PLASTIC DEFORMATION OF CIRCULAR METALLIC THIN WALL TUBES

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ABSTRACT. *Thin wall tubes provide benefits such as light weight, good energy absorption and low cost and it has been well applied in many engineering fields. The objective of this paper is to investigate the plastic collapse of thin wall tube. Three point bending test is carried out to obtain the energy stored in the deformed circular metallic thin wall tubes. During the bending test, the test specimen was set above two supports and the load is applied on the upper surface through another point in the middle of the test specimen. The energy stored in the thin wall tube can be calculated by area under the graph of load applied against deflection of thin wall tube. The shape of thin wall tube after deformation will be discussed by its metallic bonding. Variables that influence the deformation mode of thin wall tube such as length and diameter of tube also are discussed. From the results, we can conclude that the decreasing the length and increasing the outer diameter of thin wall tube will increase the energy stored in the tubes. The numerical simulation of the collapse phenomenon has been undertaken using a finite element analysis in COSMOS. Having validated the numerical model with experiments, it has been used to undertake a study of the load–deformation characteristics and energy absorption response of the thin wall tubes in varying configurations of length and dimension.*

KEYWORDS *.Plastic Deformation, Circular Metallic Thin Wall Tube, Three Point Bending Test, Energy Stored*

INTRODUCTION

The world nowadays is emphasising on issues that deal with sustainability and economical energy. As a result, this trend brings to material saving policy and thin wall tube became more and more important structural element that is used in structural design and daily application. The aim of this project is to study the properties of thin wall tube under static loads. This study will reveal the deformation mode of the thin wall tube and variables that affect the energy stored in it.

Thin wall tubes are important structural elements that have vital application in many engineering aspects such as automobile, aerospace, construction and piping systems. Despite its thinness, thin wall tubing still provides insulation and strength and is commonly used in medical and aerospace applications.

Thin wall tube provides benefits such as light weight, good energy absorption and low cost. With the increasing concern of fuel economy and stringent government emission regulations, light weight structures, especially thin wall tubes, are being adopted by engineers for the structural designs. Thin wall tubes are hollow tube with small wall thickness which provides reasonable strength in structural designs. As a result, it is a good choice for engineer to fulfil the need of the new economical trend by applying thin wall tube in their study and design.

In view of the increasing important of application of thin wall tube as mentioned above, the plastic deformation of thin wall tube should be examined. Most modern buildings, energy absorbing systems are designed in accordance with a code which is based on limit state theory. To satisfy the ultimate limit state criteria, all bending, shear and tensile or compressive stresses which would be obtained under factored loading, must be below the limit stress. The limit stress can be studied by the amount of energy that can be absorbed by the tubular member.

The objectives of this project are first of all to study the plastic deformation/collapse and energy stored in circular metallic thin wall tubes of various sizes and length. The second goal of this work is to evaluate the deformation shape of the circular metallic thin wall tubes after the three-point bending test. Finally, by using FEA simulation, virtual bending was carried out in the computer by using COSMOS software.

This research is mainly focuses on plastic deformation of thin wall tube. Although different types of materials are used in thin wall tubes, such as PVC, glass and fiber, the main specimen used for testing is metallic thin wall tube. Mild steel metallic thin wall tube will be used as test specimen in this study. This reason why metallic thin wall tube is selected is due to its high ductility. In this research, the focus is on the circular metallic thin wall tube. Circular thin wall structures are the most efficient shapes for resisting torsion and are most commonly used.

The mechanical properties of a material indicate as to how it will react to physical forces. Mechanical supposes occur as a result of the physical properties inherent to each material, and are determined through a series of standardized mechanical tests. In this research, the experiment have been conducted to examine plastic collapse and mechanical properties of thin wall tube is three point bending test. During the bending test, the thin wall tube is set above two supports and the load is applied on the upper surface through another point. The load is applied with a round shape ball with a constant speed (Figure 1).

