Journal of Applied Science and Agriculture, 9(18) Special 2014, Pages: 119-125

AENSI Journals

Journal of Applied Science and Agriculture

ISSN 1816-9112

Journal home page: www.aensiweb.com/JASA

Energy Absorption of Longitudinally Grooved Square Tubes Under Axial Compression

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ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
8 July 2014
Accepted 15 September 2014
Available online 17 October 2014

Keywords:
Thin walled structure
specific energy absorption (SEA)
initial peak force (IPF)

ABSTRACT

Energy absorption is one of the characteristics that must be included especially in transportation system. It is involved in dissipating kinetic energy during accidents when collision and crash. Normally, industries use thin wall structures due to its ease of fabrication, high in performance and low cost. This project investigates the energy absorption of longitudinally grooved square tubes under axial compression. This project is carried out by using nonlinear finite element analysis (FEA) software and experimental program. The grooves are fabricated on the square tubes by using milling machine. The parameters of the square tube include the width, length and thickness of the tube, length and width of the groove, number of groove and depth of the groove. These parameters are important in order to get a better result in term of increasing the specific energy absorption (SEA) and reducing the initial peak force (IPF). In this project, aluminium is chosen as the material to fabricate the square tube. Then, the result of the study is obtained by comparing many types of tube such as conventional tube, grooved tube with one groove on each sidewall and grooved tube with two grooves on two opposite wall. From this project, the specific energy absorption (SEA) can be increased up to 34.0394 % meanwhile the initial peak force (IPF) can be reduced up to 51.5951 %. As a conclusion, the introduction longitudinally grooved on square tube can be as en effective method to enhance the energy absorption characteristics of thin walled structures

To Cite This Article: Hafizi Lukman, Amir Radzi Ab. Ghani, Hafizan Hashim, S.N. Mohamed, Energy Absorption of Longitudinally Grooved Square Tubes Under Axial Compression. ***J. Appl. Sci. & Agric.**, 9(18): 119-125, 2014*

INTRODUCTION

In the manufacturing of transportation, there are many elements that must be introduced in order to control the quality of the product produced. For automotive industry especially, there are many studies and researches that have been conducted to improve the sustainability of the vehicles. Since the technology development has been enhanced during this day, there are a lot of methods have been investigated and studied by the engineers and researchers in order to improve the sustainability of vehicles. All vehicles should have stable collapse process so they can protect the occupant in the vehicles while reduce the damage of components of the vehicles. (Arameh Eyvazian, 2013) Good structures of vehicles must have high value of specific energy absorption (SEA) and low initial peak force (IPF) value. High demand for crashworthy design has lead the engineers and researchers to study the crashworthiness properties that must be included in the vehicle structure so it will meet the requirements demanded while the performance in term of safety criteria can be improved. (Arameh Eyvazian, 2013; Masoud Haghi Kashani, 2013)

In order to get a high value of specific energy absorption (SEA), many efforts have been shown by the engineers and researchers such as fabricate the structure by using thin walled structures with many modifications. (Masoud Haghi Kashani, 2013) The usage of thin walled structures to fabricate the vehicle structure can give many benefits like low weight, ease of production and low cost. It is also known as a good energy absorber which is really needed by all vehicles. Since it is a good energy absorber, the improvement also should be introduced in order to increase the safety factor of the vehicles. The value of initial peak force also must not be neglected because it can affect the deformation of the vehicle structure especially when the vehicle is subjected to impact. There are many methods that have been studied by the engineers and researchers to improve the design of thin walled structure. One of the methods is by the introduction of grooves at the thin walled structure. (Hosseinipour, 2002) It seems to be a great way to increase the value of specific energy absorption (SEA) of thin walled structure. Besides that, there are also other methods that can be applied to enhance the value of specific energy absorption (SEA) and peak force which are by the introduction of

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corrugation, design the thin walled structure with origami pattern, install a buckling initiator at the impact end, make the pattern windows and design a multi-cell thin-walled tubes. (Arameh Eyvazian, 2013; Song, 2012; AlaviNi, 2013; Song, 2012) To find the best parameter of the grooved tubes, investigation can be performed by many methods such as by experimental program and simulation analysis.

