

Analysis on the Safety Factor of Corrugated Tubes having Predicted Deformation Patterns

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Abstract

In this research paper the analysis of Axial crushing of Circular Tubes with Graded Corrugations is done by FEM using ANSYS 15.0 with LS-DYNA Explicit Dynamics. The analysis is carried out on simple cylindrical tubes with geometrical parameters such as different types of corrugations with different sizes, grooved tubes. Various structural analysis graphs were plotted and results show that corrugated tubes have a rather uniform and straight graph as compared to simple cylindrical tubes. Which also establishes that the structural crashworthiness of these corrugated tubes is better than normal cylindrical tubes?

Key words: Axial Crushing, Corrugated Tubes, Structural Analysis, shock absorbers, structural crashworthiness.

1. Introduction

There is always a need to enhance the absorption of energy characteristics of shock absorbers used at various places like vehicles, aircrafts, lifts, railway, couches, machinery, etc. These shock absorbers have different dissipation ways of the Kinetic energy coming from the shock (ex. At the time of an accident) like friction, fracture, bending, crushing, plastic deformation, etc. Attempts have been made since 1960s to find a pattern of how this Shock-Energy gets transformed into other forms & how the material under shock will behave during its application and how can we improve the ability of these materials to absorb this Kinetic energy.

In order to achieve the target of maximizing energy absorption Alexander TM [8] analyzed the thin cylindrical shells to develop an algorithm which is used to fine out the collapse load during the time of axial crushing of shell. Norman Jones & White MD experimented on thin walled double-hat & top-hat structures during axial crushing & noted effects of various design factors on the collapse conduct of walled structures of thin. El-Hage [5] conducted a mathematical study on characteristics of axial crushing quasi-static of square Aluminum tubes through chamfering & other triggering mechanisms.

The tubes are used with different cross-sections but higher stiffness & strength of circular tubes with their lower weight & manufacturing cost give makes them more suitable for the use of shock absorbers which was explained by Norman Jones in his book & AAA Alghamdi in his paper [24-25]. But how do these tubes behave when a load is applied on them? This has also been explained by Wlod zimierz Abramowicz & Norman Jones in their paper [27], they explained about the three possible ways in which circular tubes can crush/buckle under a load, these are Diamond, Concertina & Euler. Later, F.C. Bardi [26] Developed a Finite Element model of crushing analysis which enabled them to predict crushing energy, fold types, etc.

Now, to further enhance the absorption of the energy & axial crushing aspects of tubes several types of geometries have been experimented upon just to find out the perfect one, which can be used in vehicles,

etc. to save lives & money. S. Chung Yun [7] studied various geometrical & material variations to give energy absorption characteristic of each & every structure. Corrugated tubes had lesser peak force & a uniform load-displacement diagram than normal circular tubes. Basically, corrugations are provided to plastic deformations to occur at pre-determined spaces for uniform load-deflection diagram [9-11]. Conduct of these corrugated tubes which are crushed axially was first studied by “Singace AA & El-Sobky H.” [22]. But there has been analysis on corrugated tubes from time to time Meisam K. Habibi [1] also experimented on axial crushing & energy absorption efficiency of corrugated tubes.

But is it possible to achieve better energy absorption efficiency than these corrugated tubes? There have been tries in that direction too. Ringed circumferential tubes were analyzed by M. Shakeri [15], these tubes have an increased concertina region during buckling. Cutting corrugated grooves [16] & cutting tubes into several parts & assembling them coaxially by sorting out the disc which is non-deformable [17] are another ways of increasing energy absorption coefficient. Different filler materials (foam, honeycomb, other metals) are also utilized to enhance the efficiency of energy absorption of corrugated tubes [13] [19]. ReidSR & ReddyTY [18] studied single & double tapered tubes, they are as effective in oblique as in axial crushing [30-32]. Which is an important feature in some cases? Like at the time of accident where the direction of impact is not certain. Expandable tubes have also been tested [6] [16] under axial crushing & results show that they don't have an initial peak load. Which is a very positive result but it is not possible as yet to use these kind of structures practically (ex. in vehicles)[2-4]. Various other factors to improve energy absorption on axial plastic collapse of hollow cylinders have been studied [21].