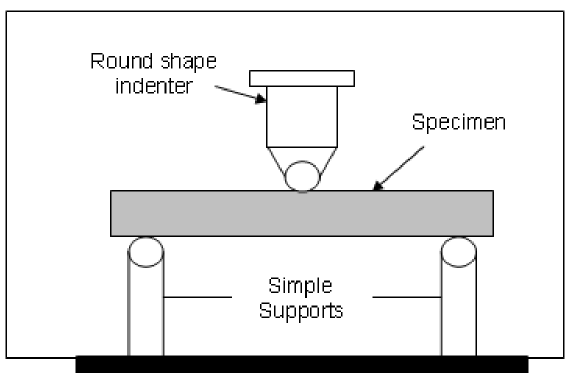

Figure 1. Test set up for the experiment

MATERIALS AND METHODS

Sample Collection

The mild steel thin wall circular tubes have different dimension with various diameters and lengths. The tube is being sorted by the ratio of outer diameter to thickness. Thin wall tube should have ratio of outer diameter to thickness to be around 20. After the appropriate thin wall tube have been chosen, the tube will be cut into required lengths.

The test specimens length were chosen as 200mm, 250mm and 300mm. Extra length was subjected to each specimen so that the specimen can be placed firmly at both supports of Instron

Universal Testing Machine. The outer diameters which are used in the experiments were 34mm, 43mm, 49mm and 60mm. The dimension of the inner diameter and outer diameter of thin wall tube should be measured carefully because of the rough inner surface of tube. An average value was taken in different positions of the tube so as to get a more reliable value.

Instruments

The two instruments used in this study are Instron 8801 Universal Testing Machine and band saw machine. The 8801 series provides complete testing solutions to satisfy the needs of advanced materials and component testing, and is ideally suited for fatigue testing and fracture mechanics. The high stiffness and precise alignment of the 8801 series ensure consistent loading that is applied to specimens in both tension and compression, giving more reliable results. Band saw machine is a powerful sawing machine that can give neat and clean cutting. The deformation shape of the tube can be examined by using this machine to cut at the deformed cross section.

Energy stored

Energy is the product of force and distance. In this research energy produced when the load was applied to deflect the thin wall tube. As mentioned in the energy conservation law, energy cannot be destroyed and created but can change in one form to another form. In this study energy was stored in the thin wall tube when the energy was used to change the shape of the thin wall tube. To calculate the energy stored, the graph of load applied against extension of thin wall tube was plotted. After that the area under the graph which was the product of the load and deflection (the energy stored on the specimen.) is calculated.

The area of under graph was calculated using grid lines which form neat boxes. Each boxes represented unit energy of the total value of the energy been absorbed. We can obtain the unit energy as a multiple as both minor unit of x-axis and y-axis. By calculating the total boxes under the graph, the energy can be obtained by following equation:

Energy= No. of boxes x unit energy

Software

COSMOS-Works is powerful, easy-to-use design validation and optimization software fully embedded within SolidWorks software. COSMOS-Works is ideal for engineers who need analysis but are not specialists in finite element analysis. COSMOS-Works is also a 3D analysis application for virtual testing of parts and assemblies. It shows engineers how their designs will behave as physical objects, testing factors such as material stress and heat conduction. COSMOS-Works give engineers high-end, easy-to-use analysis tools at a lower cost than competing applications. The virtual bending process given the displacement, stress distribution and other. We can also know the area with highest stress concentration and displacement.

RESULTS AND DISCUSSION

The results from the two experiments are generally shown by the graph below. All of the test specimens would show similar characteristics as the graph below (Figure 2).

