ISSN NO. 2320-5407

*Journal homepage: http://www.journalijar.com*

***INTERNATIONAL JOURNAL OF ADVANCED RESEARCH***

**RESEARCH ARTICLE**

# Collapse Behaviour and Energy Absorption of Aluminium Tubes Filled with Wood Sawdust

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## *Manuscript Info*

***Manuscript History:***

Received: 27 August 2015
Final Accepted: 16 September 2015
Published Online: October 2015

***Key words:***

Aluminium tube, Axial compression, Crashworthiness, Energy absorption, Thin walled circular tube.

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## *Abstract*

Experiments on filled and empty circular thin walled Aluminium AA6063 tubes with varying L/D ratios have been performed to study load compression and energy absorbed for quasi static axial and oblique loading. Dependence of deformation characteristics and energy absorption responses have been studied. Energy absorption was measured from load-displacement graph obtained from UTM using MATLAB. Tubes were clamped at the lower end and axial and oblique loads were applied by applying a force at upper end with different angles to the centreline of column. Peak loads and absorbed energies have been compared for filled and empty tubes for same L/D ratio. Experimental results are used to determine energy absorption capacity due to plastic deformation of thin walled tube. The goal of the research was to study the interaction between the forming and crash response of Al AA6063 in order to evaluate its potential for use in vehicle design for crashworthiness.



## INTRODUCTION

Thin walled tubes have been widely used as energy absorbing devices in trains, passenger cars, ships and other high volume industrial products since they are relatively cheap and weight efficient. For instance, the crash box of an automotive body in white (BIW) is often made of thin walled tubes which can absorb the kinetic energy of the vehicle through plastic deformation during an impact.

**Fig. 1**

So it has become a trend in automobile companies to use thin walled tubular structures as impact energy absorbers as they have been identified by their quality and efficiency as crashworthy components [1-5].Now-a-days vehicle frame is made of thin walled section as shown by coloured portions in Fig. 1. Due to thin walled structure body can withstand impact and it is also not increased substantially.
Properties of material used, geometry and mode of collapse as concertina, diamond or mixed are the deciding factors behind energy absorption [6]. But reduction in weight and economical aspects has given researchers an area to look for low cost and light weight materials that can absorb maximum energy. For instance, Farley and Jones [7] and Kindervater and Georgi [8] are among those who have investigated the use of non-metals and composites for designing of light weight and efficient energy absorption elements.
Experiments have revealed that energy absorbing capacity of tubes can be enhanced by using fillers like foam, granular materials like wood dust, thermocol, rice etc. The compression of the filler material and its interaction with the tube leads to higher energy dissipation provided the tube buckles progressively.
Wirshing and Slator [9] who entrapped air inside cans found that energy absorbing capacity of beer cans was increased. Many investigators have studied the effect of inclusion of different filler materials and their effect on energy absorption response. The crashworthy performance of a tubular structure due to inclusion of polyurethane foam filler has been investigated by Hinkly and Yang [10] who studied the influence of variation of density of polyurethane foam and strain rate on the energy absorption on the energy absorption performance.
Threnton [11] conducted experiments on foam-filled tubular structures of varying cross-sections and concluded that the thicker tubes absorb more energy as compared to those having less thickness. Lampinen and Jeryan [12] experimentally found that although the common mode of failure of foam-filled tubes was progressive buckling but overdense tubes would tend to collapse in Euler mode. They concluded that foam plays a major role in stability of deformation of tubular struts.
In the present investigation, the effect of foam-like wood filler on collapse of Al AA6063 circular tubes has been studied experimentally. This study brings into application the use of saw-dust produced by carpentry and woodworking processes in the design of energy absorption elements to increase their efficiency. The main objective behind using wood dust as filler is its recyclability, cheapness and it is hazard-free as compared to most conventional polyurethane foam fillers. The collapse behaviour, peak loads and energy absorbing capacity of wood saw filled tubes and empty tubes have been compared.

## II. STRUCTURAL CRASHWORTHINESS AND ENERGY ABSORBERS

Crashworthiness is the science which deals with study of energy absorption by a crash event without excessive damage to itself and passengers in it. According to Lu and Yu (2003) structural crashworthiness is the quality of response of a vehicle when it is involved in or undergoes an impact. The less damaged the vehicle or its occupants and content after the given event, the higher the crashworthiness of vehicle or better crashworthy performance. An energy absorber is a device that converts impact energy into some other form of energy. The absorber absorbs energy by irreversible plastic deformation, thus reducing the peak damaging force transmitted to the structure.

