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FABRICATION AND TESTING OF THE SHEET METAL TUBES UNDER QUASI-STATIC LOADING

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ABSTRACT

Research on energy absorption of metal has been conducted extensively over the years. Square, rectangular, circular, triangular and hexagonal shapes are the types of tubes that have been vastly investigated. The importance of this research is to measure and analyse the energy absorption characteristic of the manually fabricated tubes during impact. Axial crushing test is the most common experiment that is used to gain the energy absorption value. This report employed quasi-static axial crushing test. Square tubes, rectangular tubes, hexagonal tubes and triangular tubes were fabricated and joined by using zigzag MIG welding. From the experiment, it is found that hexagonal tube has the highest energy absorption value and triangular tubes had the lowest energy absorption value.

Keywords: energy absorption, quasi-static.

1. INTRODUCTION

There has been many researchs involving energy absorption of metal tubular structure under quasi-static loading and dynamic loading. The research is conducted in order to identify and analyse the effect of impact on the specimen. The application of engineering concept involving a thin-wall tube is used in automotive and aerospace industries. Examples of structures that have been built by using a thin-wall metal are car chassis, car body, and rail coach.

Tubular metal in the form of square, rectangular, and circular has been extensively studied and previous researcher found that in order to enhance the energy dissipated during the impact is by filling the tubes with crushable medium such as wood and foam. The filler will also increase the stability as well as decrease the possibility of the tubes to undergo Euler type of buckling. Axial crush has many important engineering safety applications in areas including crashworthiness and blast-resistant design of structures (DiPaolo and Tom, 2006). However, the result of axial crushing test in the laboratory does not necessarily can be taken into account as the actual impact that happens in the world usually has different velocity of impact.

For an empty tube, the specific energy absorption is approximately half of the foam-filled tube. The presence of foam proved to be the very advantageous as it enhance the stability of the tube by which the long wave effects are increased (Reid *et al.*, 1986).

There are the two most significant considerations in the context of impact energy absorption; Wierzbicki's folding mechanisms are employed and the foam is demonstrated as a perfectly plastic-locking material. The results of the analysis show a realistic agreement with the experimental observations. The simple approach of combining a plastic-locking model for the foam with the crushing analysis for rectangular and square thin-walled tubes leads to good correlation with the experimental observations (Reid *et al.* 1986).

The objective of this study is determine most suitable welding method in joining the tubes. Later, the tubes will be fabricated and joined with the selected joining method and will be tested under quasi-static axial loading. The experimental result of energy absorption, peak load, mean plastic half wavelength and plastic wavelength are compared with the theoretical values for each type of tubes.

2. MATERIALS

Two different mild steel thicknesses was used in this research. To fabricate square tubes and joined by different welding method, 0.9mm thickness mild steel will be used. As for fabricating square tube, rectangular tube, hexagonal tube and triangular tube, 1mm thickness of mild steel is used. Mild steel is selected because it is a widely produced and commonly used metal in any engineering applications. In addition, it has been extensively researched because of its excellent mechanical properties in term of strength, ductility and toughness.

3. METHODS

3.1 Type of welding

There are various ways in order to fabricate a square tube from sheet metal. Previous researchers used spot welding and arc welding in order to make the tube. However, this project used Metal Inert gas (MIG) welding to fabricate the tube. One of the reasons in using MIG to join the tube is that it provides faster welding time for steel compared to arc welding.

3.2 Welding method

As shown in Figure-1, three types of joining location were made in order to see the effects of each type on the energy absorption of the specimen. In the previous research, it is found that the type and location of weld have little or no effects on the tube behavior (mean load and deformation mode). The present of weld did not produce any significant distortion of the buckling pattern

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(Reid *et al*, 1986). The type of joining locations are corner weld, full center weld and zigzag center weld as in Figure-1. For the Zigzag centre weld, the distance between one weld to another is 10mm.

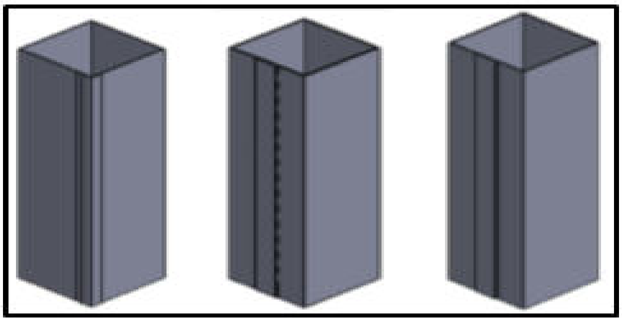

Figure-1. Types of welding method (a) Corner weld, (b) Zigzag centre weld, (c) Centre weld.

