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Experimental Study on the Influence of Stress Concentration on the Flexural Stability of Aluminum Hollow Tube

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Abstract

The hollow sections gradually replace solid sections in most structural applications in various engineering fields due to their attractive features, such as lightweight and high specific strength. In this research, one such attempt was made to investigate the flexural capability of aluminum hollow tubes (AHT) with a square cross-section. The research's objective was to study the influence of stress concentration on the flexural behavior of the hollow tube. The role of stress concentration in a structural member was crucial as it may hamper the balance of the entire system and its function. The type of stress concentration considered in the research was through the hole cross-section and quantities. Three-point bending test with concentrated load was conducted on the specimens of a hollow tube with different stress concentrations, such as a circular hole, a square hole, and perforations. The load was applied manually during the bending test. The bending test was carried out on all specimens for various support spans of 110, 130, 170, and 200 mm. The output measures of the study were maximum bending load, deflection, and flexural stiffness. The maximum bending load capacity of around 5.7 kN was observed for AHT with a circular hole with a support span of 110 mm. The maximum deflection measured at the beam mid-span increased rapidly as the aspect ratio increased from 73.33 to 93.33. After that point, the deflection variation was marginal for the increased aspect ratio from 113.33 to 133.33. This was due to the effect spring back effect, which dominated more on the bending behavior at a shorter span between the supports.

Keywords: Hollow tube, flexural stiffness, stress concentration, aspect ratio, support span

1. Introduction

A hollow section used for a structure is a type of construction used in many structural applications. It can be circular, square, rectangular, or any other section based on the need. Square and circular hollow tubes have many applications in multidirectional loading due to the uniform geometry along two or more cross-sectional axes. It has uniform strength across the complete structure, making it a good choice for many structures [1]. They also have high resistance to torsion. Stress concentration plays a vital role in affecting the performance of the structure. Because of varying cross sections, making holes for connecting to the other members is unavoidable. The influence of stress concentration can be different for solid and hollow sections [2–4]. The type of stress concentration in the structural member subjected to various loads such as axial, bending, and shear greatly influence the performance. Flexural strength, such as bending strength, is one of the important structural properties, defined as the maximum stress in a structure just before it yields in a bending test. When a specimen, usually a beam, is bent, it experiences a combined stress across its depth. On the inner surface, the stress will be at its maximum compressive, while on the opposite side, the stress will be at its maximum tensile [5]. It was found from the literature review that the cross-section of the tube and different sources of stress concentration present in the structural member greatly influenced the flexural behavior of a hollow tube. The flexural strength of hollow tubes was improved by replacing conventional materials with composite tubes in certain applications. Although enough research has been carried out in the past in the area of structural analysis for various sections against various loads [6–8], there exists a void to do the in-depth investigation regarding the flexural stability analysis of the hollow section to ascertain the results with minimum error.

2. Experimental Method

The material used in the investigation was an Aluminium hollow tube (AHT) of square cross-section with a dimension of 20 x 20 x 1.5 mm. The grade of Aluminium

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used in the hollow tube was AA6061. The composition and properties of AA6061 were shown in Table 1 and 2, respectively. The flexural capability of the Aluminium hollow tube (AHT) was investigated in detail by conducting a three-point flexural test in a Universal tester machine with a capacity of 20 kN. The bending test was carried out using the ASTM E290 standard. A concentrated load was applied at the mid-span of the specimen. The distance between the supports, "S" (support span), during the flexural test was maintained as 110, 130, 170, and 200 mm. The thickness, "t", of the hollow tube was 1.5 mm. Hence the aspect ratio, S/t, was computed as 73.33, 93.33, 113.33, and 133.33, respectively. The analysis of the flexural capability of AHT was carried out by creating a hole as a type of discontinuity with different shapes and quantities to investigate its influence on the flexural capacity of the specimen, as shown in Figure 1. Each test was repeated three times to obtain more accurate results. The experiment was done at normal room temperature, and the load during the test was applied manually. The output of the flexural test was taken through a data acquisition system (DAQ) containing sensors attached to the experimental setup and displayed. The output of the DAQ was a graphical illustration between load and deflection during the flexural test. The experimental setup and sample output were shown in Figure 2. The 3D diagram and cross-section of the specimens with dimensions considered for the flexural test was shown in Figure 3 to 5.