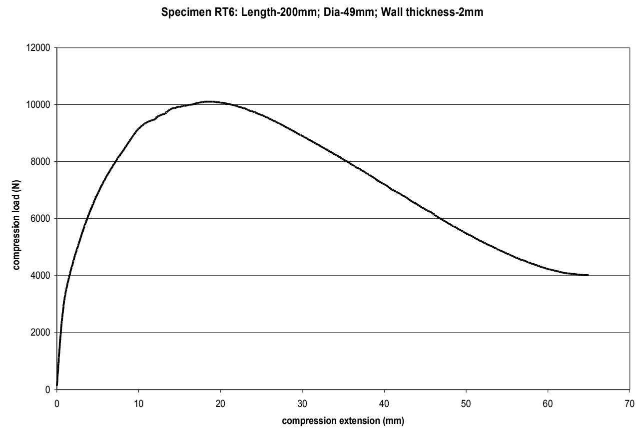

Figure 2. General graph shape obtained in experiment

The graph shows the Load (compression) against deflection (compression response) of a specimen, RT6. In the beginning of the graph, the deflection of the thin wall tube in directly proportional to the load applied. When the load removed, the tube would recover its original shape. This means that the thin wall tube deforms elastically with the load. The limiting deflection that ensured elastic deformation is around 0-10mm of this specimen in this graph.

From the comparison among the graphs obtained in all experiments, we can study that when the ratio of outer diameter against wall thickness increase, the elastic behavior of thin wall tube can continue up to larger loads before undergoing plastic deformation. On the other hand, if the length of the tube is decreased, the elastic deformation can only be retained up to smaller load. The two cases above can be explained by elastic limit. The elastic limit is the highest stress at which all deformation strains are fully recoverable. For most materials and applications this can be considered as the practical limit to the maximum stress a component can withstand and still function as designed. The limit load was higher if the ratio of outer diameter over wall thickness increases. Same thing happens to the length, when the length of the thin wall tube decreases, the limit load also increases.

When the loads continuously applied to the tube, the upper layer of the tube will bend. When the extension reaches a certain value, the slope of the graph decreases. This shows that smaller load produces more extension and plastic deformation occurs in that region. The thin wall tube can change back to its original shape after undergoing that process. When the graph reaches a maximum, the compressive load will constantly decrease to deform the tubular member. That reveals that a decreasing value of energy is insufficient to continuously deform the thin wall tube. The experiments end when the deflection of the thin wall tube reached a value around 65mm.

The yield strength is the minimum stress which produces permanent plastic deformation. From the comparison among the graphs, we can conclude that when the ratio of D/T (diameter - thickness and the length of the thin wall tube increased, the yield strength has a higher value. Toughness describes a material's resistance to fracture. It is often expressed in terms of the amount of energy a material can absorb before fracture. Mild steel thin wall tubes have high toughness because they can absorb a considerable amount of energy before fracture.

The characteristic of the graph can be described by the bonding associated in the thin wall tube element. As mentioned before, the test specimen was made by mild steel. Mild steel was a type of metal in which carbon was added to steel. Metals were giant structures of atoms held together by metallic bonds. "Giant" implies that large but variable numbers of atoms are involved - depending on the size of the bit of metal. The electron valance in the latest orbital of one atom shares space with the corresponding electron on a neighbouring atom to form a molecular orbital.

The electrons can move freely within these molecular orbital and so each electron becomes detached from its parent atom. The electrons are said to be delocalised. The metal is held together by the strong forces of attraction between the positive nuclei and the delocalised electrons. Therefore metal such as mild steel can be held strongly with the metallic bonding.

The holding energy between atoms in metal can be enhanced by inserting atoms of a slightly different size into the structure. Then the regular arrangement of the atoms will break up. Alloys such as mild steel (a mixture of steel and carbon) are harder than the original metals because the irregularity in the structure helps to stop rows of atoms from slipping over each other. That is the reason more energy is needed to deform the mild steel thin wall tube than the steel one.

Although metallic bond holds metal atoms strongly, metals are described as malleable (can be beaten into sheets) and ductile (can be pulled out into wires). This is because of the ability of the atoms to roll over each other into new positions without breaking the metallic bond. This explains why the thin wall tube can return to the original shape when small loads are applied on the tube.

