

## **Comparison of energy absorption of various section steel tubes under torsion loading**

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### **Abstract**

Thin-walled tubes are widely used as structural members in many engineering application such as transportation pipes, building structures and vehicle body. In case of vehicle body or other mobile body, thin-walled components are expected to absorb impact energy in order to protect the main structure. Therefore, the energy absorption characteristic of various kinds of tube has been studied for many decades.

This paper is also aimed to study the energy absorption of tubes under torsional loading. The study was conducted using a commercial explicit FEA code (ABAQUS). The study focused on tube with various sections, which were square, hexagonal, octagonal, and circular cross-sections. The property of material was assumed homogeneous, isotropic and perfect plastic behavior. The results from FEA were firstly validated with available theoretical solution. Then, the energy absorption capacities of each cross-section tube were compared. The result indicated that the energy absorption of circular tube is higher than that of octagonal, hexagonal and square tube, respectively.

**Keywords:** Plastic collapse, Torsion, Thin-walled structure, Polygonal

### **1. Introduction**

Thin-walled structure are widely used as structural members such as in car body, offshore pipeline and platforms, land-based pipelines, aircraft, support structure and energy absorbing devices. Many researches investigated the experiment, theoretical and simulation of various cross-sectional tubes subjected to static axial compression. One a relatively new type of energy

absorber is tapered thin-walled tubes, in which one or more of the sides of the tube are oblique to the longitudinal. They are capable of withstanding oblique impact as effectively as axial load. S.R. Reid and T.Y. Reddy [1] studied the static and dynamic behavior of tapered sheet metal tubes of rectangular cross-section. The tapered sheets include single-tapered and double-tapered tubes. He also showed the desirable

constant mean crush load- deflection response under axial loading.

Yamashita et al. [2] studies on the crush behaviors of hollow cylindrical structures with various regular polygonal cross-sections under axial compression. They found that the crush strength increases as the number of corners of the cross-section increases, though it almost saturates for the number of corners beyond 11. G.M. Nagel et al. [3] compared the energy absorption response of straight and tapered thin-walled rectangular tubes under both quasi-static and dynamic axial impact loading. It was found that the dynamic response of tapered tubes is more sensitive to impact velocity and wall thickness than taper angle at lower impact velocities. G.M. Nagel et al. [4] compared the energy absorption response of straight and tapered thin-walled rectangular tubes under quasi-static axial loading, for variations of their wall thickness, taper angle and number of tapered side. The results showed that the initial peak load increases with increasing wall thickness, yet decreases with increasing of taper angle. Furthermore, the triple-tapered tube and frusta have the highest mean load and hence energy absorption. N.K.Gupta et al. [5] studied on the collapse of aluminum cylindrical shells of different diameter to thickness ratios when subjected to quasi-static axial compression and the impact of a drop hammer. The results showed that the energy absorption capacity of the tested tubes in impact test is higher by 1.56-2.3% in comparison with the corresponding value obtained in quasi-static test. The load-deformation and energy compression curves for the set of shells of different thickness and the same diameter increases with the increment of thickness and these curves for the

set of shells of different diameter and the same thickness increases with increase in diameter. Weigang Chen and Tomasz Wierzbicki. [6] studied the torsional collapse of thin-walled prismatic columns. They developed their analysis to predict the analytical plastic collapse of square columns under large plastic rotation using energy method. The analytical solution was presented and compared well with the numerical results. The solutions were then extended for rectangular and hexagonal thin-walled columns.

The present paper is also aimed to compare the energy absorption of various section steel tubes under torsional loading by using a commercial explicit finite element programs code of ABAQUS. The various cross-sectional shapes include square, hexagonal, octagonal and circular cross-sections.

## **2. Finite element modeling**

In this study, numerical simulation of various cross-section tubes under torsional load was carried out using the commercial explicit finite element program code of ABAQUS. The models include the square, hexagonal, octagonal, and circular tube under torsional load. The structural member was computed in a full model. The tube model was constructed with a number of 4 node shell elements. Mesh size effect was studied in order to maximize accuracy, an element size of 6 was found to produce suitable results. For instance, Fig.1 depicts the absorbed energy of each tube under impact loading as a function of mesh size. It is clear from the graph that a mesh size of 6 can produce accurate results.

The material was assumed homogeneous, isotropic, constant thickness and perfectly elastic-plastic. Young's modulus  $E$  was 200 GPa,

Poisson's ratio  $\nu$  was 0.3 and the density of the material  $\rho$  was  $7800 \text{ kg/m}^3$ .

