MULTI CORNERED THIN WALL SECTIONS FOR CRASHWORTHINESS AND OCCUPANT PROTECTION

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Abstract- The desire to improve crashworthiness of a passenger vehicle for enhanced occupant safety has been a major challenge for decades. When a crash is unavoidable, it is the crash energy and the manner in which vehicle occupants experience the associated forces that will determine the Extent of injury to those occupants. The major energy management comes from the upfront crash energy absorption which can be designed to fit into the available packaging space without affecting the cost-weight effectiveness. Axial collapse of the thin walled structures has been studied in detail over decades and the understanding was limited primarily to circular tubes. It was later refined and extended to square sections.

Plastic deformation of structures absorbs substantial kinetic energy when impact occurs. Therefore, energy-absorbing Components have been extensively used in structural designs to intentionally absorb a large Portion of crash energy.

Along with this analysis, the collapse behavior of square, hexagonal, and octagonal cross-sections as the baseline for designing a newly introduced 12-edge section for stable collapse with high energy absorption capacity was characterized. Inherent dissipation of the energy from severe deformations at the corners of a section under axial collapse formed the basis of this project, in which multi-cornered thin-walled sections was focused on. With CAE simulations was performed to evaluate the responses over a range of steels grades starting from low end mild steels to high end strength.

Keywords: Crashworthiness, aluminium column, damage criteria, finite element.

1. Introduction

It subjects the vehicle structure to very high forces and deformations depending upon the mode and velocity of the collision. If these collision forces exceed the energy absorbing capacity of vehicle structure in action the effect is directly felt on the Occupants and might lead sever injuries and fatalities Understanding the process of collision and its effect of occupants of a vehicle is thus very important and this underlying need has led to the birth of the field of Crashworthiness and occupant safety. This aspect of design has become the inherent requirement for all the ground mobility vehicles. This requirement was perceived very early by the manufacturers and realized the need for incorporation of occupant protection even before the general public could consider using their products for their mobility needs. The most important step in vehicle safety was initiated in the year 1966, when the National Highway Traffic Safety Administration (NHTSA) was formed and

Introduction of mandatory safety standards which are popularly known as Federal Motor Vehicle

Safety Standards(FMVSS). These standards established a precedence to regulate various aspects of vehicle design and have become a foundational step for the safety of ground transportation vehicles all around world. It has become so mandatory that OEM (Original Equipment Manufacturers) of the vehicle have integrated these FMVSS standards into their design philosophies to develop safe vehicle structures.

2. Literature review

ALEXANDER [1] Thin-walled structures are widely applied as energy absorbers in automotive engineering, military engineering and other industries. In order to improve their energy absorption characteristics, extensive studies including experiments, theoretical analysis and numerical simulations, have been carried out. firstly developed the collapse model of circular tube and derived an approximate theoretical expression to predict the mean crushing force. Both static and dynamic studies for the circular and square tubes under axial load were done using experimental and numerical methods.

Muhammad Kamran, Pu Xue, Naveed Ahmed, M S Zahran , A A G Hani [2] The improvement of safety and crashworthiness features of aero or automobile systems are becoming more challenging with the advancements of transportation and aerospace engineering to protect the humans and vulnerable equipment. The metallic thin-walled structures have proved to be a comparable choice under dynamic crushing when these demands are to be accomplished with optimal weight feature and low cost. Impact energy is absorbed by such systems in multiple mechanisms such as fracture, splitting, bending, tension, shear and plastic deformation (Jones, 2012). Metallic tubes are one such choice which show multiple deformation modes under axial crushing with unique features such as locally deformed axisymmetric or concertina mode, diamond mode, mixed mode or globally deformed Euler buckling mode depending on the geometry, material parameters and boundary conditions.

Dadrasi Ali [3]: Various kinds of energy-absorbing systems are being extensively used in many engineering applications such as automobiles and other transport vehicles. Indeed, during an impact event, the energy of the crash and the manner in which the loads are transmitted through the system, are very important points. As a consequence, the axial crushing behavior of thin walled structures, which are efficient energy absorbers, has been a topic of great interest for many researchers. In designing such structures, maximizing their energy-absorption capability should always be a major objective. As presented in previous researches, there are two approaches to enhance the performance of the multi-cell thin-walled columns: either using advanced materials with high mechanical properties1,2 or designing optimized wall thickness and cross-sectional dimensions for such columns that can provide the best crash performances.