Poor energy absorption of a vehicle can lead to fatality of occupant. It also can damages the main components of a vehicle. Recently, all vehicles especially cars have increased their speed due to the technology development. The possibility of car crashes and collisions also will increase if the speed gets increased. This study is very important for the development of many industries especially to which is mainly involved in automotive sector. Since it is applied as the structure of the vehicle, it can help to reduce the fatalities that always happen during accidents. Besides that, the main component of the vehicle also can be protected from severe damage. This study is just not can increase the crashworthiness behavior of the vehicle, but also can increase the standard of quality in automotive industry. This study basically is to investigate the energy absorption characteristics of longitudinally grooved square tubes under axial compression by experimental program and numerical simulation analysis and to determine the specific energy absorption (SEA) and initial peak force (IPF) of the square tubes. In this project, the longitudinally grooved square tubes will be tested by experimentally and be analyzed by using finite element analysis software which is FEA. Before get analyzed, the fabrications of longitudinally grooved square tubes have to be done. The characteristics of the square tubes will be studied based on simulation by FEA and through experimental program. The result will be compared between experimentally and numerically simulation.

Methodology:

1.1 Material Selection:

Aluminium alloy was selected as the material to fabricate the square tubes. Aluminium is a material which has the properties that are desired by many manufacturing companies such as high in crashworthiness performance, cheap cost and low in weight. The materials can be obtained from the workshop of Faculty of Mechanical Engineering, UiTM Shah Alam.

Table 1: Physical Properties of Aluminium.

Young's Modulus (GPa)	65	
Poisson's Ratio	0.33	
Density (kg/m)	2700	
Yield Stress (MPa)	180	220
Plastic Strain	0	0.1

2.2 Fabrication of Square Tubes:

The first step to fabricate the square tubes was to choose the right shape of the thin walled structure. Then, it will proceed to the four major steps which include measuring and marking, cutting, milling and finishing.

Table 2: Design Dimension

Design	1	2	3	4	5
Length, L (mm)	250	250	250	250	250
Thickness, T (mm)	2	2	2	2	2
Width, W (mm)	50	50	50	50	50
Height ,H (mm)	50	50	50	50	50
Length of groove, B (mm)	0	230	230	230	230
Width of groove, G (mm)	0	24	30	40	40
Depth of groove, D (mm)	0	1	1	1	1
Number of groove, N	0	4	4	2	4

2.3 Experimental Program:

In the experimental program, a machine named INSTRON 3382 had been used. For this project, to study the crashworthiness behavior of the specimen, only compression testing was needed to be performed. It was also called as quasi static testing since the movement of compression testing was in slow motion. To conduct this testing, there were several data that need to be considered such as the geometry of the specimen and the speed of compression testing.

After that, set up the specimen that was going to be tested. Put the specimen vertically on the middle of the jig of compression testing. Then, lower the upper jig slowly but do not touch the upper surface of the specimen. The gap between the upper jig and the upper surface of the specimen should be around 1 mm. Next, set the value for both compression load and compression extension as 0 before run the testing. Lastly, run the compression testing. The time taken to complete for on testing was about 36 minutes since the speed of the compression was 5 mm/min. The graph of compression load versus compression extension will be shown on the screen of the computer. The data obtained will be used to investigate the energy absorption characteristics of the square tubes that had been prepared.

Table 3: Data To Be Computed.

Geometry	Rectangular
Length	250 mm
Thickness	2 mm
Height	50 mm
Width	50 mm
Compression speed	5 mm/min
Extension of compression	180 min

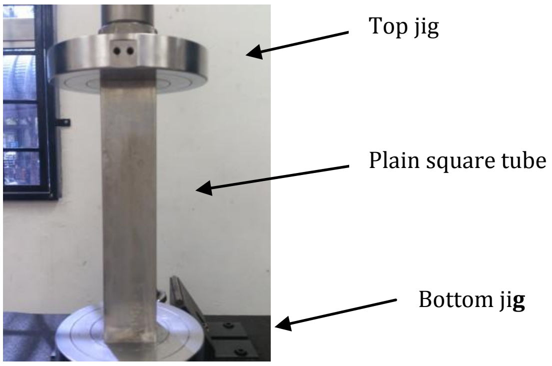

Fig. 1: Specimen placed between jigs.