Nonlinear finite element analysis of axially crushed cotton fiber composite corrugated tubes has been done on ABAQUS/Explicit by E. Mahdi [23]. But the material used is rather idealistic & it also displays the stereotype Force-Displacement curves which have been analyzed time & again for past 20-30years.

2. Finite Element Method

The finite element model (FEM) is mathematical technique for achieving the nearest solution to class of issues that are governed by the elliptic partial differential equations. Such kind of issues is known as boundary-value issues as they contain partial differential equation and the conditions of boundary. And the FEM converts equations of elliptic partial differential into group of the algebraic-equations that are simple for solving. The primary value issues that contain hyperbolic or parabolic differential equations & the initial conditions will not entirely be solved through FEM. And the differential equations of hyperbola consist of the time to be one of non-relied variables. And for converting the temporal or time derivatives into the algebraic expressions (AE), another mathematical method like FDM -finite difference method is pre-requisite. Hence for solving the initial issue, one requires both FEM and FDM where spatial-derivate converted into AE through FEM and derivate which are temporal are converted as algebraic-equations through FDM.

3. Analysis

3.1 Specification of Test Specimens

In experiments, the whole circular tubes are created by structural-steel. And the cross section of tube wall thickness is selected to be 3mm. For querying the impact of corrugation on crushing controllability and characteristics of steel tube structures, diverse groups of tests are planned. Easy and the tubes which are corrugated are segmented into clusters. Distinctive shapes of the samples are made aimed at compression assessment. Easy tubes: and in esteem to possess the reference for comparing the

development in characteristics of energy absorption of diverse tube kinds, it will be required to carry the simulations on easy structural tubes of steel with no corrugations. Further, with the study of count of the folds in simple compressed tube it is probable to generate tubes which are corrugated with similar wavelength. Corrugated kinds: 2 kinds of tubes which are corrugated are enquired for comparing the outcomes through easy ones and remaining compositions of corrugated tubes. The depth of corrugation is a significant aspect in collapse-load. And the tubes corrugated with diverse depths of corrugation are enquired in this article.

3.2 Preparation of Test Specimens

Structural tubes of steel which are Seamless of the nominal thickness & diameter are chosen owing to form the characteristics that are compared with other materials such as mild-steel. On the other hand, they were reasonably priced and simply achievable. And these tubes were planned precisely in module of designing of workbench ANSYS. And there are several tools that are utilized to create essential geometry that required for analyzing

3.3 Material Properties

The properties of structural steel which is the designing material here are illustrated in the table given below.

STRUCTURAL STEEL			
	A	B	C
1	Property	Value	Unit
2	Density	7850	kg m ⁻³
3	Isotropic Elasticity		
4	Derive from	Young's...	
5	Young's Modulus	2E+11	Pa
6	Poisson's Ratio	0.3	
7	Bulk Modulus	1.6667E+11	Pa
8	Shear Modulus	7.6923E+10	Pa
9	Specific Heat	434	J kg ⁻¹ ...

Table.1. Properties of the material used

3.4 Testing Procedure

Testing of the specimen is done using FEM as explained earlier. Procedure followed is quite simple for someone with the knowledge of software. First of all, meshing of the specimen is done after that structural loads & supports are exerted at the required points or surfaces. After providing all the inputs like force, support, end time, etc. our model is ready for solution and then the solution is obtained. Which displays the results of the initial conditions applied by us in explicit dynamics?

4. Parameters of Shock absorbers

In design of the absorption of energy instruments for diverse reasons, it will be required for the planner to know detailed, the diverse characteristics of the absorbers of energy. Therefore, diverse factors are determined for making it simple to compare diverse absorbers of energy. These factors are shown in succeeding segment.