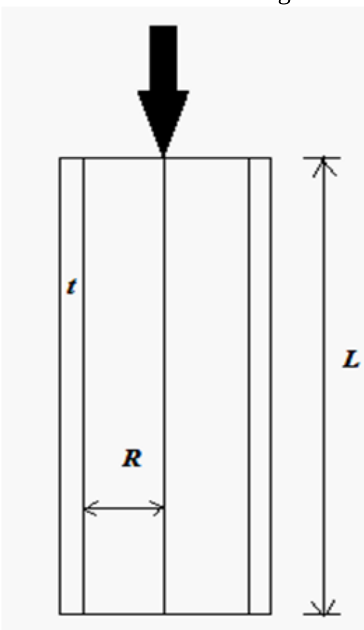
### *A. Phenomenon of crushing of energy absorbers*

A thin walled cylindrical shell or tube when subjected to a static load, as shown in Fig. 2, may have force –axial displacement characteristics similar to those in Fig. 3. It is evident that the tube exhibits an unstable behaviour after reached the first peak load at point A. Most structural designs are based on a load equal to this peak load divided by safety factor. The magnitude of this safety factor is selected by taking into account the slope AB of the load-deflection behaviour (post buckling characteristics). However, thin walled circular tubes are used in many practical situations to absorb impact energy. Indeed, Pugsley (1979) examined the axial impact of the thin walled tubes used in order to study the structural crashworthiness of railway coaches. In these circumstances, the total axial displacement of the tube exceeds considerably the displacement associated with the load B as in Fig.3.

### *B. Axial and oblique crushing of Aluminium AA6063 tubes*

During a crash event energy absorber is commonly subjected to both axial and oblique loading. Axially loaded circular tubes have so many advantages but it has a major drawback as when it is subjected to axial impact, tube sustains very high load due to which passengers in vehicle may seriously injure.
Axially loaded tube can absorb much energy and it deforms in generally progressive buckling initiates but in real situation tube is subjected to oblique load. Oblique loading comprises both axial force and moment. In oblique load both local buckling occur. Global buckling reduces energy absorption capacity. Peak force in oblique loading reduces than the axial compression.
Here aluminium tubes having outside diameter D=38 mm, wall thickness 1.6 mm, lengths L as 114 mm, 152mm, 190mm Fig.4 were crushed under axial and oblique quasi static load at inclinations of 5˚&10˚withcentreline using

Universal Testing Machine [Fig.5] at loading rate of 0.5 mm/min. The tubes were compressed upto 60mm, 80mm and 100mm for L/D=3,4 and 5 respectively. The tubes so tested were empty and filled with wood saw dust. The wood filler was having an average density of 59.6 $kg/m^3$. [Fig. 6]