3.3 Quasi-static axial crushing test

Axial compression test with a compression rate of 10 mm per min was performed on the tube by using Instron Universal Testing Machine. The tube was compressed up to 50% of its original length. The experiment wre repeated three times in order to observe the repeatability of results to obtain the average results.

4. RESULTS AND DISCUSSIONS

4.1 Axial crushing in determining the type of joining method selection

In order to determine the energy absorption of the tubes, the area under the graph was calculated by using Microcal Origin Pro software. As for the theoretical values of mean load for square tube, the following formula was used.

$$P_m = 9.6\,\sigma_y \sqrt[3]{ct^5} \quad (1)$$

From Table-1, it is found that corner weld has the highest mean load compared to zigzag center weld and full center weld. In term of percentage of difference as shown in Table-2, zigzag center weld has the lowest percentage difference with 13.48% and corner weld has highest value with 23.26%. The factor that can contribute to this difference is the surface flatness of the specimen during fabrication process. If the specimen surface is not flat enough, the material will likely experience global buckling; leading the specimen to fail during experiment.

Table-1. Calculated mean load for experimental value.

Welding method	**Area under the graph** (Nmm)	**Total deflection**	**Mean load** (kN)
Corner weld	0.9561 x 10^6	90	10.623
Zigzag center weld	1.5078 x 10^6	160	9.424
Full center weld	1.4346 x 10^6	150	9.564

Table-2. Difference between theoretical value and experimental value for mean load.

Welding method	**Experimental mean load** (kN)	**Theoretical mean load** (kN)	**Percentage of difference** (%)
Corner weld	10.62	8.15	23.26
Zigzag center weld	9.42	8.15	13.48
Full center weld	9.56	8.15	14.75

From Figure-2-4, it can be seen that for all specimens, the folding formation started at the middle part of the tube. Also, the specimens buckling formation conforms the theory made by (Reid *et al.* 1986) which stated that the tube buckles in diamond or concertina mode. It can be concluded that all specimens buckle in diamond mode.

The mean plastic half fold wavelength and plastic wavelength (Reid, *et al.* 1989),

$$H_m = \sqrt[3]{c^2 t} \quad (2)$$

$$\lambda_p = 2H_m \quad (3)$$

By using Equation (2) and Equation (3), values of H_m and λ_p were calculated and tabulated in Table-3. In addition, the deviation percentage for mean load, mean plastic half fold length and plastic wavelength were also calculated by using Equation (2) as shown in Table 4 for corner weld specimen, Table 5 for zigzag center weld specimen and Table 6 for full center weld specimen.

From Table-3, it can be seen that full center weld has the highest peak load value. This indicates that the full center weld specimen requires higher load to initiate the folding formation. Based on result inTable-4, Table-5, and Table-6, it can be concluded that zigzag center weld has the lowest percentage of error between theoretical values and experimental values. Thus, the selected joining

VOL. 11, NO. 8, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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method that is suitable in fabricating tubes is zigzag center weld.