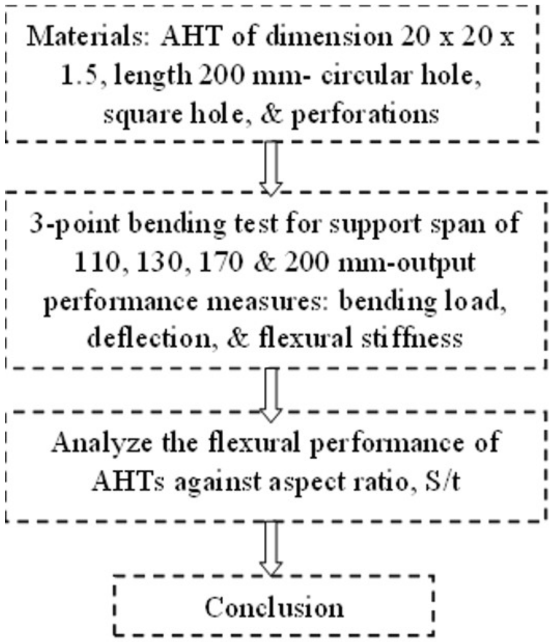


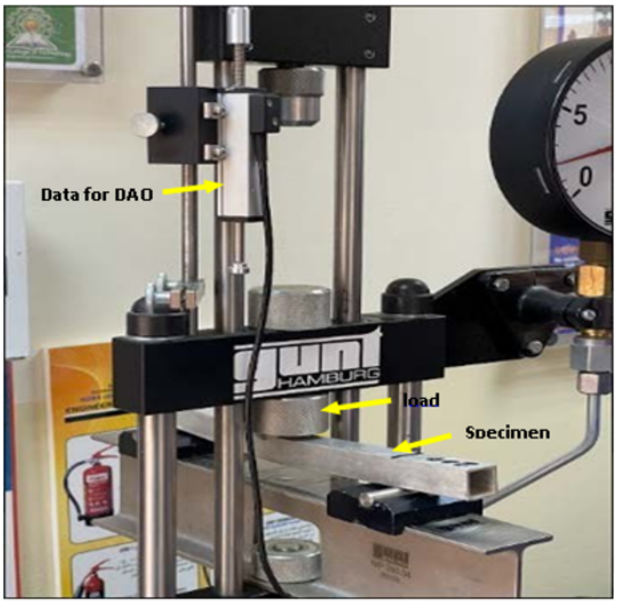
Figure 1. Experimental methodology flow chart.

Table 1. Chemical composition of Al 6061.

Chemical Element	Percentage %
Manganese	0.0 - 0.15
Iron	0.0 - 0.7
Magnesium	0.80 - 1.2
Silicon	0.40 - 0.8
Copper	0.14 - 0.4
Zinc	0.0 - 0.25
Titanium	0.0 - 0.15
Chromium	0.04 - 0.35
Others	0.0 - 0.14
Aluminium	Balance

Table 2. Properties of Al 6061.

Property	Value
Mass density	2.72 g/cm^3
Melting point	653 °C
Thermal expansion	23.5 x10^{-6} /K
Modulus of elasticity	73 GPa
Thermal conductivity	167 W/mK
Electrical resistivity	0.042 x10^{-6} Ω .m
Proof stress	245 MPa
Tensile strength	255 MPa
Brinell hardness	92.5 HB



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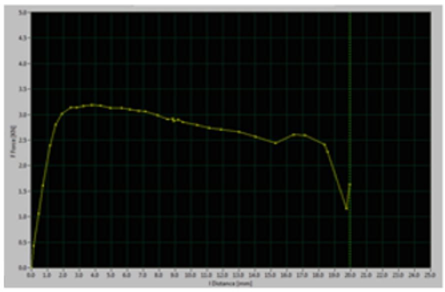
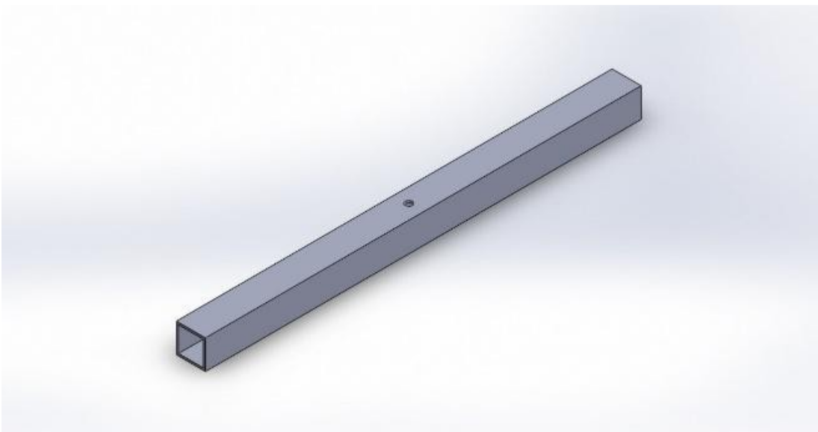
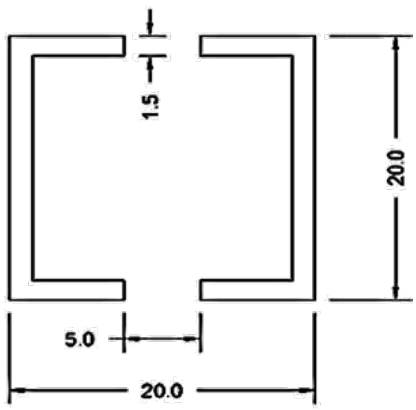