4.1 Mean crushing Load (Pave)

Mean-load is average of response of crushing load of absorber via entire deformation. And this factor is resourceful in the evaluation of energy absorbers performance and acts as significant role in planning. And

it is evaluated in the following way:

$$Pave \frac{1}{4} Etot = Lc \delta 1P$$

Where, Lc & $Etot$ are length of crush and absorbed energy totally, respectively.

4.2 ETOT

The absorbed energy at any time in the entire crushing will be attained through computation of region under the curve from displacement of load

5. Experimental Results

Following chapter shows the experimental results of different tubes after analysis.

5.1 Simple Tubes

A simple cylindrical tube with a fixed support is used firstly for the analysis, with a thickness of 3mm. A force of 100N is applied for 10s and various results are obtained. The geometrical specifications of the object are given in the following table.

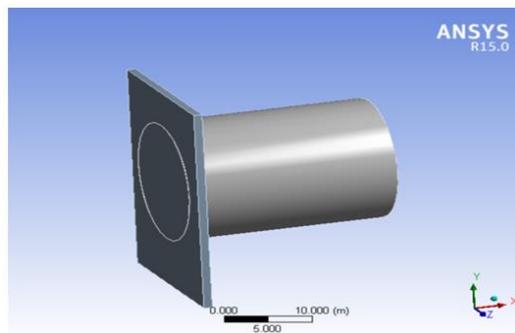


Figure.1. Simple Cylindrical tube with fixed support at one end

Axial Crushing Analysis of Circular Tubes with Graded Corrugations using Finite Element Method

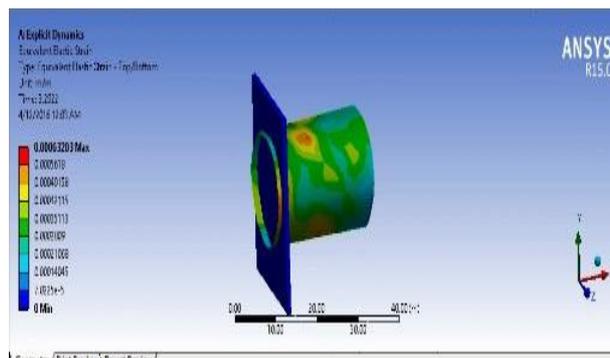


Figure 2 Deformation in Simple Cylindrical tube under fixed support at one end

Model (A4) > Geometry > Parts		
Object Name	Surface Body	Solid
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Thickness	3.e-006 m	
Thickness Mode	Manual	
Offset Type	Middle	
Reference Frame		Lagrangian
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	24.99 m	1. m
Length Y	17.453 m	29.63 m
Length Z	17.453 m	22.844 m
Properties		
Volume	4.1107e-003 m ³	676.86 m ³
Mass	32.269 kg	5.3134e+006 kg
Centroid X	12.495 m	0.5 m
Centroid Y	4.621e-016 m	-0.96126 m
Centroid Z	1.6615e-016 m	0.45236 m
Moment of Inertia Ip1	2441.9 kg·m ²	6.1979e+008 kg·m ²
Moment of Inertia Ip2	2898.1 kg·m ²	2.3151e+008 kg·m ²
Moment of Inertia Ip3	2898.1 kg·m ²	3.8917e+008 kg·m ²
Surface Area(approx.)	1370.2 m ²	

Table.2. Geometrical properties of the specimen

The various plots obtained after applying the various conditions & solving them are shown below :