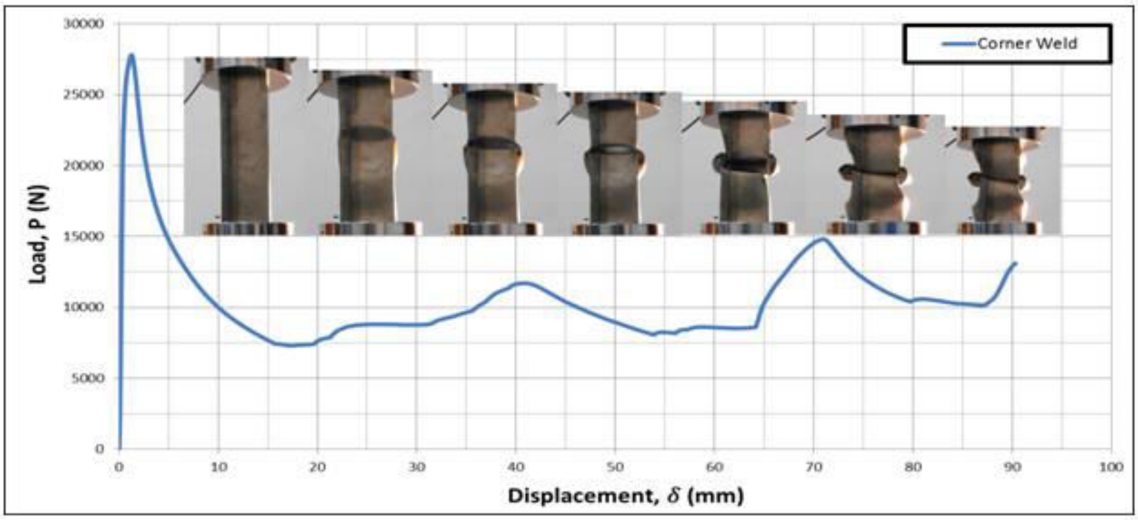
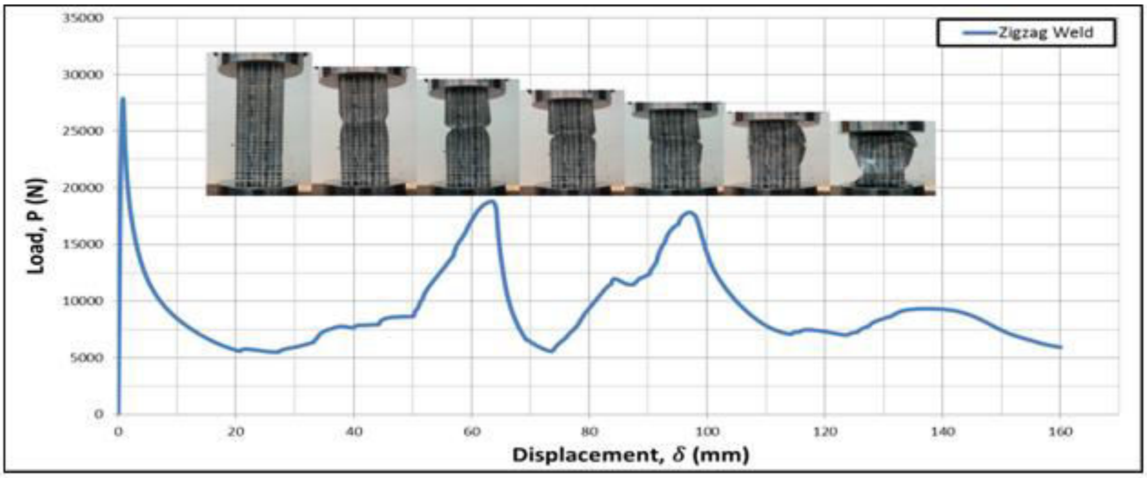


Figure-2. Load against displacement graph for corner weld.



Figue-3. Load against displacement graph for zigzag center weld.

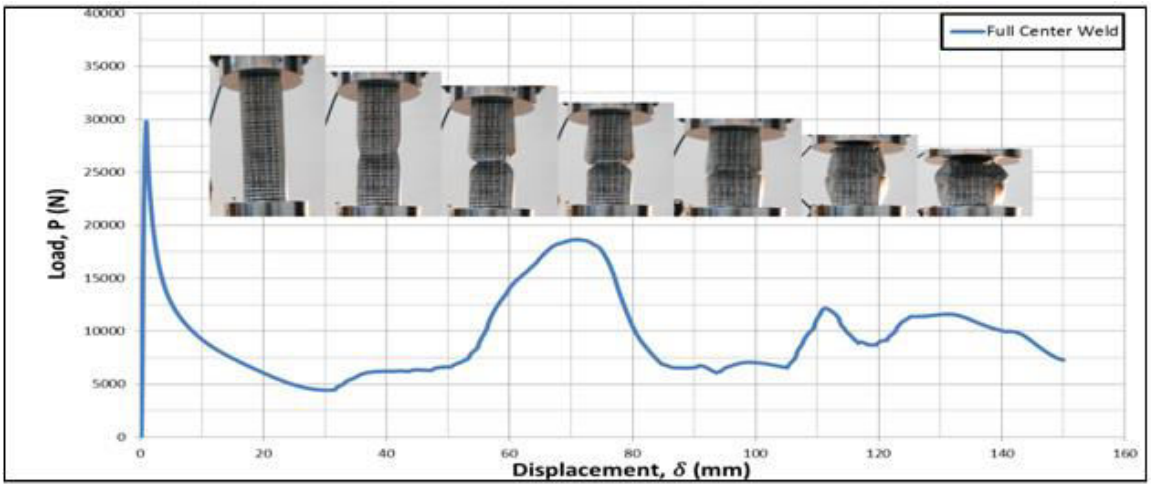


Figure-4. Load against displacement graph for full center weld.

