in order to arrange the parts in chronology, loading is applied on to the assembly among which top most plate was compressed axially while the lower plate was held Encastre rigid. Loading on the system was considered axial, as oblique loading tends to depreciate the efficiency of absorbers. Ref. [3] and Ref. [9] who has noticed from their test conducted on composite sections that angle of inclination of oblique loading is inversely proportional to the energy absorption of sections as it tends to make the structure unstable. One of the important modules of ABAQUS includes meshing, which was supplemented after loading the assembly.

Meshing helps in distribution of the section into thousands of subsections so as to examine the effect of loads at each segment of assembly. Figure 6 demonstrates the complete meshed assembly ready for simulation on ABAQUS.

Figure6. Meshed rectangular specimen for computational test

C. *Conversion Study*

It was a primary test conducted on ABAQUS on the modelled specimens in order to obtain the number of meshes required at the thickness of the rectangular sections so that it can exert high impacts. For this purpose rectangular tubes opted were of similar dimension as mentioned in table 1 while thickness was held constant of 0.001m so as to evaluate the effect of different mesh divisions on identical thickness section in terms of load carrying capacity. Variation of mesh divisions was maintained from 2,3,4,5, and 6 throughout the study. Observations from the result notify that 4 number of divisions were best enough to sustain high static loads, the reason behind this point was that 4 divisions on thickness employs fine meshing for section along with a constant load carrying capacity with 5 and 6 divisions as seen from the figure 7 demonstrating the graph plotted between number of mesh divisions and maximum load carrying capacity. Fine meshes were necessary for simulation as it offers great amount of accuracy in results.

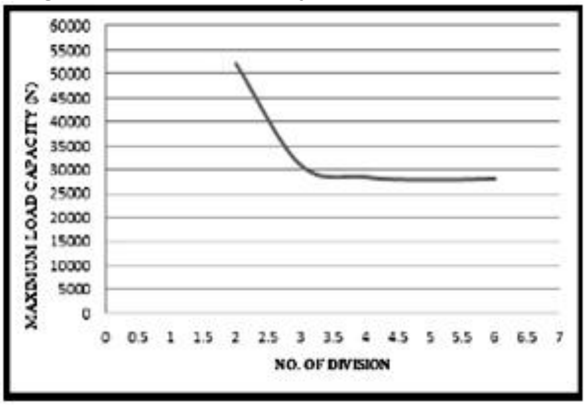


Figure7. Plot between number of mesh divisions on specimen's thickness and maximum load carrying capacity

D. *Methodology*

Conversion study contributed in the final meshing of assembly which was then submitted for simulations under quasi static axial compression loading exerted on analytical rigid plates of assembly. Load with boundary condition was applied on the top plate to a length of 0.09m at tube length of 0.1m, so as to make it compress up to its full strength. Simulations were performed on different dimensions of rectangular section as mentioned in table 1 and maximum load carrying capacity was evaluated by eventually comparing their results after distortion.

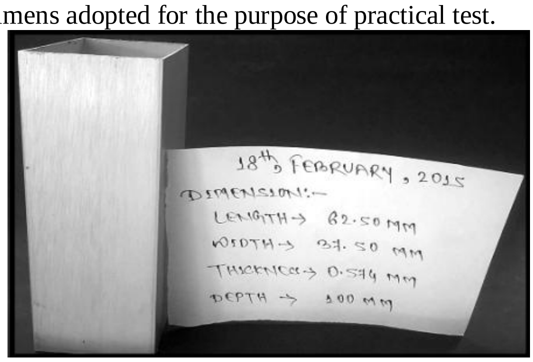
IV. Experimental Specifications

This section involves practical analysis of compression testing on rectangular specimens. Practical test were performed on compression testing machine of 1200kN capacity while dimensions opted for rectangular sections of aluminium were of particular L/t ratios as mentioned in table 3, which were previously opted as specimen SP1, SP4, and SP5 in computational analysis and had shown maximum load carrying capacities.