5.2 Equivalent Stress vs Time Graph

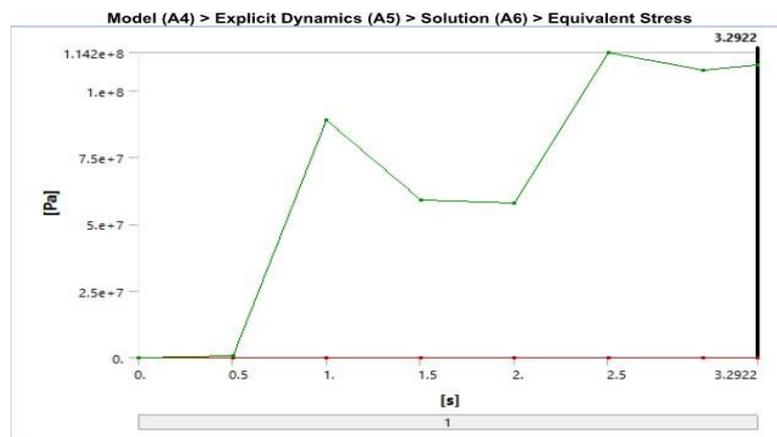


Figure 3 Equivalent Stress vs Time graph of Simple Tube during axial crushing

5.3 Equivalent Strain vs Time Graph

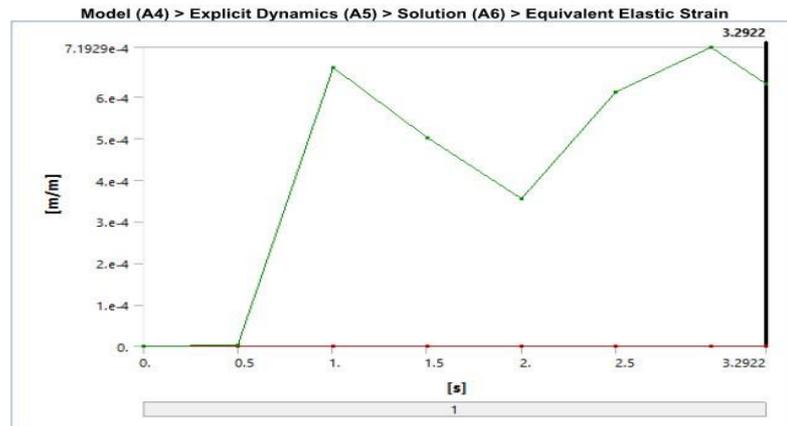


Figure 4 Equivalent Strain vs Time Graph of Simple Tube during axial crushing

5.4 Stress Ratio vs Time Graph

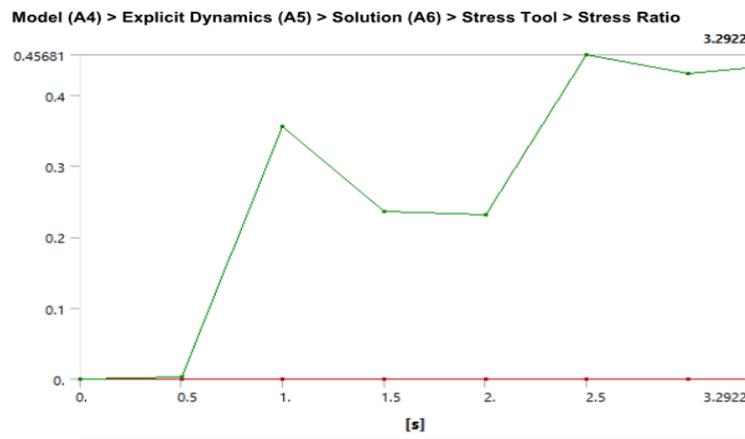


Figure 5 Stress Ratio vs Time graph of Simple Tube during axial crushing

5.5 Stress vs Strain

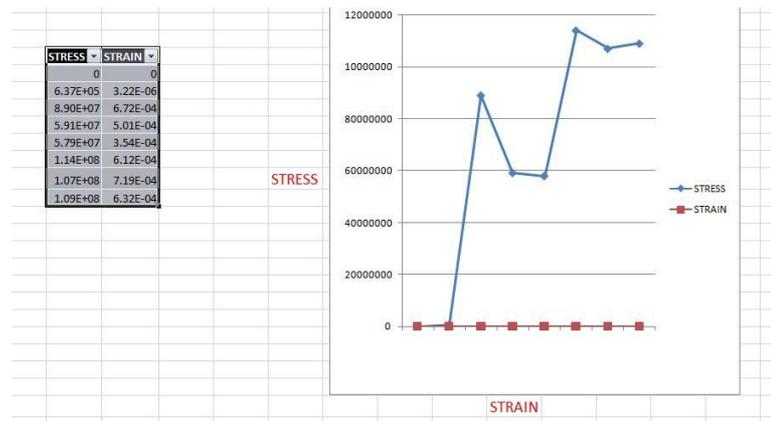


Figure 6 Stress vs Strain Graph of Simple Tube during axial crushing

5.6 Corrugated Tube

A corrugated cylindrical tube with a fixed support is used firstly for the analysis, with a thickness of 3mm. A force of 100N is applied for 10s and various results are obtained. The geometrical specifications of the object are given in the following table.

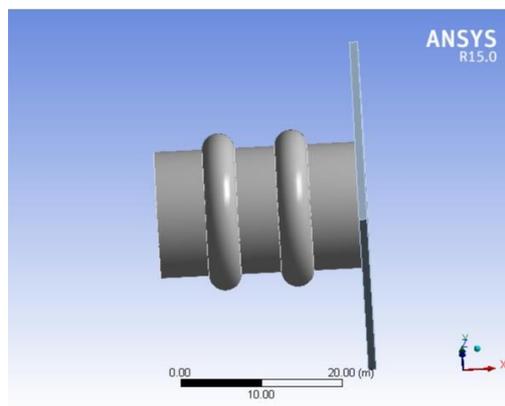


Figure 7 Corrugated Tube with fixed support at one end

