PLASTIC DEFORMATION OF SQUARE METALLIC THIN WALL TUBES

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ABSTRACT. *Thin-walled tubes are one of the most advanced components that have various applications nowadays. This paper deals with the plastic deformation of square metallic thin-walled tubes. The energy absorption capabilities of the square metallic thin-walled tubes are also studied. In this research, the experimental method and the finite element method (FEM) are used. Tthe experimental method, three point bending test was implemented to test the specimens. The Instron Universal Testing machine was used for the bending test. The COSMOS program was used to analyze all the specimens virtually. Both the results that are obtained from the experimental method and COSMOS program were compared and analyzed. It was observed that by using the finite element method (FEM), it is possible to virtually evaluate the plastic deformation and the energy absorption capability of the test specimen. It is therefore, possible to save more time and cost by using the finite element method to investigate the properties of the material during the deformation process.*

KEYWORDS. *Plastic Deformation, Square Metallic Thin Wall Tube, Three Point Bending Test, Energy Absorption capabilities*

INTRODUCTION

Nowadays, majority of structural components of sea, land and air vehicles are designed using thin-walled structures. During decades of growth of the transportation industry a variety of design rules and recommendations are established that help practicing engineers in the design of robust structures (Abramowicz, 2003). Thin-walled tubes have become the important material that have variety of usages nowadays, especially in the field of automobile and aerospace.

Square metallic thin-walled tubes have been used in this investigation because they have been widely used nowadays. Thin-walled tubes such as in the square cross-section are a common type of materials that will be used in various applications since they are relatively cheap, versatile, are of light weight, ensure material saving and efficient for absorbing energy (Nagel and Thambiratnam, 2004). All these advantages have led them to be used in a wide variety of impact loading and bending applications.

Circular shapes of thin-walled structure are the most efficient shapes for resisting torsion and consequently they are most commonly used. However, the lightweight structures, such as aircraft and spacecraft, thin-walled tubular members with noncircular cross sections such as the square cross sections are often required to resist torsion.

Thin wall tube provides benefits such as light weight, good energy absorption and cost saving. With the increasing concern of fuel economy and stringent government emission regulations, light weight structures such as thin wall tubes are being adopted by engineers for the structural designs.

In view of the increasing importance of application of thin wall tubes in structural designs, the plastic deformation of thin wall tube needs to be examined. The objectives of this project were first to study the plastic deformation and energy absorption capabilities of square metallic thin wall tubes that have various sizes and lengths. Besides, the deformation shape of the square metallic thin wall tubes after the three-point bending test are evaluated. Lastly, by using the FEM simulation, virtual bending was carried out in the computer through the use of COSMOS software.

This research mainly focuses on plastic deformation of thin wall tube. Due to its high ductility, it can be carried out easily. Mild steel thin walled tubes are chosen in this study. In this research, particular attention and effort is put into the secular metallic thin wall tube.

The mechanical properties of a material show as to how the material will react due to the changes of physical phenomena. In this project, three point bending test is carried out to examine plastic collapse and mechanical properties of square metallic thin walled tubes. During the three point bending test, the specimen is placed firmly on two supports and the load is applied onto the upper surface of the specimen. The round shape indenter is used and the load will be applied with constant speed (5mm/min) as shown in Fig 1.

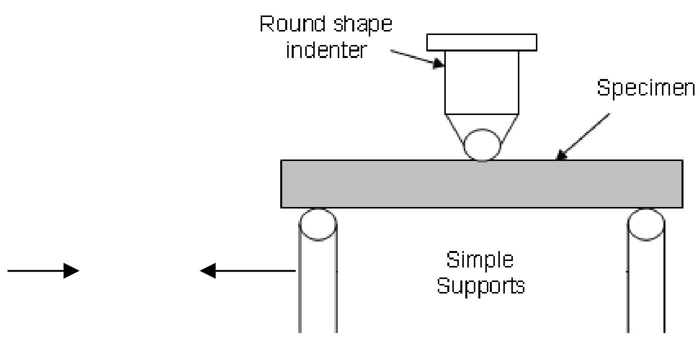

Figure 1. Test set up for the experiment

MATERIALS AND METHODS

Sample Collection

Various sizes and dimensions of square mild steel thin walled tubes are obtained from the school workshop. The tubes are sorted by the ratio of outer diameter (D) to thickness (T). Thin wall tubes should have ratio of outer diameter to thickness, around 16. After the appropriate thin wall tube have been chosen, the tubes are cut into the desired lengths.