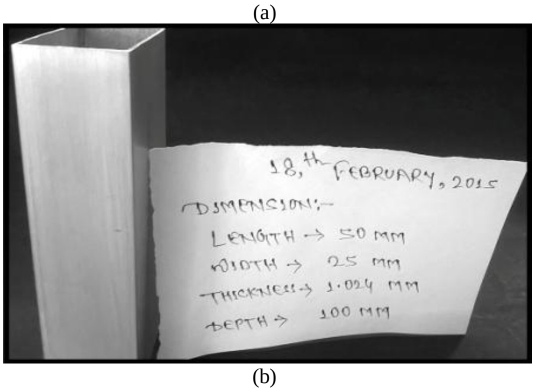
Table3. Adopted dimension of specimens for Experimental validation

L (m)	W (m)	T (m)	D (m)	L/t
0.063	0.038	0.00057	0.1	108.89
0.050	0.025	0.00102	0.1	48.82
0.038	0.025	0.00102	0.1	36.62

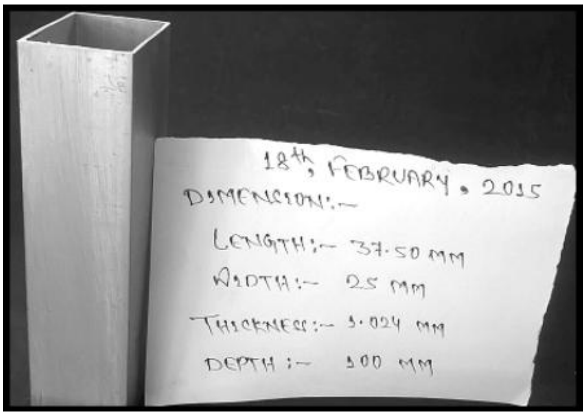
Inspection of the material specimen was also conducted before the test in order to avoid the geometrical discontinuities which may lead to poor stiffness, Ref. [11] had shown the effect of notches and discontinuities on the properties of principle material, but that is only restricted if these discontinuities are present at axis symmetric positions of the sections. Figure 8(a), (b) and (c) demonstrate the specimens adopted for the purpose of practical test.



(a)



(b)



(c)

Figure8. Test specimens for practical compression testing: (a) For L/t ratio 108.89, (b) For L/t ratio 48.82, (c) For L/t ratio 36.62

This test was essential in order to support the data accumulated from the computational evaluations.

V. Result And Discussion

After the successful completion of computational and practical experiments evaluations, both the aspects were put together to observe the similarity and discriminations between the two observations. Computational test which were carried out on 3D modelled rectangular sections have completely destructed the model at the end of simulations. Axis symmetric concertina mode of collapse was observed after the sections were crushed due to static axial compression forces. Practical evaluations of rectangular specimen have also resembled identical results after getting distorted due to crushing loads under compression testing machine. The dimensions opted for practical analysis was based on the computational evaluations so as to verify the results of collapse. Figure 9 demonstrates the regular folding of thin walled specimens comparing the computational and practical distorted sections. Beside the modes of collapse the energy absorption capacity was also observed from the load displacement curves derived from the simulation results.

The peak load carrying capacity was observed as 41576.9N for L/T ratio of 108.89 from simulations while load carrying capacity of 39138.8N was obtained in practical tests. Ratios with linear load carrying capacity with L/t ratio 108.89 were opted for validation from practical analysis of rectangular specimens. Loading angles while testing were avoided as they lead to irregular distortion and deduces buckling stages. Ref. [12] had observed that a foam filed sections exerts more loses than an empty section under the influence of loading angles. Figure 10 (a) and (b) illustrate the graphs plotted from the results of computational and practical analysis which validates the numerical results for maximum load carrying capacity of L/t ratios.