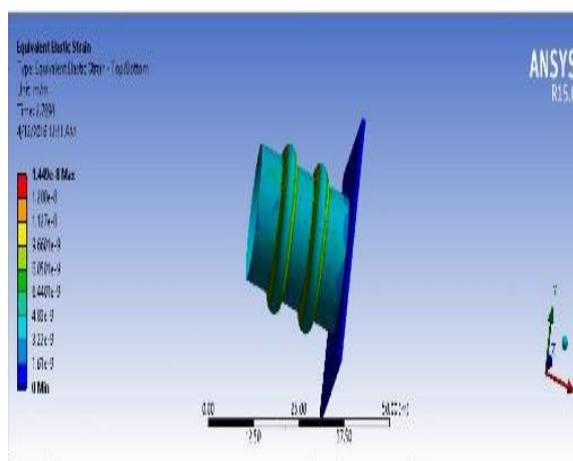


Figure 7 Deformation in Corrugated Tube under fixed support at one end

Model (A4) > Geometry > Parts		
Object Name	Surface Body	Solid
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Thickness	3.e-003 m	
Thickness Mode	Manual	
Offset Type	Middle	
Reference Frame		Lagrangian
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	25. m	1. m
Length Y	20.412 m	29.753 m
Length Z	20.412 m	30.948 m
Properties		
Volume	4.8736 m ³	920.78 m ³
Mass	38258 kg	7.2281e+006 kg
Centroid X	-12.497 m	0.5 m
Centroid Y	-2.3202e-016 m	-3.2925e-016 m
Centroid Z	-2.0785e-017 m	-0.29872 m
Moment of Inertia Ip1	2.975e+006 kg·m ²	1.1101e+009 kg·m ²
Moment of Inertia Ip2	3.2475e+006 kg·m ²	5.775e+008 kg·m ²
Moment of Inertia Ip3	3.2475e+006 kg·m ²	5.3381e+008 kg·m ²
Surface Area(approx.)	1624.5 m ²	

Table 3 Geometric properties of Corrugated Tube

The various plots obtained after finite element meshing & solving of this tube are

