UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EXPERIMENTAL INVESTIGATION ON ENERGY ABSORPTION CAPACITY OF MILD STEEL CONE SUBJECTED TO AXIAL CRUSHING

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology (Maintenance Technology) (Hons.)

By

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirement for the Degree of Engineering Technology (Maintenance Technology) with Honours. The member of supervisory is as follow:

……………………………………..

(Project Supervisor)

DR. OLAWALE IFAYEFUNMI

ABSTRAK

Struktur kon digunakan secara meluas dalam industri kejuruteraan seperti automotif, minyak dan gas, penerbangan dan lain-lain. Struktur kon juga mampu menyelamatkan penghuni kenderaan dari perlanggaran paksi dengan menukarkan tenaga kinetik kemalangan ke dalam satu lagi bentuk tenaga untuk mengurangkan kesan kemalangan ke arah penghuninya. Projek ini membentangkan kajian mengenai cengkerang kon di bawah mampatan paksi menegak melalui eksperimen untuk mengenalpasti kapasiti penyerapan tenaga. Cengkerang kon keluli telah dihasilkan dengan tiga diameter saiz yang berbeza yang 80 mm, 100 mm dan 120 mm dan ketinggian spesimen adalah 100 mm. Kelajuan mampatan yang digunakan dalam eksperimen ini adalah 1 mm/min, 10 mm/min dan 20 mm/min. Seluruh spesimen akan diuji di bawah beban paksi menegak dengan menggunakan mesin INSTRON Universal Testing Machine. Eksperimen ini adalah untuk mengenal pasti kesan kelajuan dan diameter keatas kapasiti penyerapan tenaga. Hasilnya, tenaga serapan akan meningkat jika kelajuan dan diameter meningkat.

ABSTRACT

Conical structure is widely used in engineering industry such as automotive, oil and gas, aeronautical etc. Cone structure also saves the occupant of vehicles from axial collision by converting the kinetic energy of crash into another form of energy to minimize the impact of accident toward the occupants. This work presents a study on conical shell under axial crushing through experimental approach to identify the energy absorption capacity. Mild steel cone shell was fabricated with three different diameters that are 80 mm, 100 mm and 120 mm and all specimen height is 100 mm. The crosshead speed used in this experiment is 1 mm/min, 10 mm/min and 20 mm/min. The entire specimen will be tested under axial loading using INSTRON Universal Testing Machine. This experiment is to investigate the effect of crosshead speed and top diameter on energy absorption. It is found that the energy absorption will increase as the crosshead speed and diameter increase.

DEDICATION

This report was dedicated to my beloved family especially my parents and siblings. Not to forget my fellow classmates, housemates, supervisor and lecturers involved.

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FPSO	-	Floating production storage and offloading
CFRP	-	Carbon Fiber Reinforced Polymer
EA	-	Energy Absorption
SEA	-	Specific Energy Absorption
FEA	-	Finite Element Analysis
Hc/Dm	-	Height to mean diameter ratio
CAD	-	Computer Aided Design
Solidworks	-	CAD software
Flowcut	-	Waterjet cutting software
.DXF	-	Drawing Exchange Format
WD-40	-	Antirust penetrating oil
MIG	-	Metal Inert Gas Welding
t_{max}	-	Maximum thickness
t_{min}	-	Minimum thickness
t_{avg}	-	Average thickness
E	-	Young modulus
σ_Y	-	Yield Stress
UTS	-	Ultimate Tensile Stress
Kg	-	Kilogram
kN	-	Kilonewton
kJ	-	Kilojoule
SOP	-	Standard Operational Procedure
ABAQUS	-	Finite-element Computer Code