The test specimen lengths are 200mm, 250mm and 300mm. Extra length is kept in each specimen so that the specimen can be placed firmly on the supports of Instron Universal Testing Machine. The outer dimensions of the test specimens are 13mm, 25mm, 25.7mm and 50mm. Before any calibration is being made, the specimens were cleaned by using the cloth. Several readings were taken and the average values were taken. This is to provide a more reliable value.

Instruments

Two instruments were used in this project. They are Instron 8801 Universal Testing Machine and band saw machine. The 8801 testing machine 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 application to specimens in both tension and compression, for more reliable results. A choice of maximum load capacities means that dynamic performance can be optimized for applications. The 8801 series is available in maximum axial load capacities of either ±50 kN (11 kip) or ±100 kN (22 kip). Band saw machine is a powerful sawing machine that can give neat and clean cutting. The shape of deformation of the tube can be examined by cutting at the deformed cross sectional area. In addition, the vernier callipers is used to measure the outer and inner dimensions of the specimens. This is because it could increase the measuring precision beyond what it would normally be with an ordinary measuring scale like a ruler or meter stick.

Software

COSMOS is a general-purpose finite element analysis (FEA) software package. Finite element analysis (FEA) is a numerical method for disgelising a complex system into very small element called finale elements. The COSMOS governs the behavior of these elements and creating a comprehensive explanation of how the system acts as a whole. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. COSMOS is one of the most comprehensive and sophisticated, stand-alone analysis package available. It offers a tremendous range of analysis capabilities. The COSMOS software package consists of COSMOS-Works, COSMOS-FloWorks, COSMOS Motion and COSMOS-EMS. In this project, only the COSMOSWorks is used. COSMOS-Works is 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. Besides, COSMOS-Works provides engineers high-end, easy-to-use analysis tools at lower cost. The virtual bending process given quick and clear response in the displacement, stress distribution and other parameters.

RESULTS AND DISCUSSION

In this project, two types of three point bending test have been implemented. (1) Test specimens with same dimensions but in different lengths. (2) Test specimens with same lengths but with different dimensions. The results that are obtained from both experiments were shown by the graph below (Fig.2).

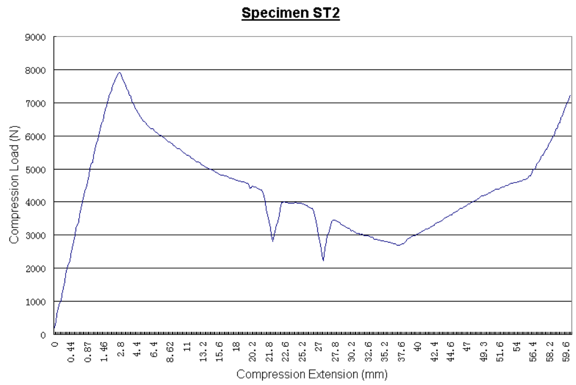

Figure 2. General graph shape obtained in experiment

The graph above shows the general load-compression behavior of empty tubular beam with the length of 200mm (Specimen ST2). The graph of compressive load against compression is plotted by using Microsoft Excel. By referring to the graph, As soon as the round shape indenter starts compressing the specimen ST2, the compressive load increases rapidly until it reaches a peak. The load at the peak corresponds to the elastic instability of the tube side walls. It can be identified by the formation of the bulge on the tube side walls below the indenter (Fig.3).