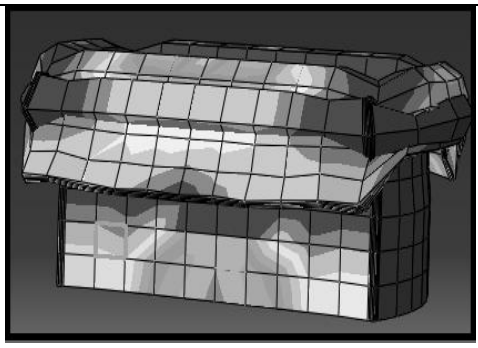
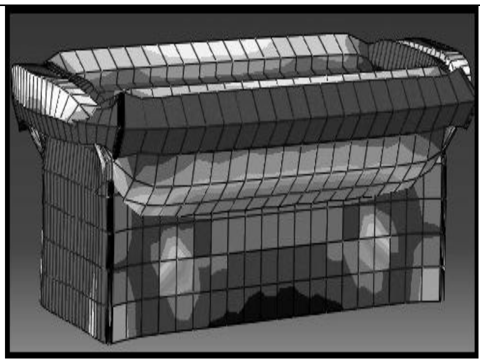
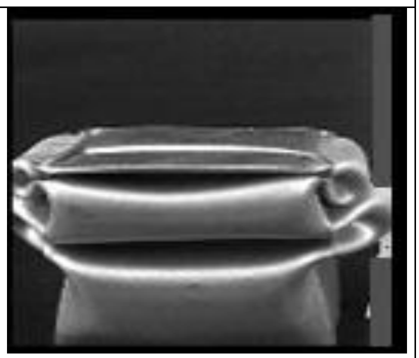
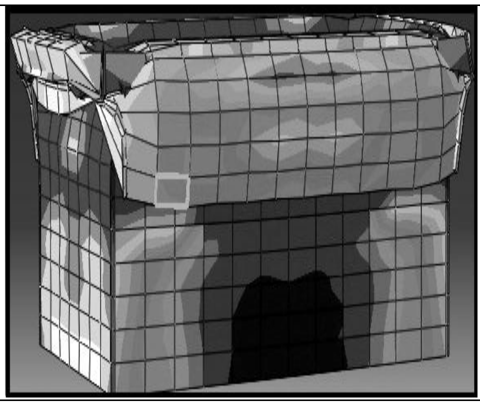
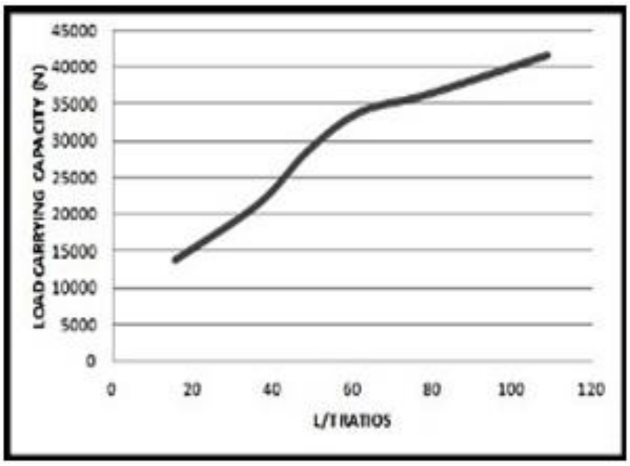
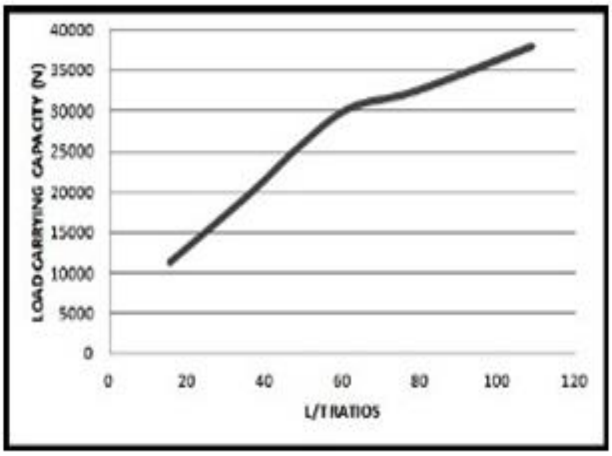
Specimen	Computational	Practical
SP1		
SP4		
SP5		

Figure9. Pattern of crushed sections from computation and practical tests



(a)



(b)

Figure10. Plot of maximum load carrying capacity for consecutive L/t ratios: (a) For numerical, (b) For practical

VI. Conclusion

This research was based on identifying the load carrying capacity of aluminium hollow rectangular sections, and to represent the role of dimensions on load carrying capacity as well as energy absorption criteria. Research was carried out in two different stages firstly computational then practical. Practical investigation was a part necessary for the validation of results obtained from computational test done on ABAQUS. It was observed from simulations that L/t ratio of 108.89 was excelling quite linearly until load carrying capacity of 41576.9N while later on it was verified with similar specimens on compression testing machine so as to notify the presence of its accurate nature. It was then found that identical result was obtained for the same L/t ratio 108.89 having a load carrying capacity of 39138.8N. Hence, both the results were found in good agreement with each other and the effect of length with thickness ratio on absorption capacity of material was deducted.

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