3. MODELLING AND ANALYSIS:

3.1 Automobile structure andCrashworthiness:

The structure of an automobile has evolved over last seven decades meeting the needs of customers with complex conflicting requirements such as cost and weight, performance and materials, and energy management and package, markets and safety regulations, economics and competition, new technology and manufacturing capabilities

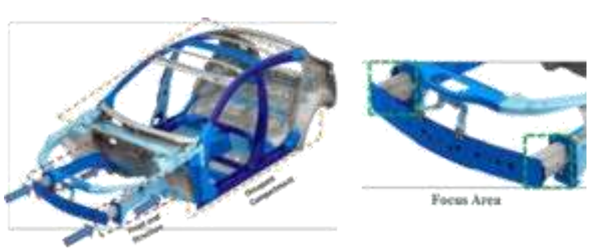


Fig -Unit-body structure

3.2 Nonlinear Analysis and FEA codes:

Nonlinear analysis involves very complex issues that pose series challenges for the analyst. The issues of convergence, choice of nonlinear solution algorithm and proper material modeling must be considered to get the proper and meaningful results from the nonlinear analysis. Unless the analyst is completely aware of these complex issues it is very difficult to predict accurate and reliable solution from the nonlinear simulations.

Different types of nonlinearities and the general approach used for nonlinear analysis are explained in this paper. This chapter also presents important features and applications of three popular finite element codes NASTRAN, ABAQUS and LS-DYNA3D.

Nonlinear analysis is used in many practical engineering applications whenever the engineer wants to take full advantage of material capacity. Often, designs based on linear analysis are too conservative and cannot be competitive in today's international markets. An engineer must take full advantage of material ductility and toughness as many materials have significant capacity beyond their initial yield strength.

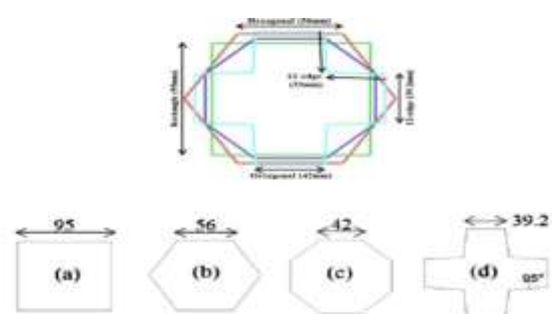
3.3 Classification of nonlinear analysis:

In a finite element analysis if either the strain-displacement matrix or the constitutive matrix is nonlinear, the resulting stiffness matrix is nonlinear. Changes in boundary condition during the course of application of load also introduce nonlinear behavior in structures. Based on the type of nonlinear effect, the nonlinear analyses are classified into three categories as below and discussed in next chapter in detail.

1. Geometric nonlinear analysis

2. Material nonlinear analysis

3. Boundary nonlinear (Contact) analysis



Cross-section of members: (a) square, (b) hexagonal, (c) octagonal, and (d) 12-edge

3.4 Design objectives:

In the design for crashworthiness, specific energy absorption (SEA) is considered to be the first measure of energy-absorption capacity of a thin-walled section and is therefore, the first objective of this optimum design was to maximize SEA. SEA for these purposes can be defined as:

$$EA = E\ int$$

where Eint the internal energy and m is total mass of the member. Typically, the collapse process involves forces which are fluctuating around mean value before they escalate to higher value when deformation is bottomed out at the end of effective stroke length, which is considered to be equal to 250 mm for all cases.