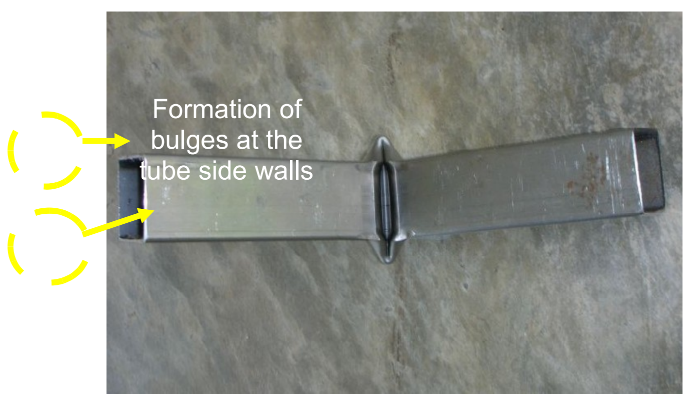

Figure 3 Formation of bulges after three points bending test

After attaining the peak, the value of the compressive load drops initially at faster rate. Then, it increases gradually up to a stable value. This stage corresponds to the localized collapse of the tube walls around the round wedge and the formation of the plastic hinge lines. The load drops sharply afterward. This may be caused as the specimen is undergoing the plastic deformation state. Finally the load value show a tendency to rise again. This stage is a stage of deformation where the panels isolated by the hinge lines on the top surface of the specimen touch the surface of the indenter. Further deformation and corresponding shape of the collapse mechanism depends on the length of the specimen.

By comparing all the graphs that are obtained from both experiments, it can be observed that as the span length increases, the peak value decreases. It shows us that higher loads are required to bend the tube with shorter span length. Through this graphs, it can be seen that the span length has great influence on the mode of deformation of the tubes. On the other hand, the area under the graph represents the energy that has been absorbed by the tube during the bending test (Fig.4).

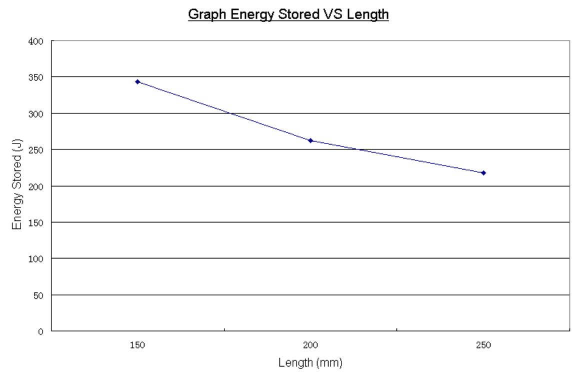

Figure 4. Graph energy stored against lengths of experiment 1

Through figure 4, it can be observed that as the span length increases, the energy absorption capabilities of the test specimens decreases. The specimens that have shortest span length have the highest energy absorption capability. Besides, in experiment 2, the test specimens have the same span lengths but with different dimensions. From the graph of energy stored against the outer dimensions of the specimens (Figure 5), it is observed that the wall thickness and the dimensions of the thin walled tubes also have influence on the mode of deformation.

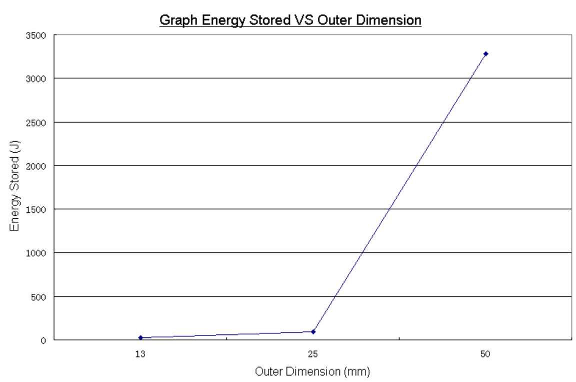

Figure 5. Graph energy stored against outer dimensions of the tubes

In figure 5, it in to be noted that as the outer dimensions and the wall thickness increases, the energy absorption capabilities of the thin walled tubes also will increase. The test specimen with larger wall thickness can withstand more load than the specimens with small wall thickness. So in this project, the test specimen ST4 (outer dimension = 50mm, wall thickness = 3mm) has the highest energy absorption capabilities.