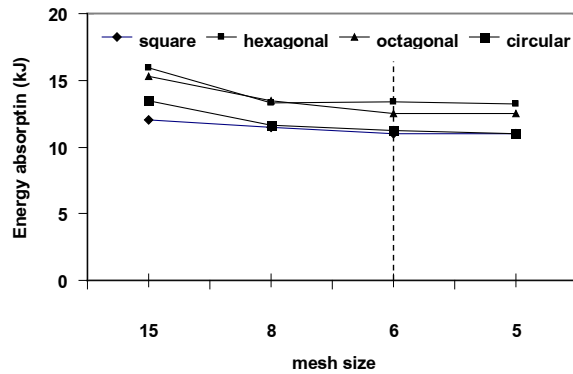
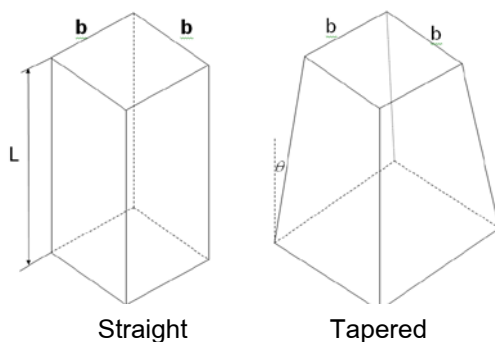


Fig.1 Convergence of absorbed energy versus mesh size for each tapered tubes under torsion loading

The cross-section shapes used in this study were square, hexagonal, octagonal, and circular tube. The circumference of a circle was 200 mm, which was equal to the sum of peripheral length of square, hexagonal, and octagonal tube. The axial length of the model was 150 mm for all cases. The wall thickness  $t$  was set to be 1.0, 2.0 and 3.0 mm and the taper angle was 0, 5, and 10 degree, as shown in fig.2.



$L=150\text{mm}$ ,  $b=50\text{mm}$  for square,  $b=33.33\text{mm}$  for hexagonal,  $b=25\text{mm}$  for octagonal and the circumference of a circle was 200 mm.

Fig. 2 Geometries and dimension of studied straight and tapered various cross-sectional tubes.

The tube was rotated by two rigid platens about longitudinal direction. The top edge was rotated with constant angular velocity of 0.0174 rad/s and the base rigid plate was fully fixed. The

end of each tube was fixed to two rigid plates using a tied constraint, as shown in figure 3.

Their deformation shapes were recoded at different stages of torsion and load-displacement responses were plotted.

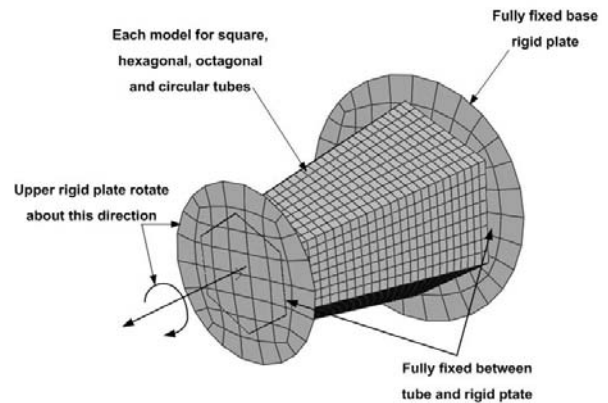
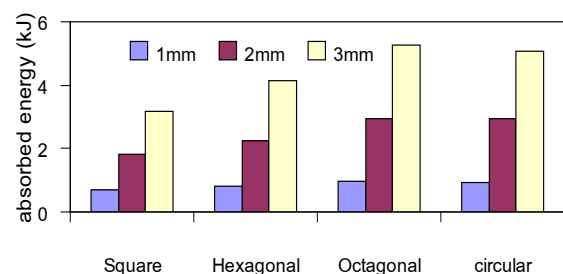


Fig. 3 Illustration of torsional model

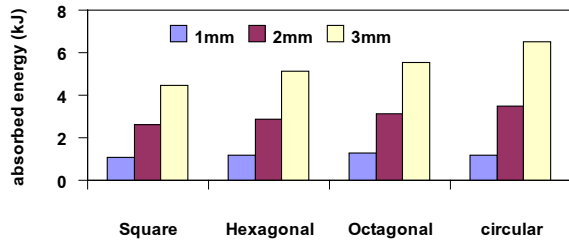
#### 4. Results

The aim of this study was to determine the relative influence of the geometry parameter and subsequent absorbed energy. The geometry parameters include the wall thickness, ( $t$ ), taper angle, ( $\theta$ ), and number of tapered sides. The response parameters were absorbed energy calculated. The energy absorptions of specimens are presented in fig. 4 and 5.

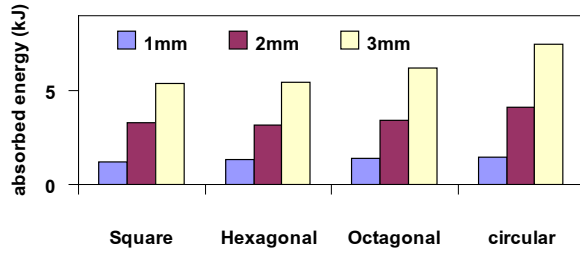
It is observed from Fig. 4 and fig.5 that the thickness tubes, for all kind of tube, can absorb more energy than the thinner tube. Considering the effect of tapered angle, it is found that as the tapered angle increases, the energy absorption due to twisting is increased. This conclusion is in contrast with the previous study on axial load [3].