Table-3. Calculated value for peak load, mean load, mean plastic half fold length and plastic wavelength.

Welding method	Corner weld	Zigzag center weld	Full center weld
Peak load (kN), P_{max}	**27.8**	**27.9**	**29.8**
Mean load (kN), P_m	10.62	9.42	9.56
Mean plastic half fold length (mm), H_m	27	25	32
Plastic wavelength (mm), λ_p	54	50	64

Table-4. Percentage of difference between theoretical value and corner weld value for mean load, mean plastic half fold length and plastic wavelength.

	Theoretical value	Experimental value	Percentage of difference (%)
Mean load (kN), P_m	8.15	10.62	23.26
Mean plastic half fold length (mm), H_m	17.2	27	36.30
Plastic wavelength (mm), λ_p	34.4	54	36.30

Table-5. Percentage of difference between theoretical value and zigzag center weld value for mean load, mean plastic half fold length and plastic wavelength.

	Theoretical value	Experimental value	Percentage of difference (%)
Mean load (kN), P_m	8.15	9.42	13.48
Mean plastic half fold length (mm), H_m	17.2	25	31.20
Plastic wavelength (mm), λ_p	34.4	50	31.20

Table-6. Percentage of difference between theoretical value and full center weld value for mean load, mean plastic half fold length and plastic wavelength.

	Theoretical value	Experimental value	Percentage of difference (%)
Mean load (kN), P_m	8.15	9.56	14.75
Mean plastic half fold length (mm), H_m	17.2	32	46.25
Plastic wavelength (mm), λ_p	34.4	64	46.25

4.2 Axial crushing on all specimens joined by zigzag center weld

As shown in Figure-5, square tube, rectangular tube, hexagonal tube and triangular tube were fabricated using mild steel sheet metal with a thickness of 1mm. Zigzag center weld was used as a welding method in joining the tubes.

VOL. 11, NO. 8, APRIL 2016 ISSN 1819-6608
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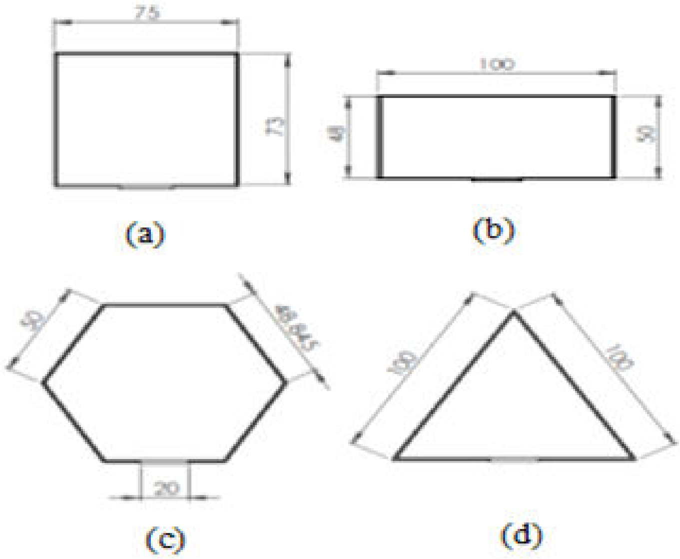

Figure-5. Top view of the tubes. (a) square tube, (b) rectangular tube, (c) hexagonal tube and (d) triangular tube.

In order to obtain the experimental mean load values, the load against displacement curve was plotted and calculated by using Microcal Origin Pro 7 as shown Table-7.

Table-7. Calculated mean load for experimental value.

Tube shape	**Area under the graph** (Nmm)	**Total deflection** (mm)	**Mean load** (kN)
Square	1.24625 x 10^6	100	12.46
Rectangular	1.19894 x 10^6	100	12.00
Hexagonal	1.79660 x 10^6	100	17.97
Triangular	0.94565 x 10^6	100	9.46

By referring to Figure 6-9, the square tube started its folding formation at the top part of the tube. The first folding formation was completed at 90mm displacement. Next, it can be seen that the folding formation of rectangular tube was started at the bottom part of the tube. The first folding was initiated at 15mm and completed at 38mm displacement. The hexagonal tube folding formation was started at the bottom part of the tube and first fold formation started at 15mm displacement and completed at 32mm displacement. As for the triangular tube, the perfect deformation cannot be obtained. This is because the tube suddenly moved to the left-hand side of the compression plate at 50mm displacement. At 70mm displacement, the specimen started to tilt. However, it can be seen that the first fold formation was initiated at 19mm displacement and completed at 64mm displacement. In addition, the folding formation of this specimen was started at the bottom part of the tube.The result of peak load, plastic half fold length and plastic wavelength of the four specimens were tabulated in Table-8.