Shape of deformation

Figure 6 shows the deformation shapes of the test specimens (experiment 1) after the three point bending test. During the implementation of the three point bending test, the load is applied constantly on to the test specimens. The test specimens were bent into V-shape after the three point bending test. In both the experiments, it is observed that the specimens that have longer lengths bend more than the test specimens that have shorter lengths. Besides, the tubes that have smaller dimensions and wall thickness could bend more compared to the tubes that have larger dimensions and thickness.

Figure 6. The deformation shapes of the specimens after three points bending test

Figure 7. Cross sectional at the deformed area of thin walled tubes

From Figure 7, it can be noted that after the three point bending test, the square shape of the tube, no longer exists. Through Figure 4-6, it can be observed that the upper surface of the tube is subjected to compression and the bottom surface of the tube is subjected to tension. Besides, bulges formed at both the side walls of the tube.

RESULTS AND DISCUSSIONS

By using the COSMOS program, both the experiments were implemented virtually. Figure 8 shows one of the results that is obtained from the COSMOS program. All the test specimens are having the same dimensions during the virtual bending process. From the figure, it clearly shows that the displacement of specimen ST2 during the three point bending test. As soon as the indenter applied load on to the specimen, it begins to bend. The red region on the specimen is the load concentration region. When the load is applied gradually, bulge is formed at both sides of the specimen (Fig.8).

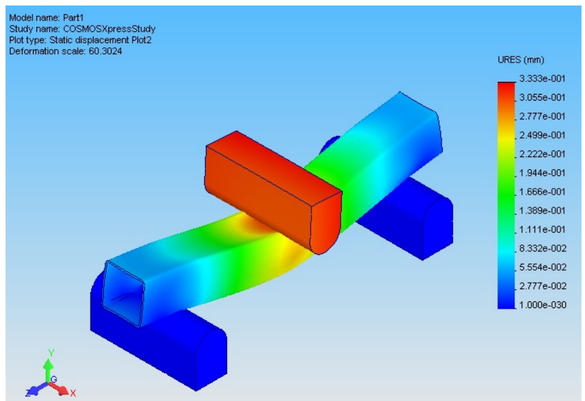

Figure 8. Displacement of specimen ST2 in COSMOS analysis

Comparing results between COSMOS and experiment

When the experiment is implemented by using the COSMOS program, it is observed that the bending process is not exactly same as in the experiments. The shape of deformation of the tubes also varied from the experimental results. Figure 9 and Figure 10 show the results that are obtained from both the virtual bending and the exact experiment (specimen ST2: outer dimension = 25.7mm; length = 200mm; applied load = 8000N). Generally, although their modes of deformations are similar, their shapes of deformation after the bending test are quite different.

During the virtual bending test, the compression load that is applied on the tube was same as the exact load in the experiment. It is observed that the tube could not bend as much as in the experiment that had been done before. Although more load had been applied, the result also remained the same.

The same procedures have been carried out for others specimens. Unfortunately, the desired results are not obtained. These may be due to the reason that there are some limitations and constraints when the COSMOS program in executed. The COSMOS program can not show the exact mode of deformation of the tube during the three point bending test. By the way, through the use of COSMOS program, it can show the area where the load will concentrate during the bending test. Therefore, by using the COSMOS program we can estimate the safety factor of the structures during the deformation process.

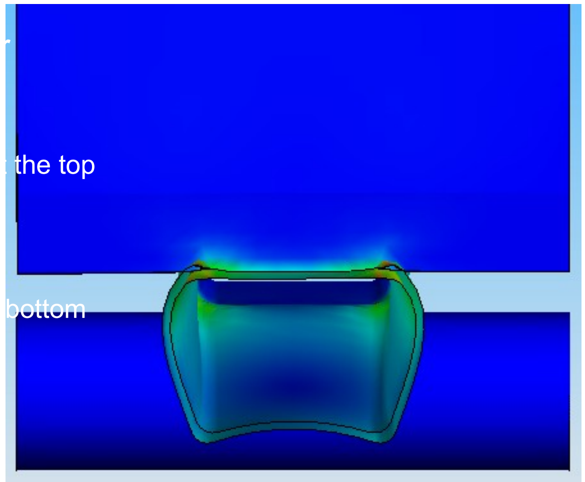

Figure 9 Cross sectional (front) view of the tube after three points bending test by using the COSMOS program (outer dimension = 25mm, length = 200mm)

