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Experimental Study of Sawdust Filled and Ribbed Stainless Steel Tubular Crash Structures

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Abstract: *Analysis of crashworthy structures has been a primary realm of interest for many researchers for quite a few years now. The quest for a better energy absorbing structure has led researchers to carryout various analysis procedures experimentally and also by simulating the characteristics. This study presents an approach for the improvement of crashworthiness in thin walled stainless-steel tubes. The crashworthiness of saw dust filled and ribbed tubes are investigated by subjecting it to a quasi-static axial compression loading. The experimental results of circular cross section thin walled tubes are compared with that of square ones. The main objective is to provide a better energy absorbing structure which results in passive safety of the passengers.*
Keywords: *Crashworthiness, Energy absorption, Quasi-static test, Thin-walled structure*

I. Introduction

Safety in the context of automobiles can be broadly classified into two main categories. One being active safety and the other being passive safety. Active safety includes devices and systems which work, either in isolation or along with other systems in order to prevent accidents from happening. This includes Anti-lock brakes (ABS), Electronic Brake force Distribution (EBD), Electronic Stability Program (ESP) and Traction Control (TC) system. And the Passive safety includes systems which help in reduction in the severity of the injury to the occupants in the vehicles in an unfortunate event of an accident such as Airbags, Side intrusion beams, and Crash box.

Crash box equipped at the front end of the cars is one of the most important automotive parts for energy absorption. This structure is expected to absorb maximum crash energy prior to other body parts so that damage of main cabin frame is minimized and passenger may be saved with minimal or no injuries. In case of frontal crash accident, the front rail is the main deformation component designed to dissipate the kinetic energy in a stable and controlled manor.

The energy absorption capacity of thin-walled tubes is significantly influenced by thematerial properties and the tube geometry [1]. A variety of thin-walled tubular sections are used for the crash structures, which include circular, square, rectangular, trapezium, hexagonal and conical [2].

Fig.1 Crash box Structures in an automobile (Courtesy: GrabCAD)

An extensive research is carried out in the area of crash structures for better energy absorption and optimization of tubes made of metals. In these studies, either empty tube or filled with some sort of reinforcements are considered. Yang and Qi [3] studied empty and filled tubes with a square cross-section under axial impact to increase the specific energy absorption and minimize the peak crushing force by varying the wall thickness, cross-section width and material properties. Zarei and Kroger [4] used a Multi design objective crashworthiness optimization method for increasing total energy and specific energy absorption by varying the length, diameter, and thickness of the thin walled tubes.

Ciubotariu [5] studied the crashworthiness of hexagonal tubes with welded stainless-steel blanks, to improve the energy absorption and maximum force. Tang et.al. [6] performed an experimental analysis to study the energy absorption characteristics of multi-cells cylindrical tubes and found that multi-cell geometries enhance the energy absorption. Zabala et.al. [7] in his study presented the crashworthiness of Carbon-epoxy composite tubular structures subjected to different contour conditions. Wide research is carried out extensively on composite materials in the quest of better energy absorbing structure. [8-11]

Tubes can be filled with certain materials like honeycombs, wood, and foams to improve crashworthiness as these materials show that they are good as energy absorbing characteristics. Haidar [12] used Rice Husk, Wood Chips, Aluminium Chips, Coconut Fibre and Palm Oil Fibre fillers in glass fibre composite thin walled tube specimen. Some used Metalpowdersglass spheres and flakes as fillers [13-14].Jute, flax, hemp, remi, sisal, coconut fibre (coir), and banana fibre are some natural fibers [15]. While some researchers carried out extensive research using uniform density and functionally graded foams fillers [16-18] to enhance crashworthiness performances.

Most of these experimental works are carried out in quasi-static and dynamic loading conditions. In the present paper the crush behavior of sawdust filled and ribbed stainless-steel tubes to improve the crashworthiness of thin walled tubular structures is discussed.

II. Experimental Testing

A. Material

The material used in this investigation is stainless steel 304. Thin walled tubes of 50 mm outer diameter circular and43 mm × 43 mm square cross sections with 0.7 mm thickness were used for the study. Specimens were cut to a length of 200 mm. TABLE I shows the chemical properties of the selected material.

