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Finite element Analysis of Honeycomb filled Metallic Tubes Subjected to Axial Loading

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Abstract— *A comprehensive study of buckling behavior of polygonal tubes with honeycomb filler under axial loading is presented in this paper. Honeycomb filled tubes have got a lot more attention due to their strong and stiff behavior with enhanced energy absorption capacity. For simulating the buckling behavior events of finite element models eigen value buckling code was used using the Abaqus/Explicit. This paper firstly investigates the buckling behavior of polygonal tubes without honeycomb filler and then the antipodal with honeycomb filler. The calculated buckling response of polygonal tubes is shown to better resembled when honeycomb filler is used.*

Keywords— axial loading, buckling load, finite element analysis, honeycomb filler, hollow tubes.

I. INTRODUCTION

Nowadays lots of research is explored for the protection of structures against blast and impact loadings. For protecting people and stuff from calamities detailed studies have been conducted to make the structure stand as a bulwark. Columns being a primitive part of the preponderance of structures makes the prognosis of their capacity imperative for inclusive structural efficiency. Thin-walled structures have been widely used due to its lightweight, ease of fabrication, low price, and a very high strength to weight ratio over the comparable solid structures. The efficiency and protean of thin-walled metallic tubes makes it the most common for construction and mechanical applications. The behavior of the tubes is solely dependent on the cross-sectional shapes. When the cross-section is changed or combined the behavior of the tube also changes [1], therefore it is a herculean task for designers and engineers to find out the best configuration for a circumstantial exercise. Due to individualize characteristics of the different cross-section, numerous probe is conducted by researchers including rectangular, hexagonal, triangular, pentagonal, octagonal, 12-sided star, 16-sided star, lateral corrugations to name a few [2-5]. Z. fan conducted quasi-static axial compression test on thin-walled tubes with different cross-sections. It was found that by increasing the number of corners of polygon its energy absorbing capacity also increases but to a certain extent [6]. The previous study shows that the buckling load was of the thin-walled metallic tubes were increased when the cross sections were combined [7] and corrugation was introduced [8]. In addition to these, metallic honeycomb is also used widely as an extension for its high energy dissipating mechanism and an excellent strength to mass ratio. This begets the need for extensive literature on honeycomb by diversified theoretical, experimental and numerical means. Hexagonal cell honeycomb is generally paid a lot more attention [9].

Wierzbicki conducted axial crushing of hexagonal honeycomb using the super folding element theory for finding the strength and the results were in good agreement with the experimental results [10]. From the work of different researchers, it was easily found that the honeycomb, if used as a filler, can absorb a lot of energy (quasi-static and dynamic) when subjected to axial loadings. However, the dynamic compressive strength of honeycomb is found better than the antipodal quasi-static one [11-14]. The axial crushing resistance of honeycomb filled square tube was studied by Santosa [17]. The results were concluded that the mean crushing strength of honeycomb filled square tubes were enhanced in comparison with the empty tubes.

The present study starts with the buckling analysis of thin-walled metallic tubes of different cross-sectional shapes followed by the honeycomb filled metallic tubes for getting an insight of the effect of honeycomb filler.

Nomenclature

CT	Circular tube	OT	Octagonal tube
ST	Square tube	HF	Honeycomb filled
RT	Rectangular tube	E	Empty
HT	Hexagonal tube		

II. GEOMETRIC MODELING

2.1. Structure of honeycomb filler

Honeycomb is a two-dimensional cellular material. The present study is done on hexagonal shaped honeycomb. The width of the cell wall and thickness of honeycomb filler were fixed as 13.86 and 0.50 mm respectively. The length of the filler in the axial direction was same as that

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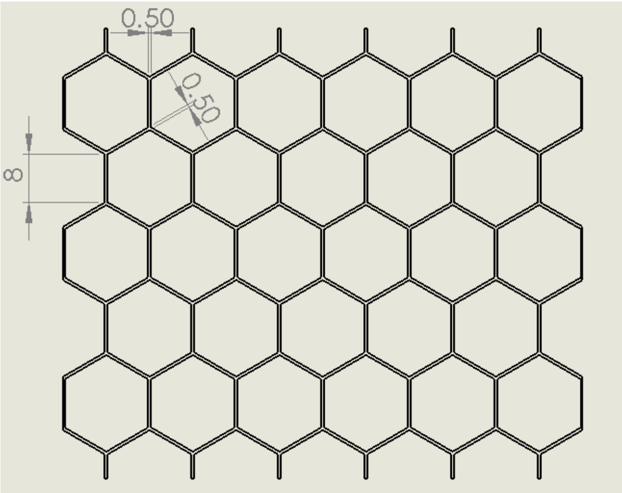


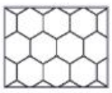
Fig. 1: Sketch of honeycomb filler

of the tube. A detailed sketch of the filler is shown in Fig. 1.