(b)

Figure 2. (a) Experimental set up for flexural test and (b) sample output.

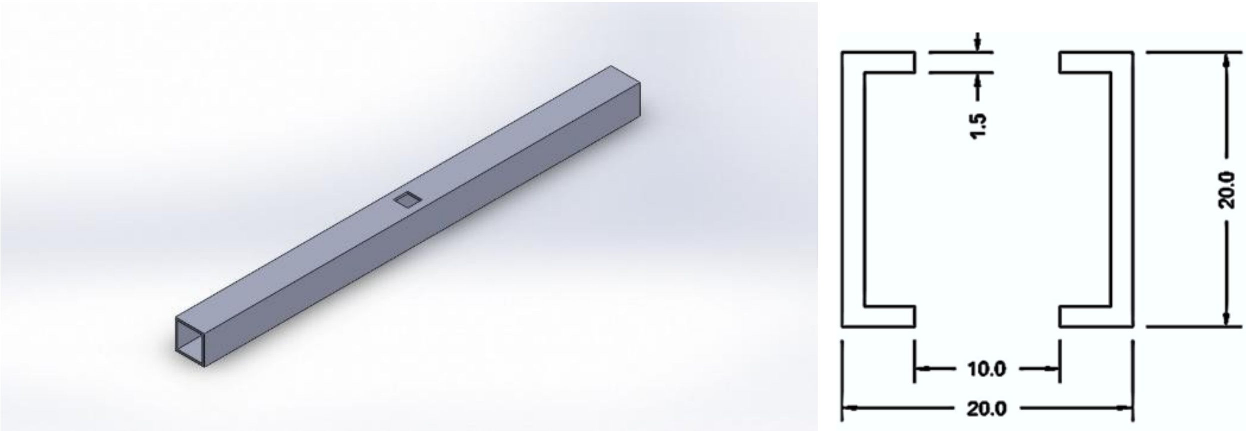


(a)



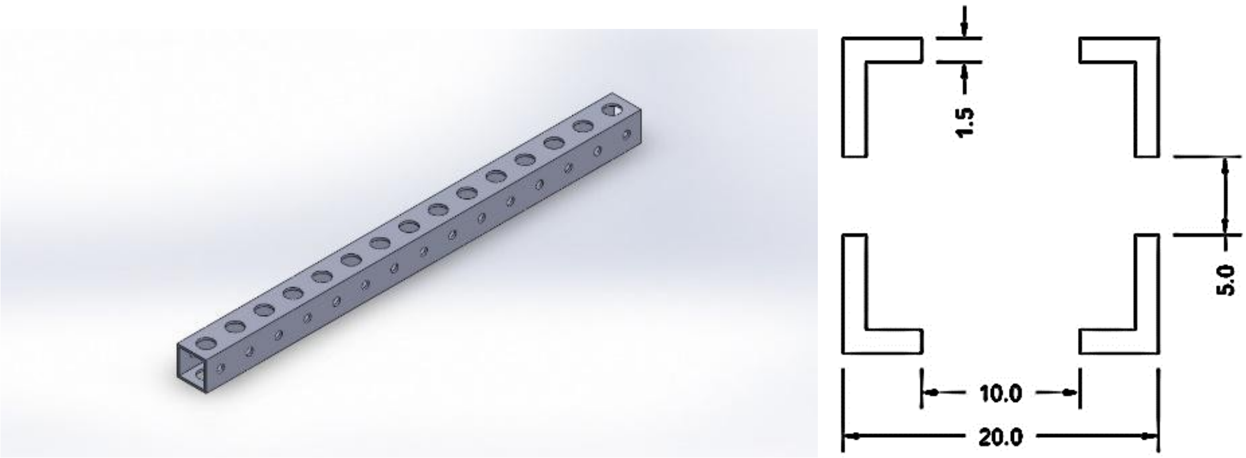
(b)

Figure 3. AHT with circular hole (a) 3D and (b) cross section.