Table-8. Calculated value for peak load, mean load, mean plastic half fold length and plastic wavelength.

Tube shape	**Peak load** (kN)	**Mean plastic half fold length, H_m** (mm)	**Plastic wavelength, λ_p** (mm)
Square	36.024	17.0	34.0
Rectangular	39.200	15.5	31.0
Hexagonal	52.103	16.0	32.0
Triangular	36.747	17.5	35.0

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Meanwhile, Table-9 show the percentage of difference between the theoretical and experimental mean load for all tubes.

Table-9. Comparison between theoretical and experimental values for mean load.

Tube shape	**Theoretical mean load** (kN)	**Experimental mean load** (kN)	**Percentage of difference** (%)
Square	14.2	12.46	13.96
Rectangular	10.45	12.00	12.92
Hexagonal	29.46	18.00	38.67
Triangular	16.18	9.46	15.64

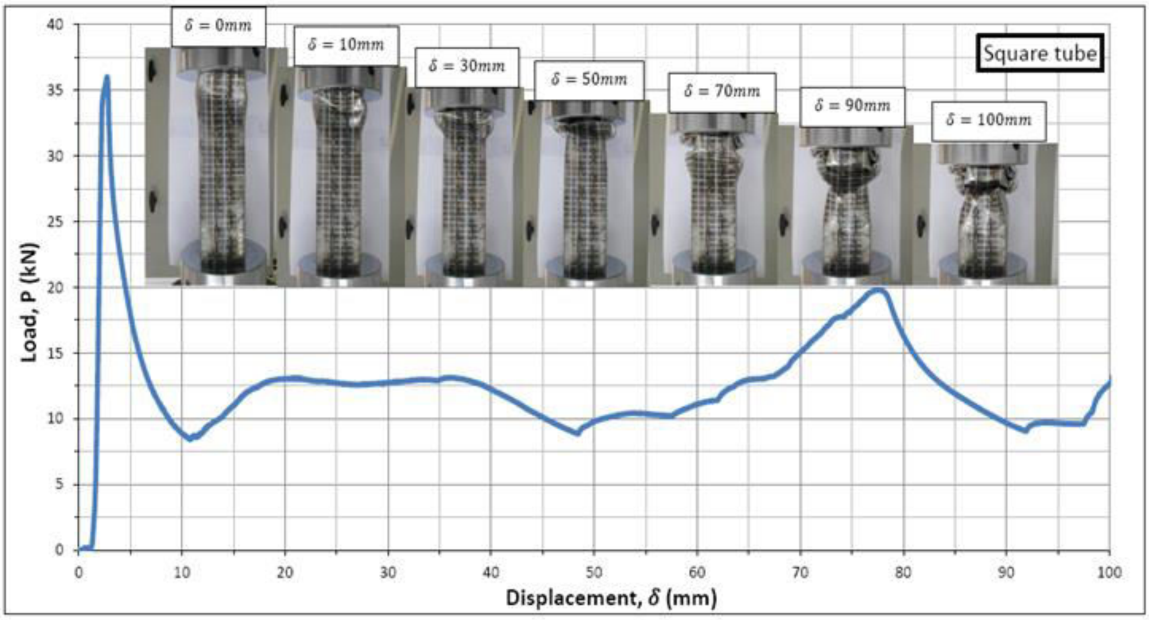

Figure-6. Load against displacement curve for square tube.