5.7 Equivalent Stress vs Time Graph

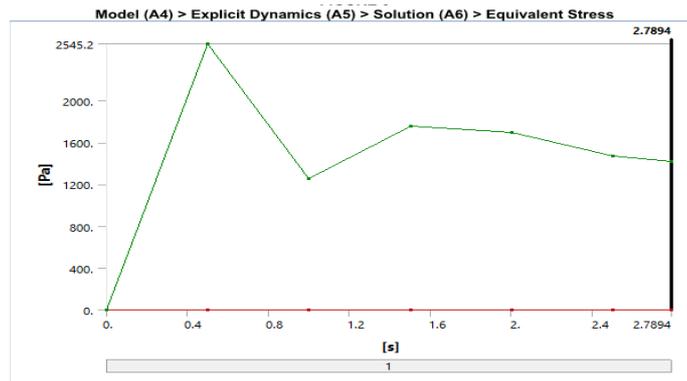


Figure 8 Equivalent Stress vs Time Graph

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5.8 Equivalent Elastic Strain vs Time Graph

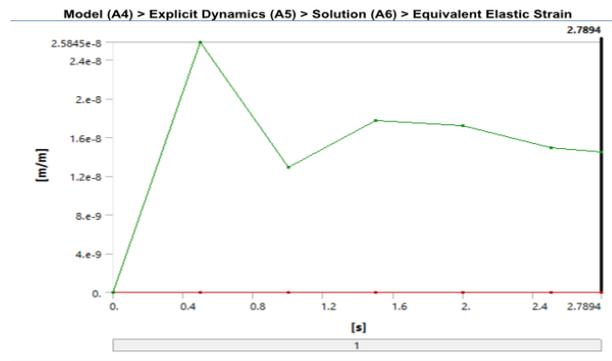


Figure 9 Equivalent Elastic Strain vs Time graph of Corrugated Tube

5.9 Stress Ratio vs Time Graph

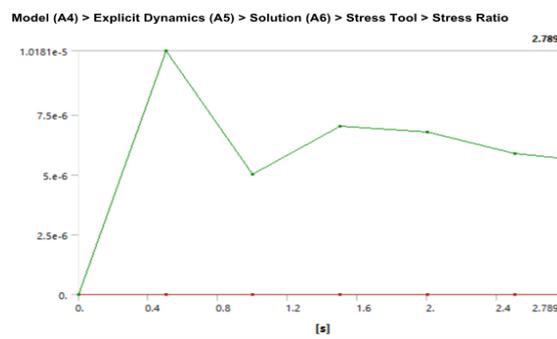


Figure 10 Stress Ratio vs Time graph of Corrugated Tube

5.10 Stress vs Strain Graph

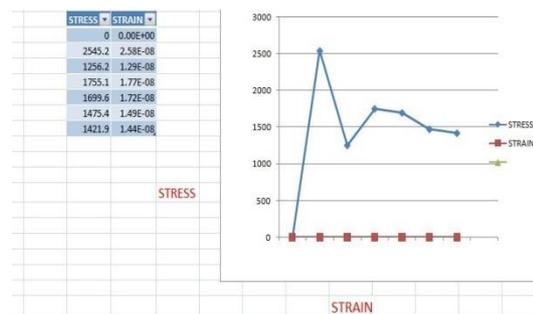


Figure 11 Stress vs Strain graph of Corrugated Tube

6. CONCLUSION

The elastic limit of corrugated tube is much better in comparison to simple tubes. Corrugated tubes have predicted deformation patterns. Safety factor is better & remains constant in case of corrugated tubes. A uniform Strain vs Time graph is obtained for corrugated tubes which show that corrugated tubes deform much more uniformly as compared to simple tubes. Stress ratio vs Time plot shows that corrugated tubes have lesser difference between min & max stresses which shows that peak load in case of corrugated tubes

is lesser.

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