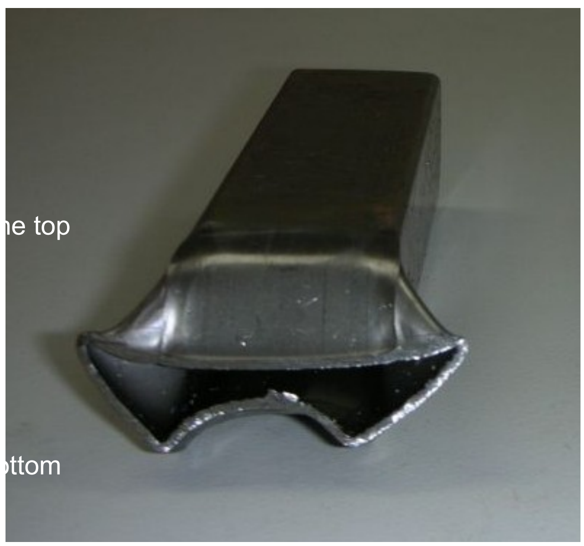

Figure 10. Cross sectional (front) view of the tube after three points bending test through experiment (outer dimension = 25mm, length = 200mm)

Comparing results with circular thin walled tubes

Both the results that are obtained from the square thin walled tubes and circular thin walled tubes are combined, compared and analyzed. It is observed that the energy absorbing capability of square thin walled tube is higher than the circular thin walled tube. During the three points bending test of square thin walled tubes, more load is required to bend the tube since the square tube is comprised of four corner edges. These corner edges are the main factors that enabled the square tube to withstand more load than the circular thin walled tubes. Bulge and wedge are formed at both the sides of the tube during the three points bending test

From the graph of load (compression) against deflection that has been plotted in Figure 2, it clearly appeared that the value of the load increases in the beginning. After attaining the peak, it drops sharply and increases again afterwards. This phenomenon shows that most of the load is used to deform the corner edges of top surface of the specimen. When the specimen suffered from plastic deformation, the load drops again. Then, the value of the load increases again since it is used to deform the corner edges of the bottom surface.

Through this observation, it can explain why most of the structural members nowadays are using square tube as their main frames. The square tubes have higher energy absorbing capabilities compared to the circular tubes. Besides, it also proves that the square tubes can withstand more than the circular tubes.

CONCLUSION

Through this research, the plastic deformation of the square thin walled tube is evaluated. The mode of deformation of the bending process for the thin wall tube is shown in the graphs. Apart from that, the total energy stored by the thin walled tubes during the three points bending test is evaluated. By referring to the experimental results, it is observed that the thin walled tubes which have shorter span length, larger outer dimension and wall thickness may have higher energy absorption capabilities. Besides, more load is needed to bend the thin walled tubes during the bending test for the tubes that have shorter span length, larger outer dimension and wall thickness.

There are some aspects that can be improved for further study of this project. During the implementation of this project, only the mild steel thin walled tubes are used. Others materials such as the alloy steel or aluminium can also be experimental this kind of research. By doing so, more results can be obtained and comparisons can be made. In addition, other powerful FEA software can be used to analyze the testing process, for instance, the ANSYS software package. Since there are some limitations in the COSMOS program, during the simulation of the virtual bending solution, the results that are obtained do not compare well with the experimental results.

Furthermore, there is a machine limitation of the Instron machine during the implementation of the experiments. The maximum specimen length that can be supported by the Instron machine is 30cm. As a result, the specimens that have the span length that longer than 30cm can not be tested by using this machine.

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