2.4 Numerical Simulation Analysis:

For this project, FEA had been used to investigate the energy absorption characteristics of the square tubes. The process included from the drawing of the specimen in the software until the running of simulation. To run the numerical simulation analysis, it was a must to ensure that all steps in module column have been completely performed. There are 8 modules that should be completed in order to produce accurate results which include part, property, assembly, step interaction, load, mesh and job. Square tube was designed as 3D deformable extrusion shell meanwhile for the both jigs, they were designed as 3D discrete rigid planar shell. All the designs must be in meter and then, the properties of the square tubes were included. Refer Table 1 for the properties of aluminium alloy. For grooved square tubes, there is a must to assign the section in which the thickness of grooves is 1 mm meanwhile for the other part is 2 mm.

Then, set the time period as 0.045 which is equal to 180 mm as the maximum compression extension in experimental program. Next set the contact type as tangential behavior and the friction formulation as penalty. The coefficient of friction in this simulation analysis is 0.25. The meshing size of square tube has to be small which is 0.002, so the data needed will interpreted and simulated accurately. However, for both jigs, the meshing size was bigger which 0.05 is since they are only used as the holder and the hammer of the simulation analysis of compression test. Lastly, in the job module, run the simulation analysis by creating a job.

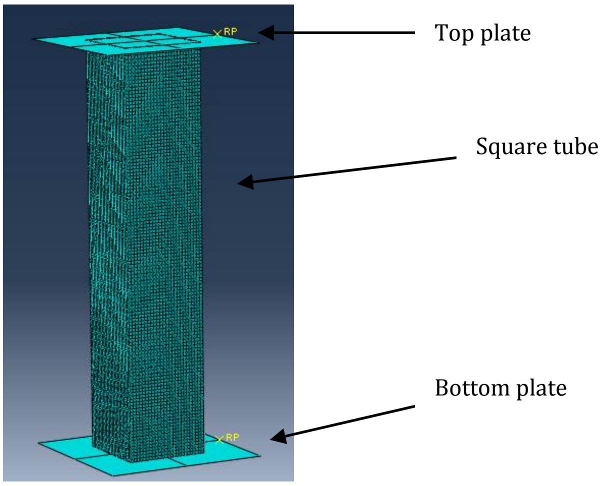

Fig. 2: Mesh Assembly of Square Tube.

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2.5 Comparison Between Two Results:

After obtained the results for both of the experimental and simulation analysis, compared the results to determine the correlation between them. The efficiency will be determined by this comparison.

RESULTS AND DISCUSSION

3.1 Axial Compression Of The Square Tubes:

Square tubes were analyzed by using experimental program and numerical simulation analysis in term to investigate the energy absorption characteristics which include specific energy absorption (SEA) and initial peak force (IPF). Each of the design showed different results in term of specific energy absorption (SEA) and initial peak force (IPF). Design 1 showed the highest IPF and the IPF decreased when the width of grooves increased. But for design 3, the IPF was higher than the IPF of design 2 even though the width of grooves was larger. However, in simulation analysis, it showed that the IPF was gradually decreased as the width of grooves increased. Square tube with 2 grooves which was design 4 seemed to be inefficient compared to the square tube with 4 grooves which was design 5 although the width of grooves was same. The value of IPF of design 4 was lower as compared to the design 5. SEA for design 5 did not follow the pattern of increment because after calculated, the SEA was the lowest among the designs although the width of grooves was the highest. It may be due to the errors and will be discussed in the next sub chapter. The efficiency in term of experiment was also a bit high because the errors that had been identified after compared to the simulation analysis were very little. For example, design 1 showed only 0.0455 % of error after compared between experimental program and simulation analysis. Design 5 experienced the highest error which was 17.4493 % meanwhile, for design 2, 3 and 4 the errors were only 0.2819 %, 17.2562 % and 1.5251 % respectively. The highest decrement of IPF were determined in design 5 which were 51.5951 % and 41.3901 for both experiment and simulation analysis. Meanwhile, for SEA, the highest increment was 34.0394 % when the width of grooves was 30 mm which was design 3.