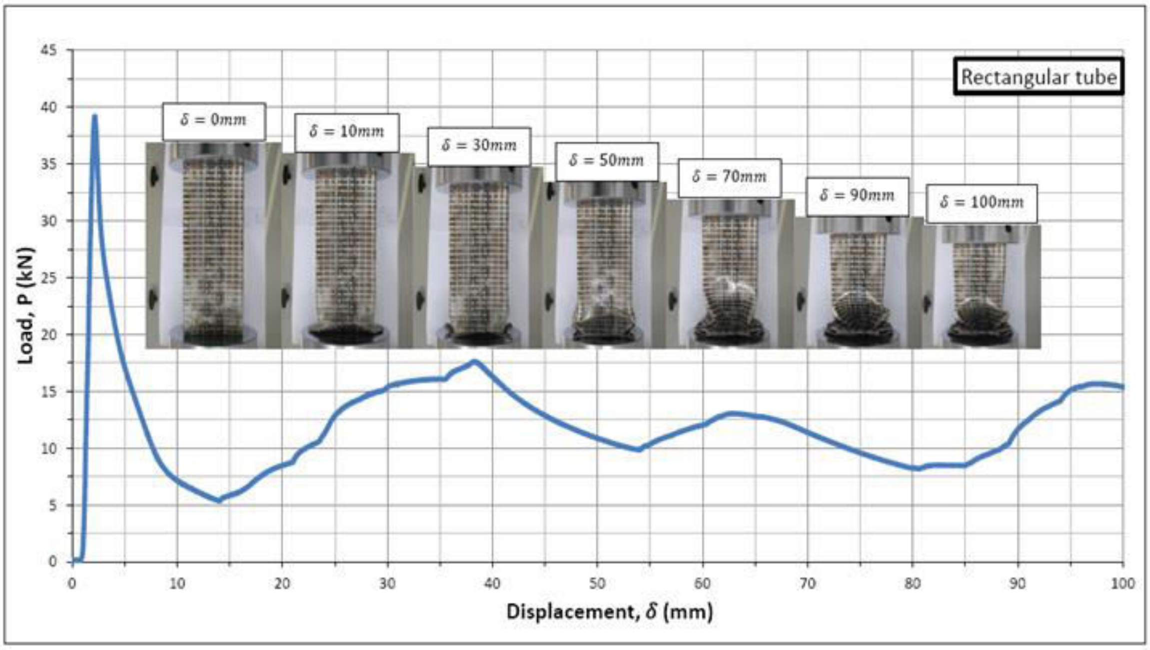

Figure-7. Load against displacement curve for rectangular tube.

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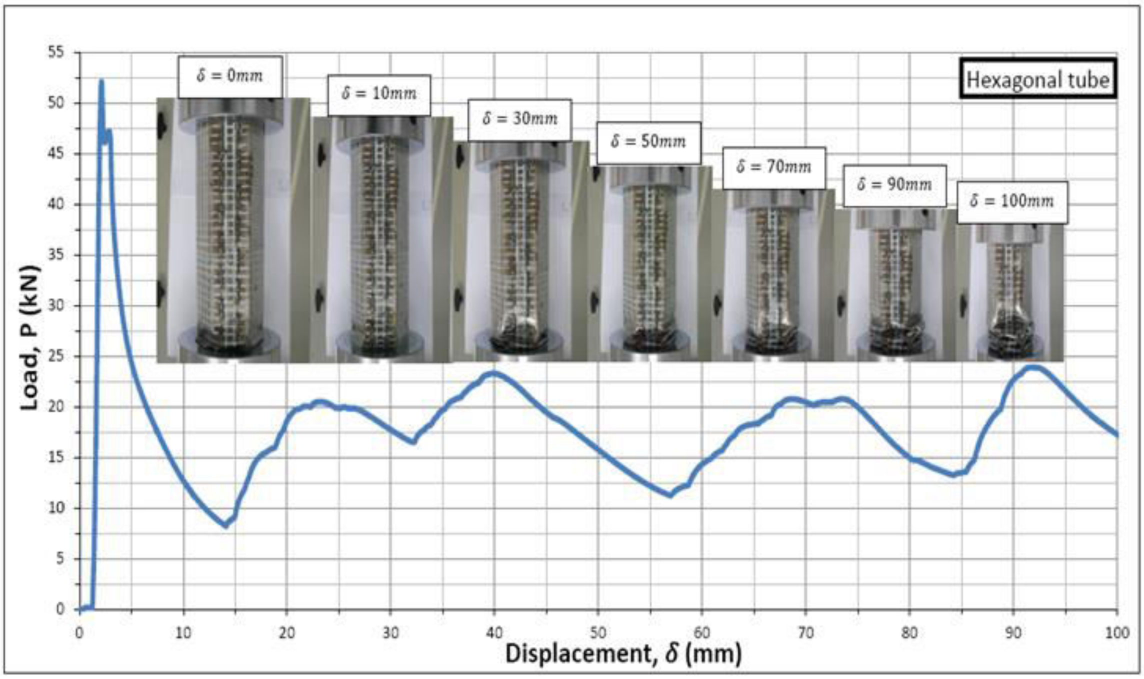

Figure-8. Load against displacement curve for hexagonal tube.