When a small stress is put onto the thin wall tube, the layers of atoms will start to roll over each other. If the stress is released again, they will fall back to their original positions by the attractive force of metallic bonds. In the beginning of the experiment the test specimen showed this phenomenon. The thin walls tube can be deflecting around 10mm and return back to its original shape without undergoing any shape change. (Figure 3)

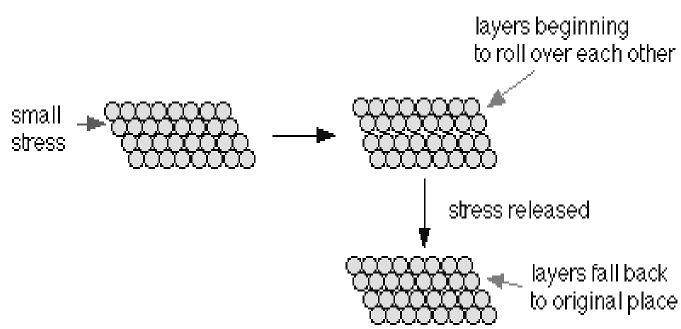

Figure 3. Elastic deformation

When a larger load is applied to the thin wall tube, the thin wall tube will continuously deform. However, when the stress is released, it cannot return to the original shape. This is because the metallic bonds between the atom layers have collapsed and the metallic bond is unable to pull back the atoms the original shape. As a result, if a larger stress is put on, the atoms roll over each other into a new position, and the metal is permanently changed (Figure 4).

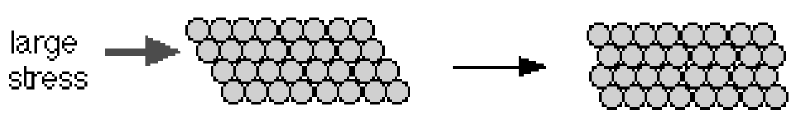

Figure 4. Plastic deformation

Energy Stored

The area under the graph of load applied against extension of thin wall tube will give the energy stored in the tubular members. The following table consists of data of unit energy and total boxes under the graph (Table 1).

Table 1. Energy stored in the thin wall tube

Specimen no.	No. of boxes under graph	Unit Energy (Nmm)	Total Energy (J)
RT5	3235	200	647.00
RT6	2324	200	464.80
RT7	3360	100	336.00
RT8	3235	200	447.00
RT9	2324	200	464.80
RT10	2419	200	483.80

When we plot the graph of energy against the outer diameter of the thin wall tube, the relationships between them is show in Figure 5.

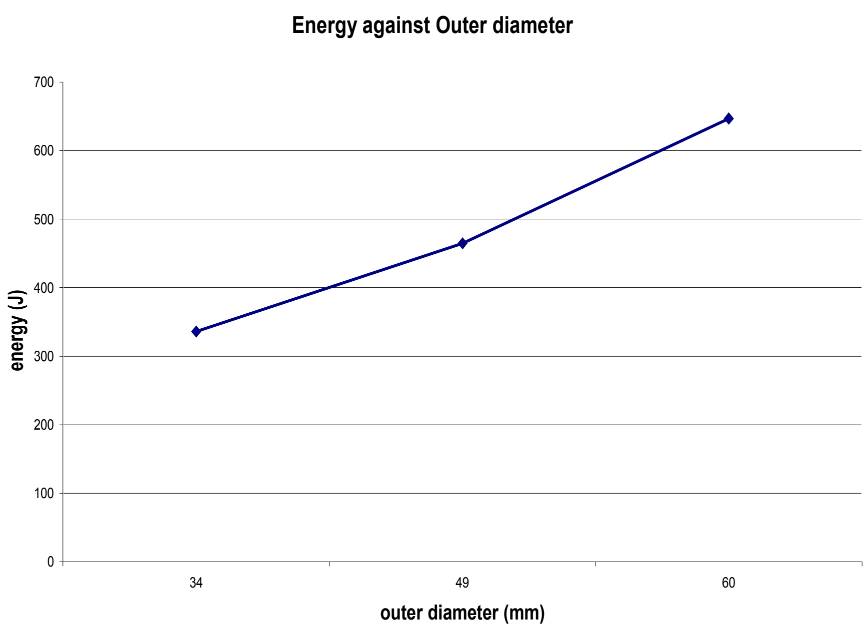

Figure 5. Graph that showed the relationships between energy and outer diameter

From the tube, as the outer diameter of the thin wall increases, the energy stored also increase. That means that a bigger tube could withstand larger load.