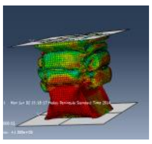
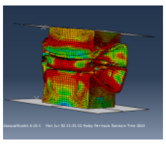
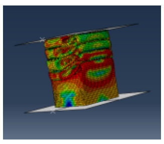
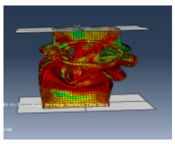
Table 3: Energy Absorption Characteristics.

Design	1	2	3	4	5
Experiment					
IPF (N)	73892.266	55224.442	59080.333	58729.011	35767.487
Decrement (%)	0	25.2636	20.0453	20.5208	51.5951
Simulation					
IPF (N)	73925.9	55380.6	50385.7	57846.8	43327.9
Decrement (%)	0	25.0863	31.8429	21.7503	41.3901
Design	1	2	3	4	5
SEA (J/kg)	15225.6944	20335.7143	20408.4188	17301.0486	16501.8079
Increment (%)	0	33.5619	34.0394	13.6306	8.3819

3.2 Deformation Modes Of The Square Tubes:

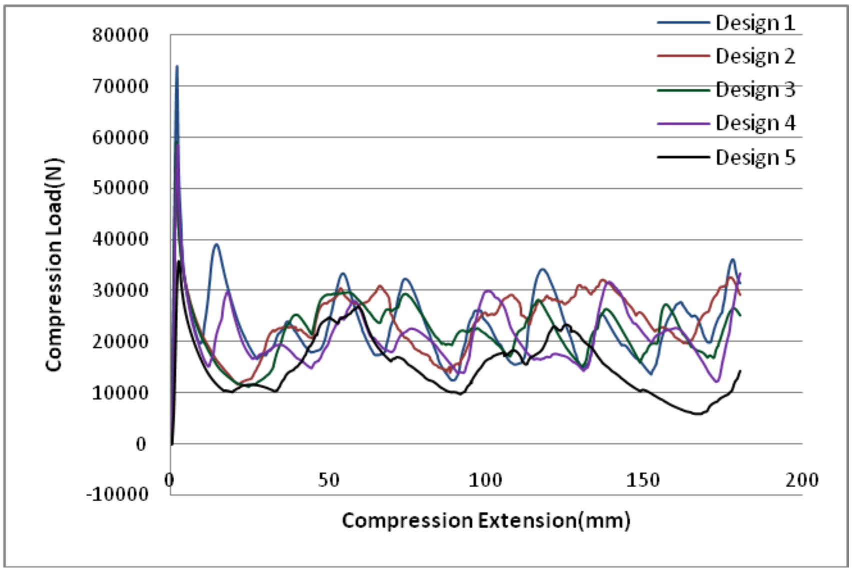
Deformation modes also play an important role to determine the energy absorption characteristics of the square tube.

Table 4: Last Results Of Deformation Modes.

Design	1	3	4	5
Experiment				
Simulation Analysis				

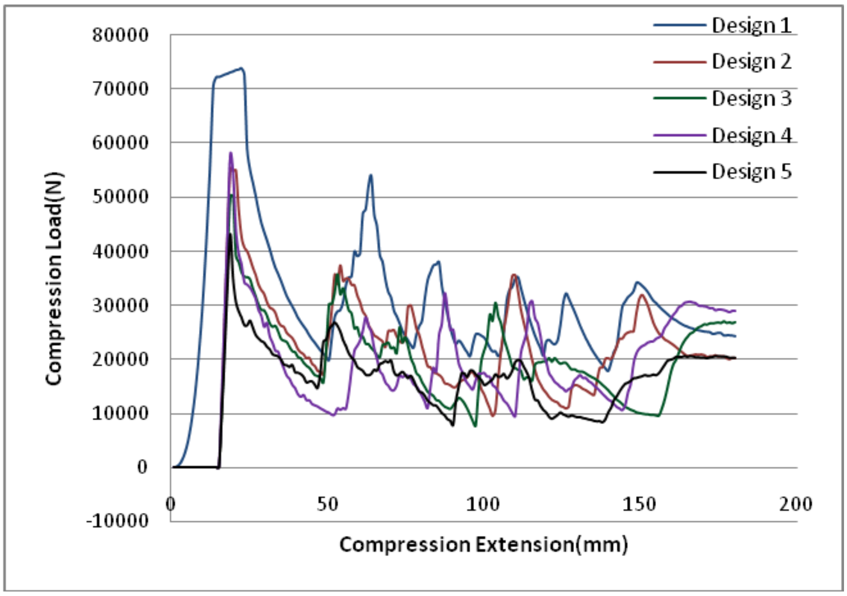
As observed, deformation mode of design 1 was concertina since the folding was regular from the starting point until the last deformation. The deformation of square tubes started at the part which had low stiffness. Although the starting points of deformation for design 1 were different, the results obtained still almost the same between experiment and simulation analysis. However, for design 3, 4 and 5, the deformation mode was not regular as design 1 and some of the designs experienced mixture mode which was concertina and diamond mode. The deformation mode change from concertina to diamond mode as the width of grooves increased. As can been seen, design 5 experienced a diamond deformation mode because the width of the grooves were larger than design 3. The red color in the simulation showed the high stress on the square tubes and it always appeared on the folding and the bottom part of square tubes. Based on the simulation analysis that has been performed, the stress was getting higher as the square tube started to compress. The stress was high at the bottom part of the square tube since it needed to react with the force subjected to the square tube. Although the deformation mode for grooved square tubes were not so smooth compared to the plain square tube, the specific energy absorption (SEA) had been increased and showed a decrement in initial peak force (IPF).