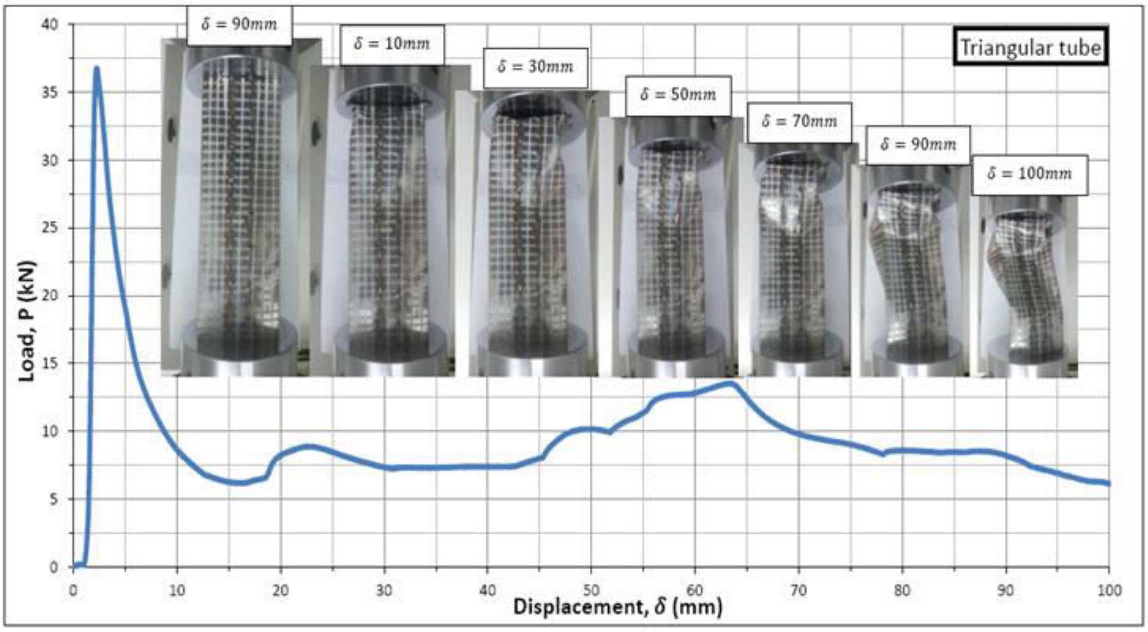

Figure-9. Load against displacement curve for triangular tube.

Figure-10 shows the superimposed graph of load against displacement for all four specimens. It can be observed that hexagonal tube has the highest peak load value while triangular tube has the lowest peak load value. All specimens were compressed up to 100mm.

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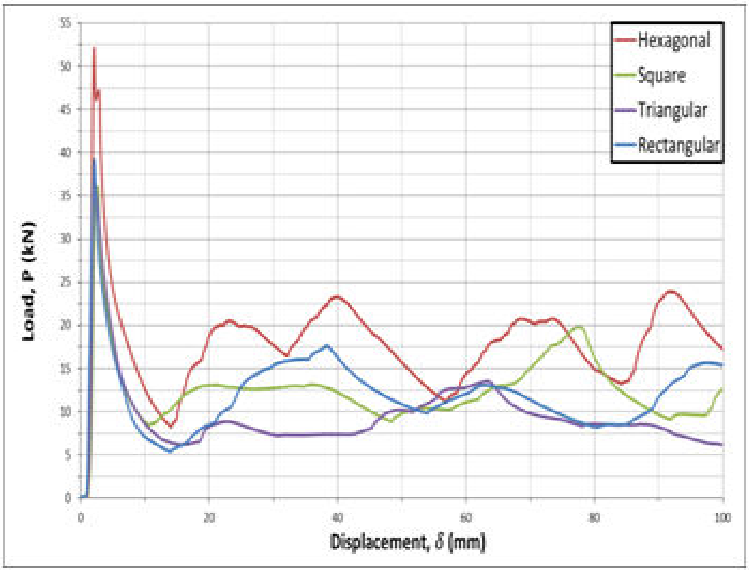

Figure-10. Superimposed graph for load against displacement.