In the second experiment, the outer diameter of the thin wall tube has been fixed and the variable to be tested is the length. The goal of this experiment is to study the effect of the length on energy stored on the tube. Following are the results of the experiments: (Table 2)

Table 2. Energy stored in the test specimen in experiment 2

Specimen No.	Length (mm)	Outer Diameter(mm)	Area Under Graph(J)
RT 8	250	49	447.00
RT 9	200	49	464.80
RT 10	150	49	483.80

When plotted the graph of energy against the outer diameter of the thin wall tube, one can know the relationship between them. (Figure.6).

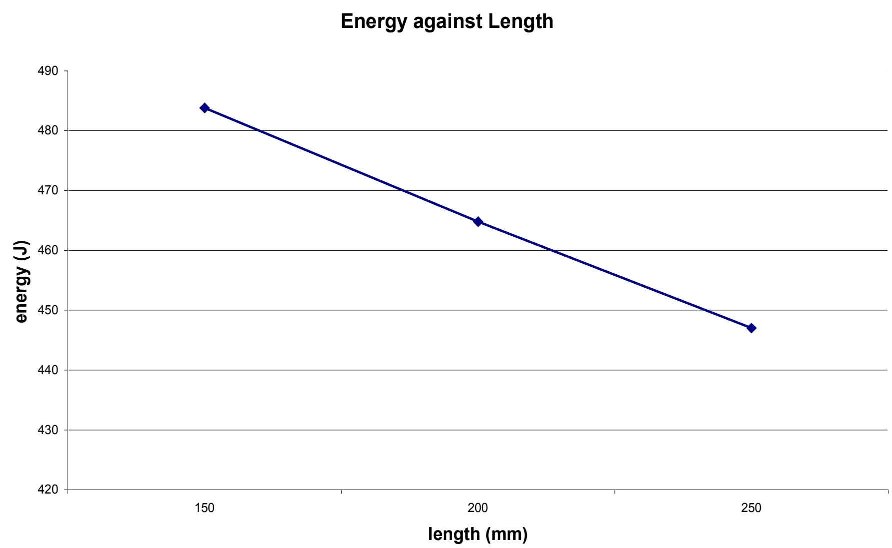

Figure 6. Graph that showed the relationships between energy and length

From the graph, it can be noted that the length of the thin wall tube was inversely proportional to the energy stored. That means, more energy is required to deflect shorter tube. That is because shorter tube has limited ductility which requires larger load to deform it.

Deformation Shape

When the load is applied to the thin wall tube in the three point bending test, the straight thin wall tube will bend into V-shape. From the observations of the experiment, two things can be noted down. The longer thin wall tube bends easily than the shorter one (Figure 7). Another point is that larger diameter thin wall tube can not bend as much as the smaller diameter one.

Figure 7. Deformation of thin wall tube after three point bending test

After the three point bending test, the deformed thin wall tubes were cut across at the deformation area. The cutting process was conducted in the workshop of School of Engineering and Information Technology by using band saw. The shape of the tube after deformation was no longer a round shape as shown in Figure 8.

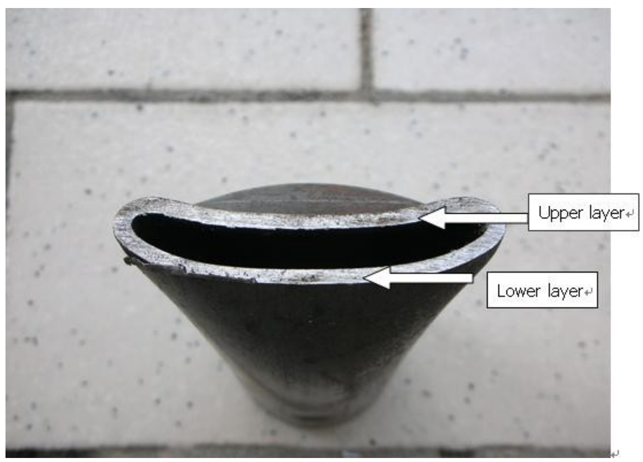

Figure 8. Cross sectional cut at deformed area of thin wall tube.