a) Tapered angle,  $\theta = 0^\circ$



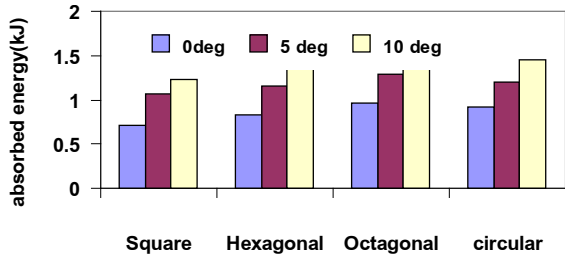
b) Tapered angle,  $\theta = 5^\circ$



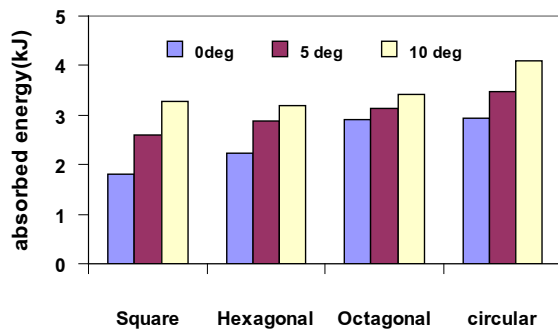
c) Taper angle,  $\theta = 10^\circ$

Fig.4 The comparison of the energy absorption of each specimen with different thickness.

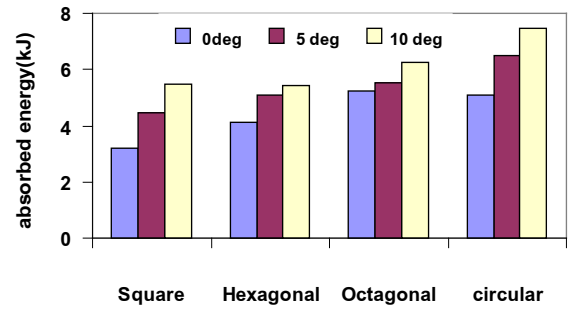
Figure 5 demonstrates the relationship of specific energy absorption and the tapered and of each specimen. It is observed that the specific energy absorption of circular tube is higher than that of the octagonal, hexagonal and square cross-sectional tubes, respectively. This indicates that as the number of corner increases, the specific energy absorption is also increased.



a) Wall thickness,  $t = 1mm$

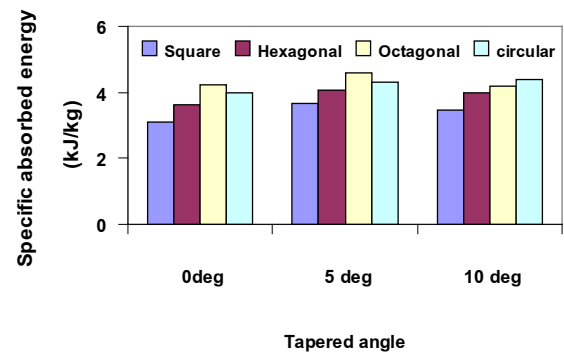


b) Wall thickness,  $t = 2mm$

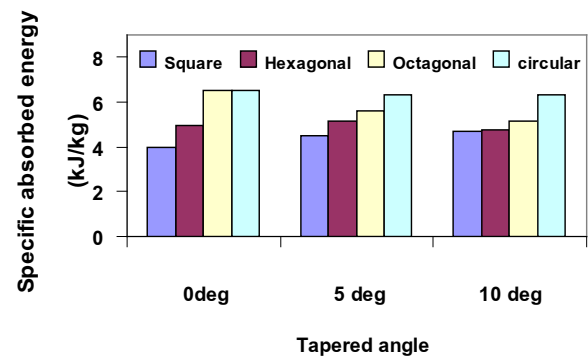


c) Wall thickness,  $t = 3mm$

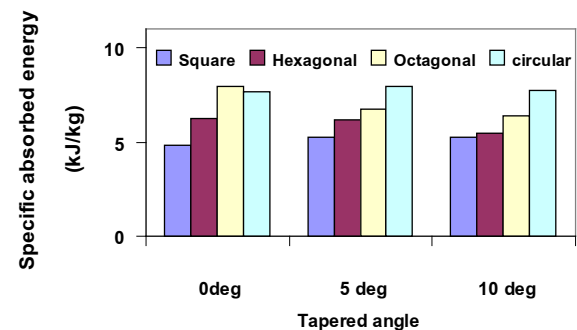
Fig. 5 The comparison of the energy absorption of each specimen with different tapered angle.



a) Wall thickness,  $t = 1mm$



b) Wall thickness,  $t = 2mm$



c) Wall thickness,  $t = 3mm$

Fig. 5 Relative effect of tapered cross-sectional tubes and specific absorber energy

## 5. Conclusion

For the twisting of tapered thin-walled various cross-section tubes, it was found that the energy absorption increases as the wall thickness increases. Furthermore, the absorption increases slightly as the number of corner of tube increases. Therefore, the tapered circular tube has the highest specific energy absorption capacity. While the specific energy absorption for square cross-section is lower than for circular, hexagonal and octagonal cross-sectional tubes, respectively.

## 6. Acknowledgement

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## 7. References

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