The difference between theoretical value and experimental value may be affected by the geometry imperfection of the tubes. As the tubes were manually fabricated, human error must be considered. It is also noted that the angle at each corner of the tubes are not as good as the extruded metal tubes. This was due to the tolerance of the bending machine that was used to fabricate the tube. In addition, some part of the tube cannot produce a perfect folding formation (progressive deformation) because the zigzag center weld method caused some interference during the experiment. Part that has not been welded was easily folded compared to the part that has been welded as shown in Figure-7. Uneven surface flatness during the experiment may also contribute to the difference between theoretical and experimental values. This is because if the surface of the tube is not completely flat, Euler buckling might occur during the experiment, thus the test specimen can be considered as failed.

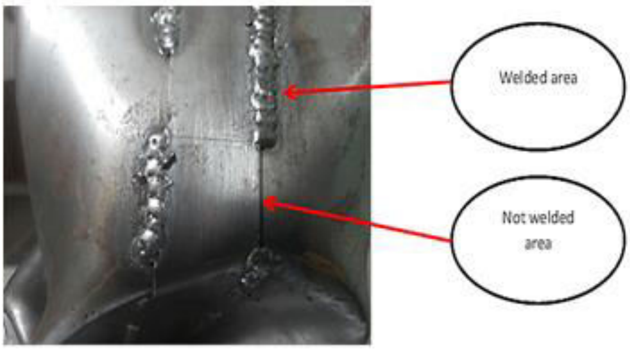

Figure-11. Illustration of zigzag center weld.

To reduce the deviations, the geometry imperfection can be improved by fabricating the tube as precise as possible. The tubes body and angle must be checked regularly to avoid any over bending. For the surface flatness, it can be improved by grinding the surface of the tubes. However, a completely straight line that serves as a guideline must be draw first on the tubes body to aid in the grinding surface. If the guideline is clearly invisible or not presented, the grinding process might be disturbed.

5. CONCLUSIONS

During the first part of the experiment, it is found that the zigzag center weld has the lowest discrepancy values between the experimental and theoretical calculation compared to the other two types of welding method; corner weld and full center weld. Thus, zigzag center weld is selected to be the joining method for all specimens that are going to be fabricated. The second part of the experiment was conducted and it is found that between the four tube shapes, hexagonal tube has the highest energy absorption while triangular tube has the lowest energy absorption. This conclude that the if the number of corner is increased, then the energy absorption value will beincreased. There were some factors that contribute to the difference between theoretical and experimental values; imperfection of the tube geometry and the surface flatness of the tube. In order to improve the result, the tube geometry must be fabricated as precise as possible.

REFERENCES

A.A. Nia, J.H. Hamedani. 2010. Comparative analysis of energy absorption and deformations of thin-walled tubes with various sections geometries, Thin-Walled Structures, 48, pp. 946-964.

A.A. Nia, M. Parsapour. 2013. An investigation on the energy absorption characteristics of multi-cell square tubes, Thin-Walled Structures, 68, pp. 26-34

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A.A. Nia, M. Parsapour. 2014. Comparative analysis of energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and octagonal sections, Thin-Walled Structures, 74, pp. 156-165.

A.M.S. Hamouda, R.O Saied, F.M. Shuaeinb. 2007. Energy absorption capacities of square tubular structure, Achievement in Materials and Manufacturing Engineering, 24(1).

B.P. DiPaolo, J.G. Tom. 2006. A study on axial configuration response of thin-wall, steel box component: the quasi static experiments. International Journal of Solid and Structures, 43, pp. 7752-7775.

N. Jones, (1989). Structural impact. Cambridge University Press, pp. 412-431

S.R. Reid. 1993. Plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers, Int. J. Mech. Sci, 35 (12), pp. 1035-1052.

S.R. Reid, T.Y. Reddy, M.D. Gray. 1986. Static and dynamic axial crushing of foam-filled sheet metal tubes. Int. J. Mech. Sci., 28 (5), pp. 295-322.

T. Wierzbicki. 1983. Crushing analysis of metal honeycombs, Pergamon Press Ltd, 1(2), pp. 157-174.

T. Wierzbicki, W. Abramowicz. 1983. On the crushing mechanics of thin-walled structures, Journal of Applied Mechanics, 50, pp. 727-733.

T.Y. Reddy, S.T.S Al-Hassani. 1993. Axial crushing of wood-filled square metal tubes. Int. J. Mech. Sci., 35 (3), pp. 231-246.

W.Abramowicz, N. Jones. 1986. Dynamic progressive buckling of circular and square tubes. Int. J. Impact Engng, 4 (4), pp. 243-270.

W. Abramowicz, T, Wierzbicki. 1989. Axial crushing of multicorner sheet metal columns, Journal of Applied Mechanics, 56, 120.