The stress distribution can be examined by classifying the thin wall tube into upper layer and lower layer as shown as Figure 8. The outer diameter and inner diameter of the upper layer would encounter compressive stress. However both outer and inner diameter of the tube would undergo tensile stress. The two wedges of the deformed shape also have high stress contribution where stress concentrates on this two wedge.

Both the tube ends also are subjected to lateral deformation after the three point bending test. The amount of deformation is influenced by the thin wall tube length and D/t ratio. From the picture shown below (Figure 9), one can see that, as the length of the thin wall tube decrease the lateral deformation of the tube will become more obvious. This is the same case as the tube with increasing D/t ratio. The deformation of the tube at its end imply that the energy is stored in the thin wall tube. This is the reason for getting the result that shorter tube with higher D/t ratio can store higher energy because portion of the energy is used to produce lateral deformation at both the ends of the tube.

Figure 9. Deformation at tube end with different length

Figure 10. Deformation at tube end with different diameter

Results from COSMOS

By using the COSMOS program, both the experiments were implemented virtually. The results of the program shows that the stress distribution of the load, type and way of deformation and others. Figure 11 shows one of the results that is obtained from the COSMOS program.

The picture shows the amount of displacement of thin wall in different regions. The highest deformation is shown by red colour. There was a reference of colour bar beside the model to show the brief value of each colour represented. In the simulation of the virtual bending solution, the result obtained is not as the experimental results. The shape of deformation cannot be simulated in the software. However the virtual bending process gives quick and clear response in the displacement, stress distribution and others. We can know the area with highest stress concentration and displacement. This helps us to gain more understanding about plastic deformation of the specimen.

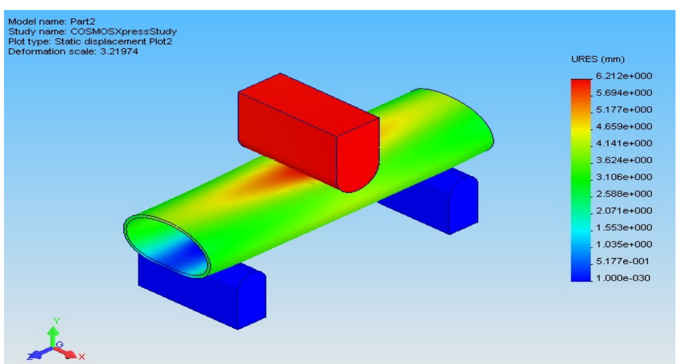

Figure 11. Results obtained from the COSMOS program for the three point test

Comparison of Circular and Square Thin Wall Tube

After the experiment a comparison between circular thin wall tube and square thin wall tube have been carried out. From the result, we can conclude that the square thin wall tube can absorb more energy than the circular one. This is because more energy was used to form bulge and wedge in the square tube. Through this observation, one understand the reason why most of the structural members nowadays are using square tube. However, circular thin wall tube can deflect more than the square one. That is why circular thin wall tube is well applied in the piping system because of high ductility where bending within the tube can be easily formed.

CONCLUSION

Although there were certain limitations and constraints, the overall objective of this study is achieved. Through this research the plastic deformations of thin wall tubes have been studied. The process undergone in the deformation such as elastic deformation and plastic deformation can be shown by the graph of load against the tube deflection. Moreover, the area under the graph given the energy stored in the deformed thin wall tube. From the experimental results, one can find that more energy is applied to deform shorter and larger diameter tube.

There are some constraints in the study which can be improved for the further work. The first limitation is the specimen limitation. In this experiment, only mild steel thin wall tube is tested. However, if other types of material such as aluminium and other alloy steel are utilized, then a clearer understanding can be obtained by comparing the graph and data. Other than this, there is machine limitation in conducting the experiments. The maximum displacement of two supports in Instron Universal Testing Machine is 3m. This constraint does not allow longer specimens to be tested. Moreover, the machine will automatically stop when the deflection of the specimen reaches 65mm. This hinders to study the further deformation of the specimen.

There was also limitation in software. The COSMOS software was user friendly and not effective software. In the simulation of virtual bending solution, the result obtained not very close to the experimental results. It is suggested that other finite element software such as ANSYS can be utilized to compare the experimental results.

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