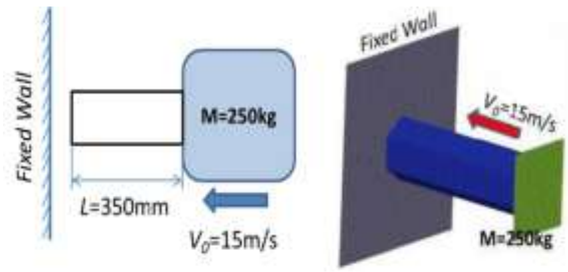
4.Finite Element model formulation and Simulations:

The characteristic understanding of the process, in which thin-walled structures are compressed using state of art, CAE methodologies can help to elucidate effectively their responses under quasi-static and dynamic loadings. Non-linear finite element code, ABAQUS was actively used in this research to study the collapse patterns and analyze the energy absorbing characteristics of thin-walled sections with various sections subjected to axial impact loading.

The specimens were modelled using the ABAQUS . To accurately capture the folding pattern with characteristic wavelength, the mesh size and density has to be chosen 2.5 mm.

The crush behaviour of thin-walled sections under quasi-static loading enables to capture the fundamental characteristics of collapse process with Mean crushing force (Pm) and Energy Absorption (Eabs) as dominant parameters. However crush behavior is devoid of any dynamics effect which is the main feature of dynamic impact load cases. Most of the energy absorbing devices are developed for structures that are designed to withstand impact load conditions. The important feature of dynamic impact is that the loading occurs within a short duration of time. Its due to this transient nature of the process, the deformations are predominantly dynamic in nature.

The FE model is constructed similar to the Quasi-static model with 1.6mm thickness and 350mm length using DP600 and Aluminum for the material and AUTOMATIC SURFACE_TO_ SURFACE contact algorithm for self and contact with rigid wall. The Specimen in this case is attached to a rigid plate with mass of 250 kg and accelerated with *INITIAL_VELOCITY option at 15m/s (with responses at lower velocities being similar). The responses of the dynamic crushing are strongly influenced by the material rate sensitivity properties which are in turn dependent on material characterization at different strain rates. The assessments then would limit to evaluate the material strain rate sensitivity and robust performances of the FEA models in predicting the dynamic crush force characteristics which later are evaluated in full vehicle tests.



Dynamic crush test setup and CAE Model

4.1 Model Analysis :

Geometric model: The geometric model as shown below

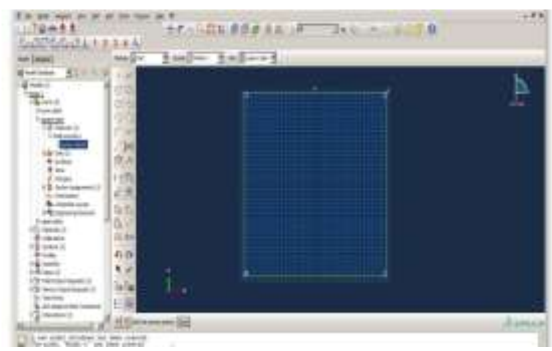


Fig : ABAQUS Procedure Steps for creating crush tube

Creating mesh for both Top plate, square tube and bottom plate:

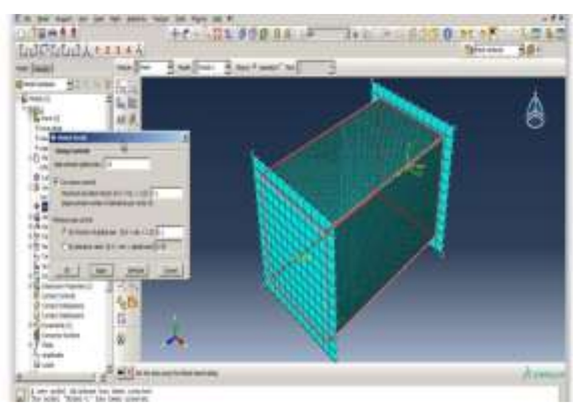


Fig: The meshed model for the both Top plate, square tube and bottom plate

4.2 Total Deformation on Square tube for Aluminum Materials:

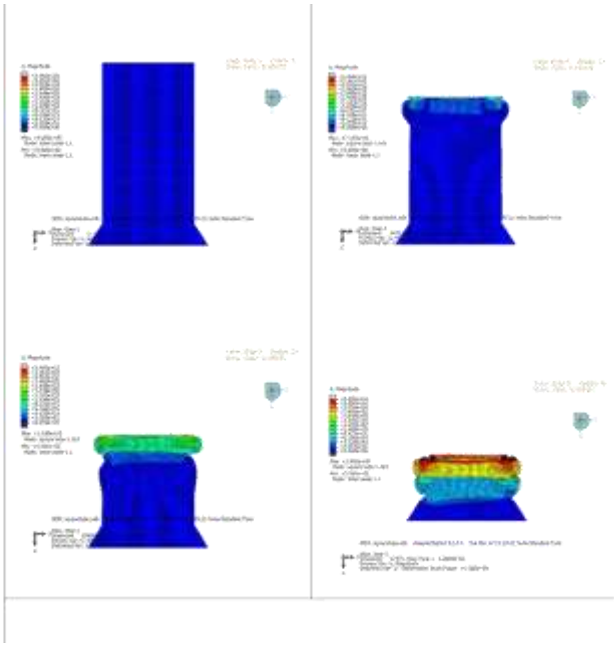


Fig: Total Deformation for Square tube a) 1st fold b) 2nd fold c)3rd fold d)4th fold of tube

4.3 Total Deformation on Hexagonal tube for Aluminum Materials

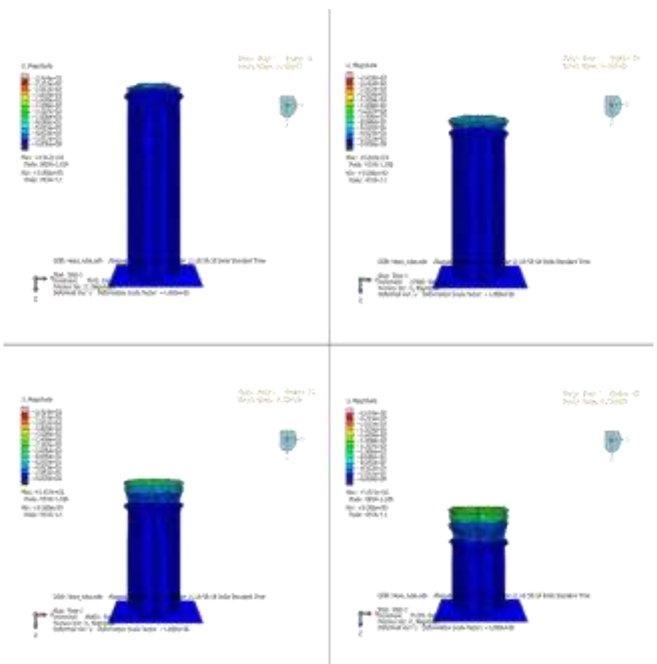
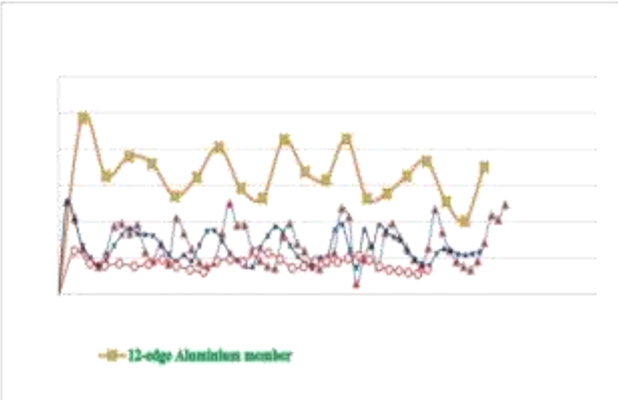


Fig: Result of square tube for Aluminum for Displacement (mm) vs axial crushing force (kN)

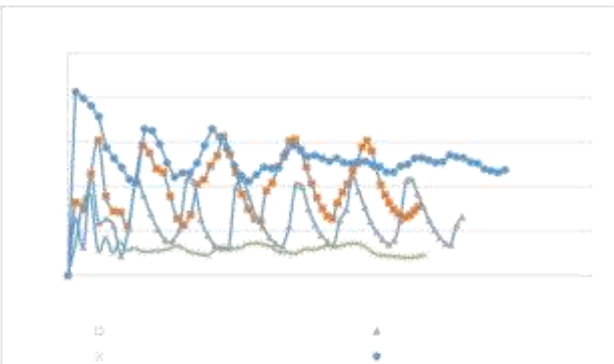
5. Result and discussion:

The SEA each crush absorber prepared in simulation were then measured as shown in the previous section, the values of which are presented in Tables from tables

Displacement(mm)	Axial crushing force (kN)
0	0
10.2430687	2.048613739
20.24799156	4.049598312
30.01683235	6.00336647
39.62129211	7.924258423
49.08109283	9.816218567
58.41963577	11.68392715
67.61408234	13.52281647
76.64803314	15.32960663
85.55132294	17.11026459
94.34779358	18.86955872
103.0359802	20.60719604
111.5848541	22.31697083
119.9786835	23.99573669
128.2167053	25.64334106
136.2754517	27.25509033
144.155304	28.83106079
151.882019	30.37640381
159.4793854	31.89587708
166.9560547	33.39121094
174.2835236	34.85670471
181.4600983	36.29201965
188.496109	37.6992218
195.3758545	39.0751709
202.0726318	40.41452637
208.6081696	41.72163391
215.0192871	43.00385742
221.3245239	44.26490479
227.5281372	45.50562744
233.6418152	46.72836304
239.6688232	47.93376465



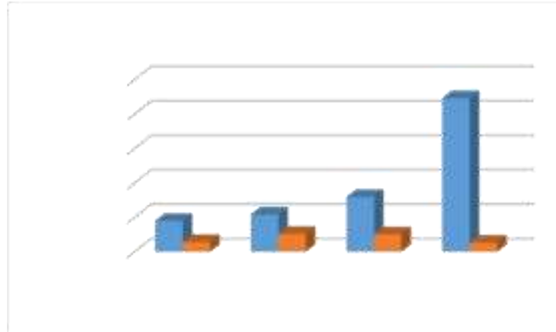
Graph : Comparison of SAE of DP-600 and Aluminium for different cross-section Axial crushing force–displacement



Graph: Comparison of SAE of DP-600 for different cross-sectionAxial crushing force–displacement

		DP-600	Al
SL . NO	Maximum Energy Absorbing		
1	4-Sided	443080.6	137117.9972
2	6-Sided	536458.4	254295.9167
3	8-Sided	790445.7	248276.5723
4	12-sided	2226239	127677.6467

Table: Max. Energy absorbing capacity of each cross-section and Material



Graph: Energy absorption in DP-600 and Aluminium for different cross-section

6. CONCLUSIONS:

The collapse behaviour and energy abortion characteristics of multi cornered thin walled sections with cross sections of Square, Hexagon, Octagon were investigated in this research. The design of section with 12-Edges to improve the performance was developed.

Analystical foundations for characterizing the collapsing behavior were developed based on the SFE (Super folding Element) and was further extended to multi cornered sections to develop important collapse parameters and provide a direction for designers in developing efficient energy absorbing devices.

This project presented the crashworthiness design optimization of thin-walled multi-corner members, including the square, hexagonal, octagonal, and 12-edge cross-sectional profiles made of the materials DP-600 and Aluminium. This newly introduced 12-edge configuration was developed based on the idea of distributing more materials near the corner by introducing more corners in the cross-section. The main objective of this project was to show how cross-section of different materials will change which was applied to a dis-continuous design space would lead to an efficient and effective design approach for the crashworthiness investigation of the crush absorbers.

1. From the bar charts it is observed that DP-600 Steels having the highest energy absorption For 12-edge cross-section. Whereas Aluminium is having lowest for 12 edge cross-section.

2. Alternative choice for DP-600 Steel after 12-edge cross-section, 6-sided cross-section is having the next highest energy absorption. Whereas aluminium is having next alternative 8 sided

3. For the optimum design, energy absorption (EA), the cross-sectional configuration, material type was selected as two design variables. The project is helpful

to applied in industrial applications, such as crash-worthiness design of automotive crumple zones. The findings drawn from this project could be helpful in crashworthiness improvement of automotive body structure.

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