TABLE I: Stainless Steel 304 Chemical Composition

	Content wt. (%)
C	0.08
Mn	2
P	0.05
S	0.03
Si	0.75
Cr	18-20
Ni	8-12
N	0.1
Fe	rest

Reinforcements substantially increase the energy absorption capability of the tubes, while at the same time it should be efficient in terms of mass, space and cost. In the quest for these properties, in the current study saw dust is used as reinforcement as it has low density and better energy absorption capability. Another study is made by welding the 8 mm x 8 mm square cross section Mild steel rods on the thin walled tubes in the form of ribs for improving the energy absorbing properties.

B. Quasi Static Compression Test

The experimental tests were performed on the Fine Spavy Universal Testing Machine of 40 KN capacity. The specimen is placed between two flat plates and a weight of 1000 Kg is applied at a constant speed of 6 mm/min. The load was applied till more than 50% of the component is compressed. The energy absorption and max load taken by the thin walled tubes were studied. Many researches show that the thin-walled structures under axial loading deform by Progressive buckling, Euler-type buckling, and Dynamic plastic buckling [19].

Fig.2 Saw dust reinforced and ribbed thin walled tubes

C. Performance indicators

The performance of the crash structures is specified by the Maximum force to deform the structure (F_{max}), Energy absorption (E_{abs}), Specific Energy Absorption (*SEA*), Mean deformation load (F_{mean}) and the Deformation Force Efficiency (*DFE*) parameters [20]. These parameters are defined as follows:

The total energy absorption in a deformation is the area under the load-displacement curve.

$$E_{abs} = \int_0^s F\, ds \qquad (1)$$

where, F is the deformation force and $s$is the axial deformation distance

Specific Energy Absorption assess the energy absorbing capacity of the structure. It is also used as an indicator of the weight efficiency of an absorber. Higher SEA indicates a more efficient crash absorber in terms of its weight.

$$SEA = \frac{E_{abs}}{m} \qquad (2)$$

where, m is the total mass of the tubular structure

Mean deformation load is defined as the ratio of energy absorbed to the theoretical maximum energy that can be absorbed.

$$F_{mean} = \frac{E_{abs}}{s} \qquad (3)$$

Deformation Force Efficiency is the measure of load fluctuations which is defined as the ratio between the mean and max deformation forces

$$DFE = \frac{F_{mean}}{F_{max}} \qquad (4)$$

III. Results And Discussion

A. Test on Circular Tubes

Fig.3 show the crushing modes of the circular tubes under quasi-static loading. Two modes of deformation are majorly observed. The hollow and saw dust filled circular tubes deform by progressive folding whereas ribbed circular tube show some longitudinal cracks from the tip of the tube where the ribs are welded which open while the displacement increases. The Load-displacements curve of circular tubes is shown in Fig.4. The performance indicators in TABLE II indicate saw dust filling increases the SEA value by 33.69% compared to hollow circular tube. Therefore, saw dust filled structures have better crashworthiness. However ribbed circular tubes can take maximum load but they reduce energy absorption capability of the structure.

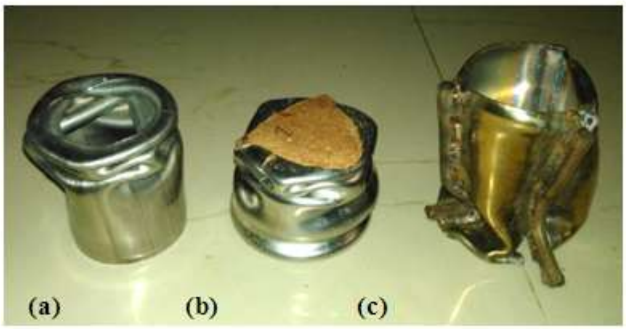

Fig.3 Deformation behavior of (a) Empty circular tube (b) Sawdust filled circular tube (c) Ribbed circular tube

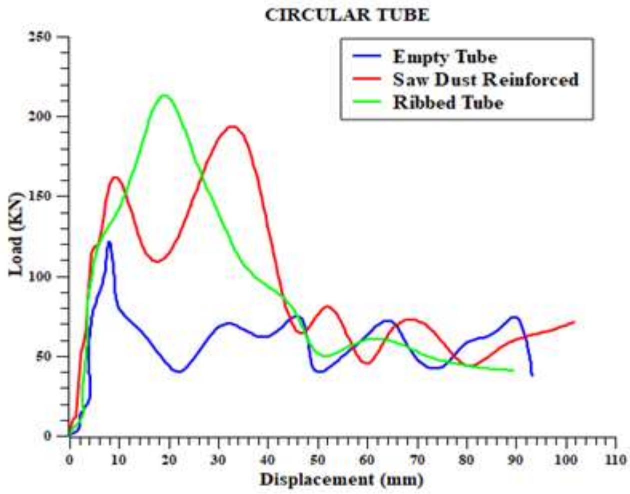

Fig.4 Load-Displacement curves for Empty circular tube, Sawdust filled circular tube & Ribbed circular tube