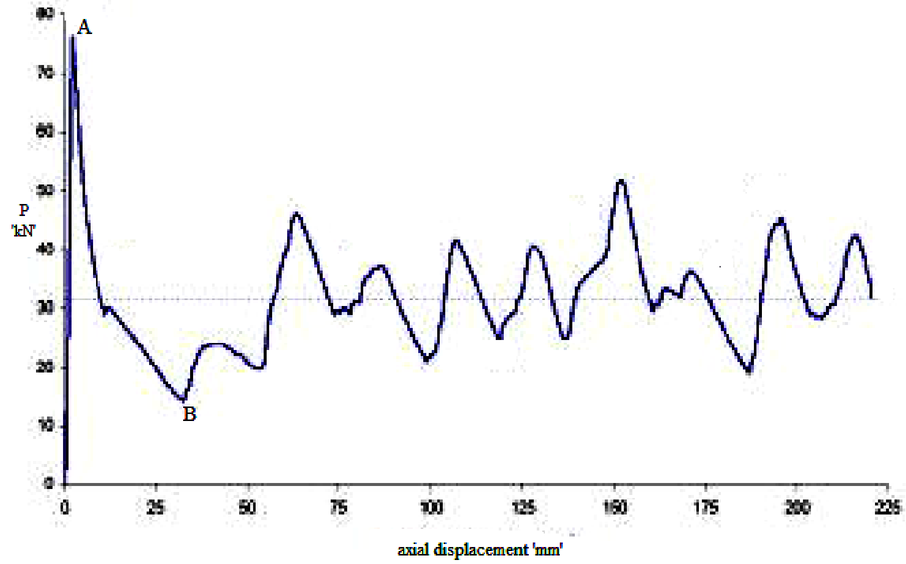




Fig.4

Fig.5

Fig.6

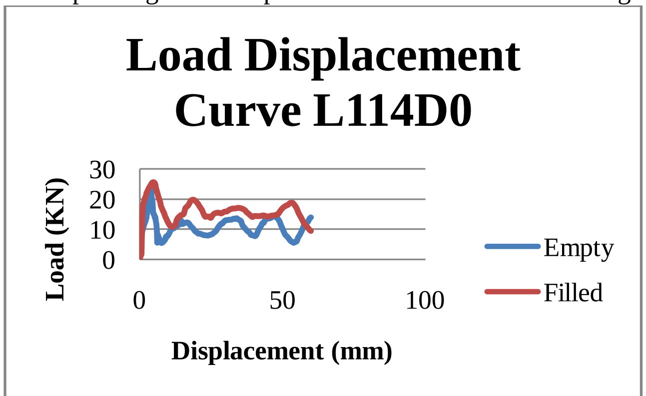
## III. ANALYSIS

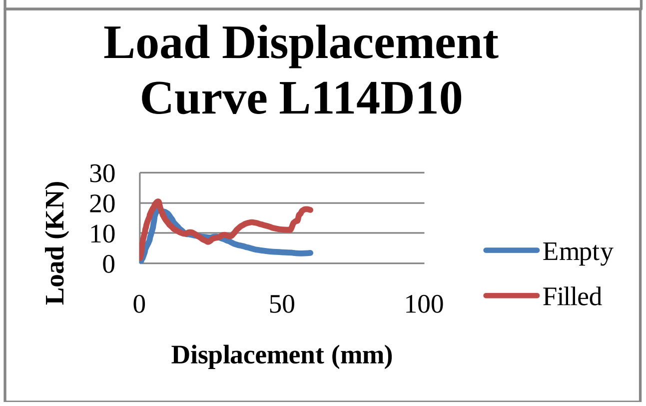
### *A. For L/D =3*

**TABLE I**

| Filled | | Empty | | Angle |
|---|---|---|---|---|
| Energy Absorbed (Joules) | Peak Load (KN) | Energy Absorbed (Joules) | Peak Load (KN) | |
| 958.07 | 25.56 | 642.13 | 23.46 | 0 Degree |
| 860.88 | 23.2 | 713.83 | 19.38 | 5 Degree |
| 717.47 | 20.48 | 453.21 | 17.74 | 10 Degree |

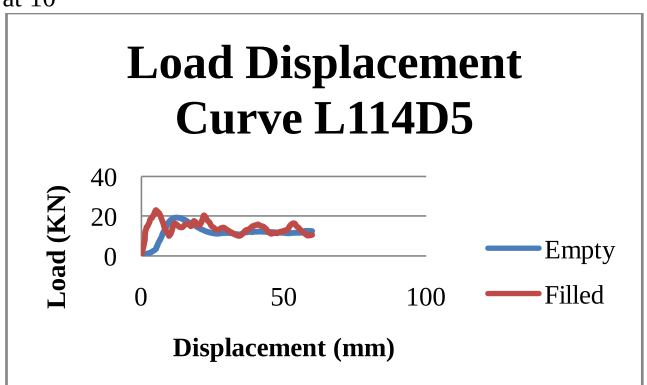
Corresponding Load Displacement curves for different angles have been shown as below-




Load Displacement Curve for L/D=3 at $0^0$

Load Displacement Curve for L/D=3 at $10^0$




Load Displacement Curve for L/D=3 at $5^0$

**Fig.7**

**Fig.8**


**Fig.9**

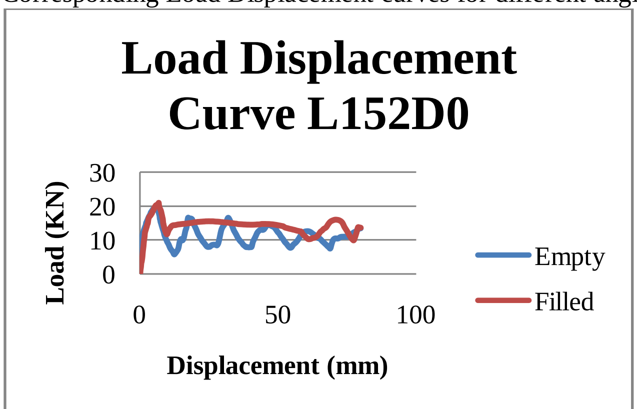
- Axial compression of L/D=3 in filled and empty tubes shows mixed mode of wrinkling. One or two rings are formed on top end of tube and then diamond rings are formed as shown in Fig. 7.
- In oblique loading of 5 degree, the mode of buckling is diamond but it switched its axis of buckling as shown in Fig. 8. For filled tubes it is the angle at which tubes can store maximum energy.
- In 10 degree oblique loading wrinkle formation started at bottom end as well as upper end of tube. But this wrinkling is not completed due to shear force effect and wrinkle at bottom end switched its axis so irregular diamond mode of buckling formed on tube as in Fig. 9.