CHAPTER 1

INTRODUCTION

1.1 Background

In recent decades, the study on engineering structure is applicable in many engineering field including civil, chemical, mechanical, automotive, marine and aerospace. Shell structure had been one of the engineering structures that are common in engineering studies. A shell is a type of structural element and a three dimensional solid with small thickness which is described by its geometry. Shell structures are used in many engineering application such as offshore and onshore pipelines, tanks, aircraft fuselages, boat hulls, and the roofs of buildings. The common shell structures that often had been studied are conical, cylindrical and torisphere shell. In offshore and oil industries, those shells can be found in applications such as pressure vessels, onshore and offshore pipelines, offshore platforms legs, storage tankers, floating production storage and offloading (FPSO) and flow reducer in pipelines (Ifayefunmi, 2013). Conical shells are frequently used as transition elements between cylinders of different diameters or end closures and sometimes as stand-alone components in various engineering applications such as tanks and pressure vessels, missiles and spacecraft, submarines, nuclear reactors, jet nozzles, space vehicles, nuclear power plants and such other civil, chemical, mechanical, marine and aerospace engineering structures (Sofiyev, 2011; Duc et al., 2017). Conical shells are important structural elements for many engineering fields, and their loss of stability by buckling is one of the most important and crucial failure phenomena (Jabareen and Sheinman, 2006). Recently, more study on the energy absorption of shell structure was conducted because the application of these structures had been widely used in engineering sector. Nowadays, conical shell structures are also gaining popularity in the engineering industry in term of application as energy absorbers. Conical shell with crashworthiness characteristic is one of the important factors in designing the transportation means such as automobiles, rail cars and aeroplanes. This is because it concerns to vehicle structural integrity and its ability to absorb energy as well as providing a protective shell around the occupants (Alkateb, 2004).

1.2 Problem Statement

Various studies on energy absorption using tubular structure have been done by previous researcher to minimize the risk towards passenger by dissipating the kinetic energy of collision by plastic deformation of the structure. Tubular structure is preferred because of its easy manufacturing (Hamouda, 2007; Niknejad et al., 2012). Among different shape of tubular structure, researcher had been investigating which shape can absorb more energy, which answer to suitable direction of energy absorber device, dimension, position and optimal angle to deform the structure to dissipate collision energy. Thin walled structure such as cone is used in automotive sector due to the advantages of light weight and excellent energy absorption characteristics. For instance, it is used as transition connector between cylinders with difference diameter in car chassis, still the energy absorption structure requires a wide range of studies and additional analysis to achieve the desired purpose. Thus, this study attempts to find out the effect of different top diameters and different crosshead speeds towards the energy absorption capacity to use it as an energy absorption device during collision to keep occupant survive during crash.

1.3 Objective

1. To manufacture mild steel cones with different top diameter.

2. To study the effect of different top diameter and crosshead speed on energy absorption capacity of mild steel cone under axial compression.

1.4 Scope

The scope of the study includes manufacturing of mild steel cones with different top diameter. Next, studying the effect of different top diameter and crosshead speed on energy absorption capability of mild steel cone under axial compression. This research is focusing on geometry of cone and crosshead speed. All factors that will be affecting the energy absorption capacity on the conical shell structure will be studied. Next, the chosen material for the conical structure is mild steel. The thickness of mild steel plate used for all of the specimens is 1 mm. The tensile strength of the mild steel plate will be obtained from tensile testing that will be conducted on six coupons from the mild steel plate; three coupons will be cut out in axial direction and three more in the horizontal direction. This research involved eighteen specimens which all of it will be subjected to axial compression test using INSTRON Universal Testing Machine. The top diameter of the cone varies from 80 mm, 100 mm and 120 mm while for the bottom diameter is 140 mm for all specimens. 6 cones for each top diameter was fabricated resulting in a total of 18 specimens. The specimens were labeled as A1 - A6, B1 - B6, C1, - C6 for 80 mm, 100 mm and 120 mm diameter cones respectively. Three (3) different crosshead compression rates will be used to test the cones which are 1 mm/min, 10 mm/min and 20 mm/min.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction into energy absorption of conical tube

In the past decades, there has been an increasing interest towards the investigation of thin-walled metallic structures i.e. cylindrical, conical, spherical, rectangular that area capable in absorbing great amount of energy (Smith et al., 2016).

Energy absorption is the ability of tubular structure to absorb or dissipate the kinetic energy of crush to protect the occupant of vehicle due to the plastic deformation of tubular structure (Niknejad and Rahmani, 2014).

The function of an energy absorber is to absorb kinetic energy upon impact and dissipate it in other form of energy, ideally in a reversible manner. Non-reversible (inelastic) energy can exist in various forms such as plastic deformation, viscous energy and friction or fracture energy (Olabi et al., 2007).