2.2. Structure of metallic tubes

Thin walled tubes with different cross-sectional shapes were used. The perimeter of all the geometric configurations was same which was 190 mm. Five cross sections were taken namely circular, rectangular, square, hexagonal and octagonal. Thickness and length of all the tubes were kept constant at 1 mm and 600 mm respectively. Geometry and dimensions of empty tubes and honeycomb filled tubes are presented in Table 1.

Table 1. The geometry of tubes under study

Profile	**Specimen**	**Dimension (mm)**	**Profile**
Circular	ECT	Diam. = 60.5	
	HFCT		
Square	EST	47.5 × 47.5	
	HFST		
Rectangle	ERT	55 × 40	
	HFRT		
Hexagon	EHT	31.66 (each side)	
	HFHT		
Octagon	EOT	23.75 (each side)	
	HFOT		

III. FINITE ELEMENT MODELING

3.1. Material model

The material for the tubes as well as honeycomb filler was low carbon steel (A36), which was assumed to be elastic, isotropic and homogeneous. It has the mass density ρ = 7.85 g/cc and Poison's ratio ν = 0.3 . The value of Young's modulus was taken as E = 210 Gpa. Strain rate effect was not considered.

3.2. Finite element model

In order to explore the buckling characteristics of different geometric configurations and the effect of honeycomb filler, the analysis was divided into two sets. Firstly empty metallic tubes with different cross sections were analyzed followed by the honeycomb filled metallic tubes. Critical load of the different specimens was examined using Abaqus/Explicit. Eigenvalue buckling was carried out using three eigenvalues and six eigenvectors. The tube was kept between two rigid plates, the bottom of the tube was fixed while the load in the axial direction was applied to the opposite free end. An element size of 6 mm was used for meshing the tubes as well as honeycomb filler. The tubes and honeycomb were meshed by C3D8R 8 node linear brick elements while the plates were meshed by using R3D4 a 4 node 3D bilinear rigid quadrilateral elements.

IV. RESULT AND DISCUSSION

In this section, the critical load for the thin-walled metallic tubes with different cross-sectional shapes with and without honeycomb filler is presented. Each configuration was analyzed with simple loading condition, keeping one end free while applying load on the other end. Eigenvalue buckling approach was used for calculating the results which are based on classical Euler buckling concept. The method follows textbook approach for predicting the eigenvalues of an elastic structure under a given set of loading conditions and constraints. Three eigenmodes were calculated with six signal vectors. The values of the test are formulated in Table 2.

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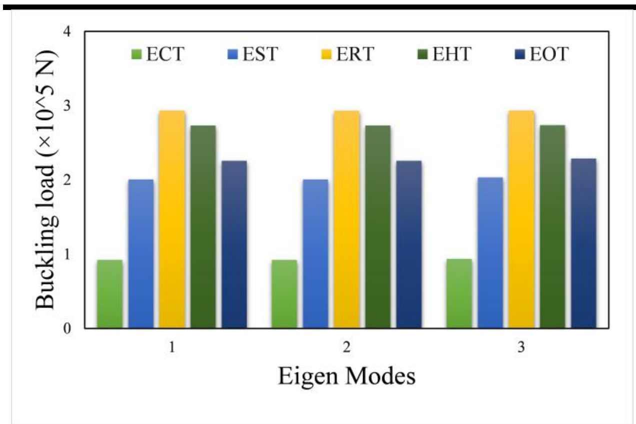

Fig. 2: Buckling load of empty metallic tubes

Fig. 2 shows the buckling behavior of empty metallic tubes with different cross-sectional shapes. The shapes were altered from circular to polygonal shapes. The shapes were altered with an even number of corners. Buckling load for the conventional circular tube was kept as a benchmark for comparing the behavior of all other tubes. It was noticed that the buckling load was maximum in the case of rectangular cross-section as the increase in critical load clocked to 196%. However, when the corners were increased progressively there was a decrease in the buckling load but still much greater than the circular section. All the structures were stable in all the three eigenmodes as the change in load hardly crossed 1% barrier.