***B. For L/D=4***

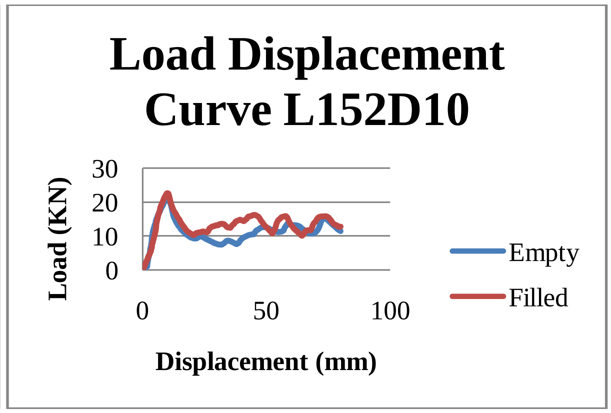
**TABLE II**

| Filled | | Empty | | Angle |
|---|---|---|---|---|
| Energy Absorbed (Joules) | Peak Load (KN) | Energy Absorbed (KN) | Peak Load (KN) | |
| 1162 | 20.96 | 920 | 19.9 | 0 Degree |
| 1110.6 | 23.6 | 784.84 | 23.48 | 5 Degree |
| 1074.1 | 22.74 | 909.2 | 21.08 | 10Degree |

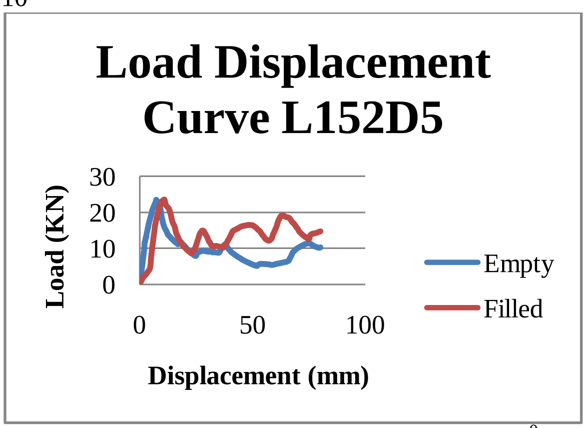
Corresponding Load Displacement curves for different angles have been shown below-




Load Displacement Curve for L/D=4 at $0^0$




Load Displacement Curve for L/D=4 at $10^0$




Load Displacement Curve for L/D=4 at $5^0$

**Fig.10**

**Fig.11**

**Fig.12**

- Axial compression of L/D=4 in filled and empty tubes shows diamond mod… from bottom end of the tube. Number of wrinkles per unit circumference are increased in this case as compared to that of L/D=3 as shown in Fig.10.
- In oblique loading of 5degree, wrinkle formation started from fixed (bottom) end and two irregular diamond rings are formed at fixed end as in Fig. 11.
- In 10 degree oblique loading, irregular diamond mode of wrinkling switched its axis so wrinkle formation also changed as in Fig. 12.