(a) **(b)**

Figure 4. AHT with square hole (a) 3D and (b) cross section.



(a) **(b)**

Figure 5. AHT with perforations (a) 3D and (b) cross section.

3. Results and Discussion

The performance measures observed during the flexural behavior of AHTs were maximum bending load, maximum deflection, and flexural stiffness, shown in Table 3 and Figure 6 - Figure 8, respectively. The maximum bending load capacity decreased with an increase in aspect ratio for all kinds of stress concentrations on the Aluminium Hollow Tube (AHT). AHT with a square hole experienced the least bending load among the other types of stress concentration. This may be attributed to the square hole having sharp corners compared to a circular hole and perforations, which in turn failed to resist bending. An increase in aspect ratio increased the bending moment at the middle of the span for the same loading, increasing the stress intensity across the section. The maximum deflection measured at the mid-span of the beam increased rapidly as the aspect ratio increased from 73.33 to 93.33. After that point, the deflection variation was marginal for the increased aspect ratio from 113.33 to 133.33. This was due to the effect spring back effect, which dominated more on the bending behavior at a shorter span between the supports [9]. At a higher aspect ratio, the spring back effect reduced its intensity, which had an insignificant effect on the deflection [10]. The flexural stiffness measured during the bending test was observed to have a mixed trend, which may be due to the stress concentration's significant influence on the beam's resistance against loading. Due to the poor flexural capability of the AHT with a square hole, the stiffness was not affected by the increased aspect ratio. The sample deformed specimen with a circular hole with a support span of 200 mm was shown in Figure 9.

Table 3. Experimental results of flexural test of Aluminium hollow tube.

S.No.	Specimen	S/t	Maximum bending load (kN)	Maximum deflection (mm)	Flexural stiffness (kN/mm)
1	Square hole	73.33	4.243	4.233	0.193
2	Square hole	93.33	3.568	4.445	0.168
3	Square hole	113.33	2.936	5.363	0.133
4	Square hole	113.33	2.123	6.778	0.133
5	Circular hole	73.33	5.791	3.149	0.624
6	Circular hole	93.33	4.651	3.589	0.063
7	Circular hole	113.33	3.691	4.297	2.553
8	Circular hole	113.33	3.039	4.224	1.969
9	Perforation	73.33	4.856	3.621	0.777
10	Perforation	93.33	4.063	4.471	2.505
11	Perforation	113.33	3.016	3.791	0.524
12	Perforation	113.33	2.808	6.344	1.101

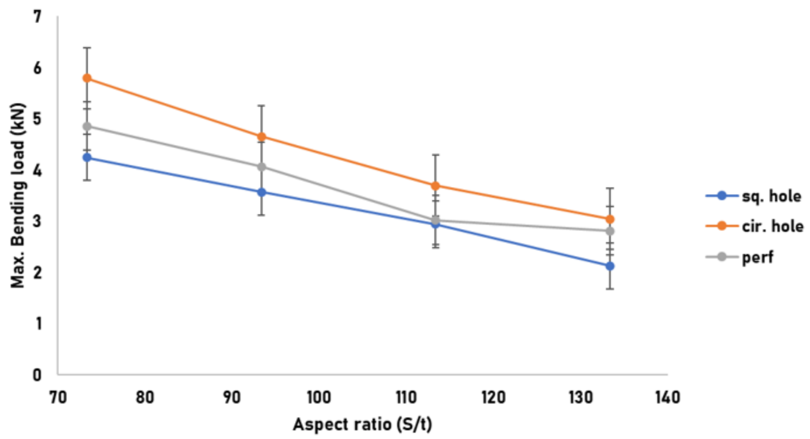


Figure 6. Maximum bending load for various aspect ratios.