3.3 Pattern of Results:
Experiment:



(a)

Simulation Analysis:



(b)

Fig. 1: Axial Compression Load-Extension Curves: (a) experimental and (b) simulation analysis

Both of the graphs showed a good correlation of pattern since the square tubes get modified especially in term of getting increased the width of the grooves. For the experiment, the fluctuations of graph for design 1 is more regular compare with the others because reaction forces exerted on the square tube did not distributed to the other area since it was just only plain. Meanwhile, the graphs plotted in numerical simulation analysis were in more sharp fluctuations because the data interpretations during the axial compression were detail compare with experiments. Both of the graphs showed that there was no second peak force experienced after the initial one. The graphs started to decrease and fluctuate based on the force exerted on the square tubes. According to the graphs obtained, SEA can be identified. Graphs for design 1 both in experiment and simulation analysis showed the highest internal energy because the areas under the graphs were largest. However, after calculated, the values of SEA were not so high compared to graphs of grooved square tubes. The starting points for the IPF also were different for both graphs of experiment and simulation analysis. It was because the way in term of carried out the testing was very different.

3.4 Factors Affecting The Errors:

One of the factors that can contribute to these problems is material factor. The material that had been received from the supplier did not have accurate dimension. It was because the thickness of the square tubes was different for each sidewall. There were 1.7 mm and 2 mm of thickness for the sidewalls. Secondly, the factor that caused to the problems was fabrication factor. It may be called as human error. There were certain parts of surfaces of the square tube that being fabricated during milling process which were uneven such as the upper and bottom part. These factors can contribute to the irregular deformation mode of the square tube while subjected to compression testing. Lastly, the factor that had been identified which can cause to these problems was there were certain surfaces which did not completely flattened by using file and sand paper.

Conclusion:

Energy absorption characteristics in term of initial peak force and specific energy absorption (SEA) of longitudinally grooved square tubes were investigated and identified by using experimental program and numerical simulation analysis. To run the experiment, the square tubes were fabricated and then the grooves were introduced by performing milling process. Grooved square tubes were tested and simulated and after that they had been compared with the normal square tube which was design 1.

Introduction of grooves to the square tube had affected the energy absorption characteristics when subjected to the axial compression whether in experiment or simulation analysis. Initial peak force and specific energy absorption (SEA) had shown an enhancement in term of decrement and increment. The value of initial peak force get more decreases while the specific energy absorption (SEA) get more increases when the width of grooves were increased. By referring to the results obtained, it had shown that the square tube with two grooves was not efficient as square tubes with four grooves in term of energy absorption characteristics. Besides that, the deformation modes of grooved square tubes were more irregular compare with the plain square tube although the results obtained were more efficient. This project had successfully achieved its objectives in term of investigation of longitudinally grooved square tubes under axial compression by experimental program and numerical simulation analysis and determines the specific energy absorption (SEA) and initial peak force.

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