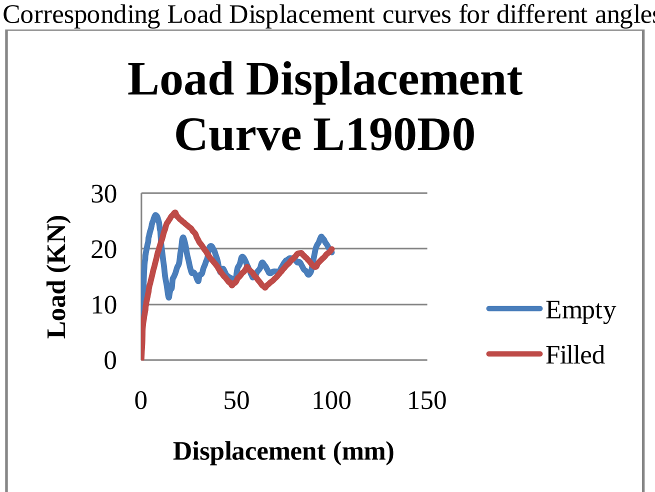
### *C. For L/D=5*

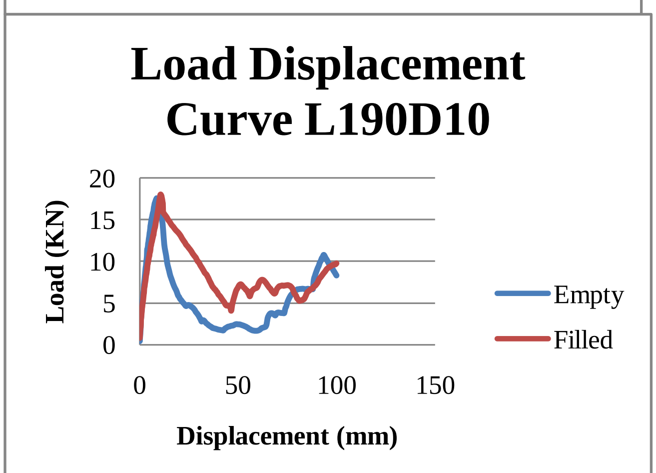
**TABLE III**

| Filled | Empty | Angle |
|---|---|---|

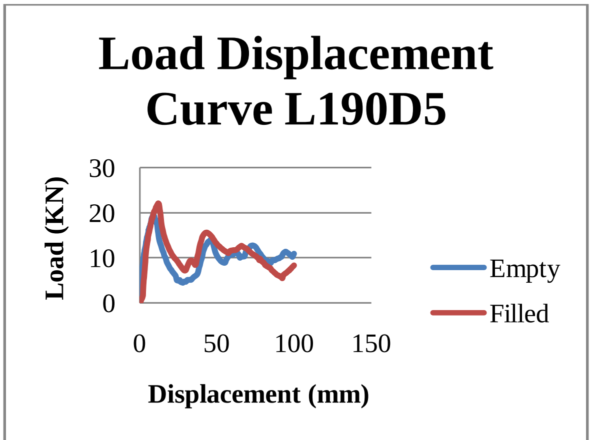
| Energy Absorbed (Joules) | Peak Load (KN) | Energy Absorbed (Joules) | Peak Load (KN) | |
|---|---|---|---|---|
| 1788 | 26.56 | 1754 | 26.14 | 0 Degree |
| 1103.1 | 22.16 | 1027.2 | 19.68 | 5 Degree |
| 858 | 18.06 | 571 | 17.6 | 10 Degree |

Corresponding Load Displacement curves for different angles have been shown below-




Load Displacement Curve for L/D=5 at $0^0$ Load Displacement Curve for L/D=5 at $10^0$




Load Displacement Curve for L/D=5 at $5^0$

Fig.13


Fig.14

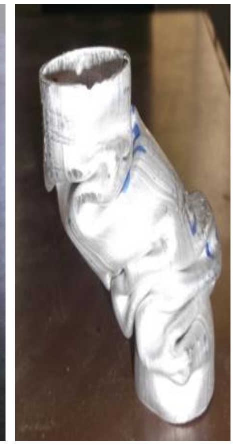


Fig.15

- Axial compression in filled and empty tubes shows mixed mode of wrinkling as in Fig.13.Peak load and energy absorbed are found higher when checked in one to one correspondence with L/D=3 and L/D=4.
- In 5 degree oblique loading, initially ring formation started from bottom but due to local buckling at middle, tube starts buckling at this location and mode of buckling switches its axis as in Fig.14.
- In 10 degree oblique loading ring formation started from bottom and two irregular diamond rings are obtained at bottom end. After that tube buckled and switched its axis, now one ring is formed on top end so there is irregular diamond mode of wrinkling as visible in Fig.15.

## IV. CONCLUSION

The collapse of axially and oblique crushed empty and wood sawdust filled Al AA6063 tubes was investigated experimentally with different L/D ratios keeping d/t ratio fixed. Two response parameters peak load and energy absorption capacity were examined with variation in length and inclination. It was observed that deformation mode depends on both load angle and L/D ratio. The energy absorption of the filled tubes was improved significantly and their peak load was also higher as compared to corresponding to empty tubes. The choice of sawdust was based on economical and environmental grounds. It was introduced as a substitute for conventional fillers. Sawdust is cheap and environmental friendly which makes it a favourable choice for a filler in the design of energy absorbing system.

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