The next phase of simulation was carried out by filling the tubes with honeycomb filler. The load variations of honeycomb filled tubes are shown in Fig. 3. A significant increase in buckling load was observed. The highest rise in buckling load occurred when the rectangular shaped honeycomb filled tube was used (HFRT). HFHT was also very close to the highest one. The eigenmodes in this section were also stable. Buckling load here also was found to be decreasing with the increase in a number of corners.

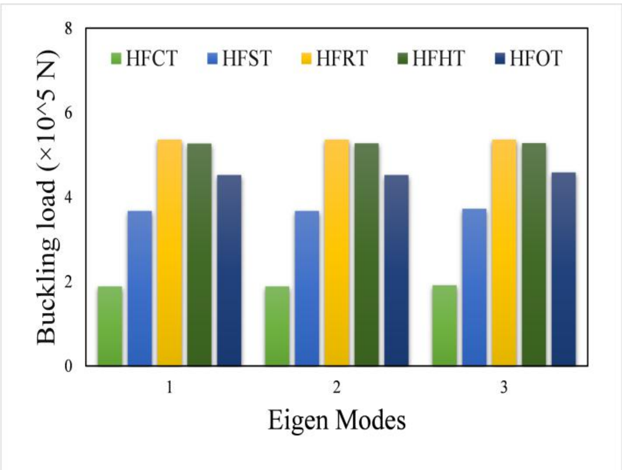

Fig. 3: Buckling load of honeycomb filled metallic tubes

Among the tubes, a comparison was made for finding the effect of honeycomb filler on cross-sectional shape. The circular tube was at the top of the list while rectangular was at the bottom. From this assessment, it was found that the honeycomb filling was least effective in rectangular and square cross-sectional tubes. Change in buckling load with honeycomb filler was lowest in HFRT and HFST.

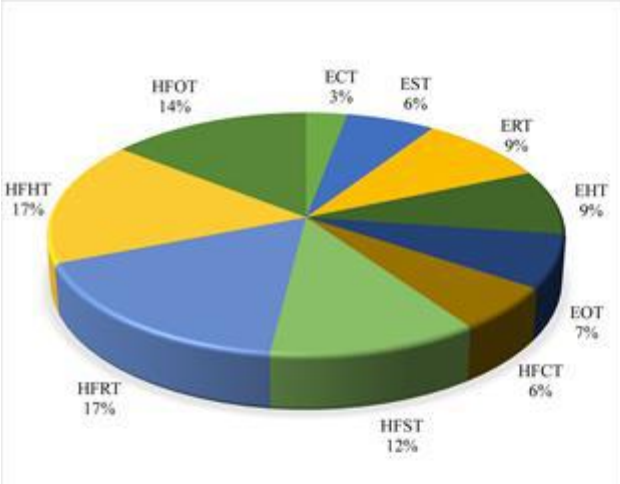

Fig. 4: Comparison of buckling load for different specimen

The effectiveness was increasing with the increase in a number of corners. The most effective configuration was the circular tube followed by octagonal tube. A comparative representation of all the tubes is presented in the form of the pie chart in Fig. 4.

Table 2. Buckling load for different specimens

Specimen	Buckling load (×10^5 N) Mode 1	Mode 2	Mode 3
ECT	0.9221	0.9224	0.9357
EST	2.0045	2.0045	2.0334
ERT	2.9312	2.9304	2.9321
EHT	2.7325	2.7327	2.7357
EOT	2.2569	2.2570	2.2864
HFCT	1.8846	1.8851	1.9124
HFST	3.6720	3.6720	3.7249
HFRT	5.3617	5.3620	5.3651
HFHT	5.2721	5.2726	5.2788
HFOT	4.5257	4.5259	4.5849

V. CONCLUSION

The buckling load for the empty and honeycomb filled metallic tubes were explored at quasi-static axial loading numerically using eigenvalue buckling method (classical Eulerian approach). The response of the tube was observed to be varying with a change in cross-sectional shape and honeycomb filling. Following conclusions can be drawn:

- Buckling load was minimum for the circular tube in both empty and honeycomb filled metallic tubes respectively.
- Highest buckling load was observed in the rectangular section for both empty and honeycomb filled tubes respectively.
- All the tubes were stable in all three eigenmodes.
- The circular and hexagonal cross-section was most effective after honeycomb filler in terms of buckling load variation.
- Since the honeycomb filled tubes look promising structure, hence further comprehensive studies are needed.

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