B. Test on Square Tubes

Square tubes mainly deform by longitudinal cracks at the corners. The cracks open and the folding of the walls can be observed on the outer side as the displacement increases. Fig. 5 and Fig. 6 show the crushing modes and Load-displacement characteristics of square tube respectively. Similar to circular tube, saw dust filling in square tube increases the *SEA* value by 43.16% proving saw dust filled square tube has better energy absorption than empty square tube and ribbed tube (TABLE III).

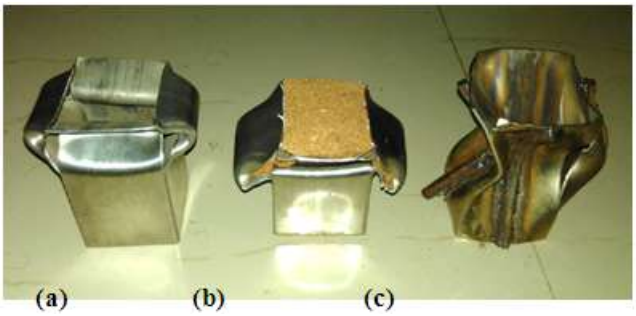

Fig.5 Deformation behavior of (a) Empty square tube (b) Sawdust filled square tube (c) Ribbed square tube

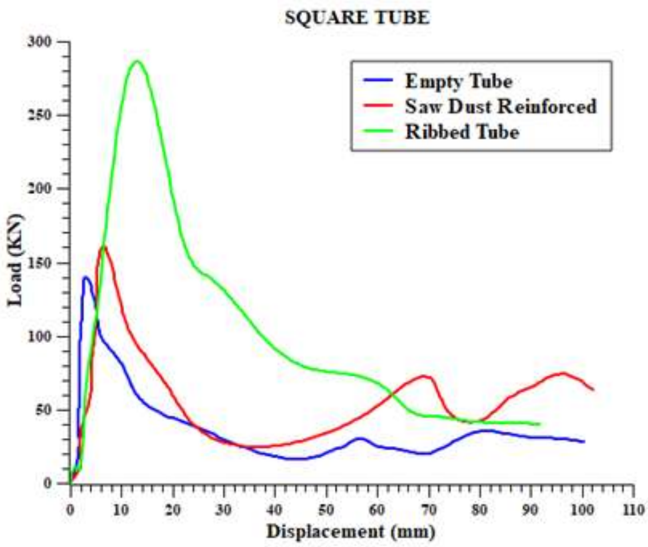

Fig. 6 Load-Displacement curves for Empty square tube, Sawdust filled square tube & Ribbed square tube

The comparison of square and circular geometry's energy absorption performanceunder axial loading using different reinforcements provescircular is more effectivein energy absorption and can minimize the impact loadstransmitted to the structure.

TABLE II: Performance Indicators of Circular Tube under Quasi-static Loading

Parameter	Empty Tube	Saw Dust Reinforced	Ribbed
F_{max} (KN)	141.7	182.3	213.6
E_{abs} (J)	1632.23	4237.27	1163.71
s (mm)	100.3	102.2	91.8
SEA (J/gm)	6.16	9.29	3.15
F_{mean} (KN)	16.27	41.46	12.68
DFE (%)	11.48	22.74	5.94

TABLE III: Performance Indicators of Square Tube under Quasi-static Loading

Parameter	Empty Tube	Saw Dust Reinforced	Ribbed
F_{max} (KN)	136.85	164.35	285.25
E_{abs} (J)	271.93	754.89	409.29
s (mm)	93.2	101.6	89.3
SEA (J/gm)	0.79	1.39	0.84
F_{mean} (KN)	2.92	7.43	4.58
DFE (%)	2.13	4.52	1.61

III. Conclusion

The crush and energy absorption response of the empty, saw dust filled and ribbed tubes of circular and square cross sections has comprehensively investigated under quasi-static loading conditions. The loading parameters were kept constant throughout the study. Energy absorption of circular tube is found more effective than square. With any reinforcements used for square geometry, still circular proves to be more effective. Saw dust effectively enhances the energy absorption performance of vehicle protective structures. The *SEA* of circular and square tube with saw dust filling improved by 33.69% and 43.16% compared to empty tube.

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