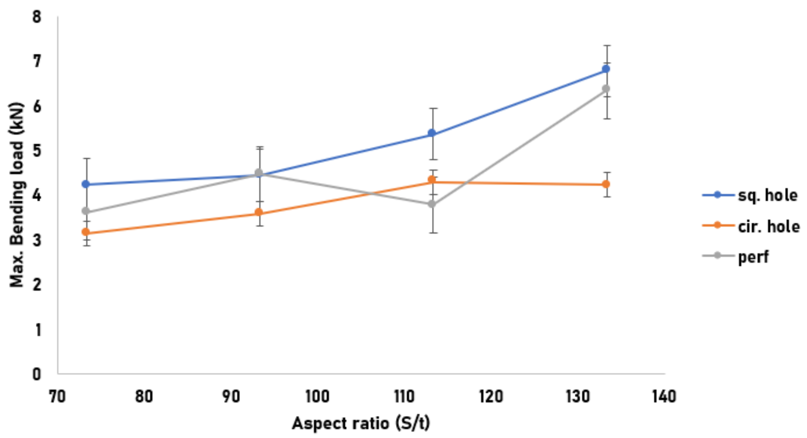


Figure 7. Maximum deflection (bending) for various aspect ratios.

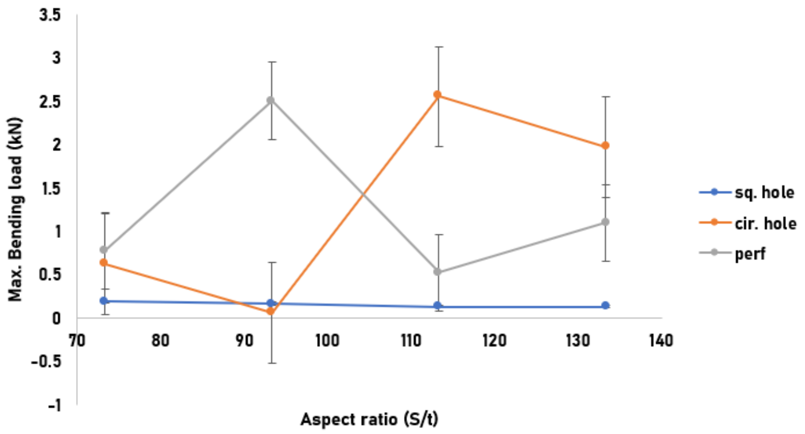


Figure 8. Flexural stiffness for various aspect ratios.

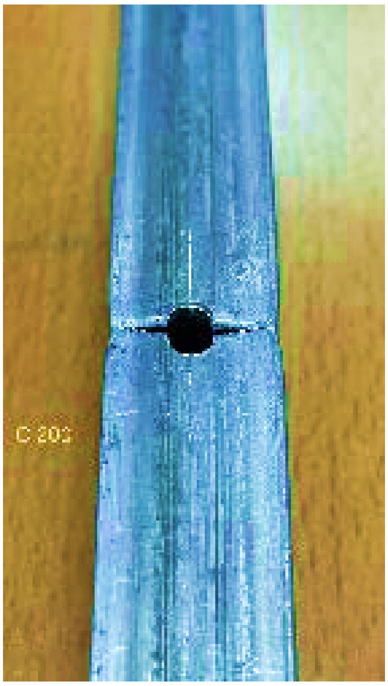


Figure 9. Sample deformed specimen (circular hole with support span 200 mm).

4. Conclusion

The attempt was made successfully on the flexural stability analysis of the Aluminium hollow tube with different types of stress concentration effects. The following were the conclusions drawn from the investigation.

(i) The aspect ratio (ratio between the support span and thickness of the tube) significantly influenced the overall flexural behavior of the hollow tube.

(ii) The shape of the hole, which was considered a stress concentration effect, strongly influenced the beam's flexural stability.

(iii) Maximum bending load of 5.7914 kN was observed for AHT with a circular hole at a support span of 110 mm, whereas the least bending load was noticed for AHT with a square hole at a support span of 200 mm.

(iv) Similar to bending load capacity, flexural stiffness was also observed to be maximum for AHT with a circular hole and least for AHT with a square hole.

(v) Stress concentration due to discontinuities decreased the material's resistance against bending and increased the failure severity through visible cracks.

(vi) Sharp corners in the square hole resulted in higher stress concentration than the circular hole, increasing the sensitivity of the specimen's failure.

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