Metallic thin-walled structures are widely employed as energy absorption elements, because of their high strength, excellent load-carrying capacity and low cost (Lu and Yu, 2003). Thin-walled metal tubes are also commonly used as energy absorption components due to their high manufacturability (Airoldi and Jenszen, 2005).

In recent years, due to the advantages of light weight and excellent energy absorption characteristics, thin-walled structures have been widely used in crashworthiness applications, such as automotive industry, to protect passengers from severe injuries (Liu et al., 2016) and (Chen et al., 2001).

The ability to absorb impact energy and be survivable for the occupant is called the ‘‘crashworthiness’’ of the structure. Crashworthiness is concerned with the absorption of energy through controlled failure mechanisms and modes that enable the maintenance of a gradual decay in the load profile during absorption (Alkbir et al., 2014).

Crashworthiness studies have attracted much attention, particularly to evaluate the deformation behaviour and to determine the energy absorbing efficiency of various thin walled components of different composites. In automotive engineering, crashworthiness is defined as the capability of a vehicle to protect its occupants from serious injury or death in case of accidents of a given proportion (Ghasemnejad et al., 2009).

As energy absorbers, crashworthy components have been designed in various geometrical shapes i.e. cylindrical tubes, square tubes, cones, conical frusta, square frusta and grooved or un-grooved pyramids (Johnson et al., 1977).

2.2 Effect of material type on energy absorption of cone

Lackman et al. (1961), has presented early experiments on elastic buckling of conical shell subjected to axial compression. Two sets of nickel specimen having cone angle of 20 and 40 degree, and having constant wall thickness, were tested using Olsen Universal testing machine.

Most of the reported works in the literature on such tubes have used mild steel as the basic material for understanding the energy absorption efficiency. However, in the light of efficient fuel economic, aluminium as a lightweight material is gaining popularity (Deb et al., 2004).

Hsu and Jones (2004), investigated the response of thin walled circular stainless steel, mild steel and aluminium alloy tubes subjected to quasi-static and dynamic axial loading.

It was found that stainless steel tube absorb the most energy per unit volume however its dimensionless energy absorbing efficiency was the lowest of the three material. The aluminium alloy was found to be most efficient but absorbing the least energy per unit volume.

Dayong et al. (2016), researched on collapse characteristic and energy absorption of glass cloth/epoxy composite tube with different fiber orientation. The energy absorption capability could be improved by selecting proper fiber orientation and found that energy absorption capability in impact crushing test to be slightly lower than in quasi static crushing test.

Reid (1993), had provided insight of various modes of deformation that can be achieved from axial compression of ductile material such as mild steel. Discussion was made on the axial splitting, inertia and buckling modes of deformation in which attention was given to the gross plastic deformation of various specimens. Also, studies conducted on thin walled tubes filled with polyurethane foam which can increase the specific energy absorption capacity such a devise without compromising it weight.

McGregor et al. (2016), experimented the behaviour of braided Carbon Fiber Reinforced Polymer (CFRP) tubes subjected to quasi-static and dynamic axial crushing. The rate of loading greatly influenced the crushing behaviour. The degradation of energy absorbing capability of the tubes at dynamic rates was attributed to a combined effect of reduced interfacial strength, increased brittleness of the polymer matrix, and reduced coefficient of friction values at the higher rates.

Liu et al. (2017), recently investigated energy absorption in CFRP and aluminium. The test results showed that the multi-cell CFRP square tubes had much better performance in energy absorption capability compared to the Aluminium tubes. It was interesting to note that the double-cell CFRP tube exhibited the highest Specific Energy Absorption (SEA) value among the CFRP specimens, whereas the triple-cell Aluminium tubes exhibited the highest SEA value among the Aluminium specimens, which were attributable to the different interaction occurred in the connecting region.

A studied by Yang et al. (2016), using brass tubes with and without origami patterns under axial crushing. The results showed that, under axial crushing, tubes with pre-folded origami patterns would significantly reduce the initial peak force while increase (or maintain) the specific energy absorption as compared to circular tubes, provided that the tube thickness was sufficiently small.

2.3 Effect of triggering mechanism on energy absorption of cone

Among various deformation modes, axial splitting/curling is known as an efficient energy absorption method due to its large stroke to length ratio. Compared with axial buckling and in version mode with no cracking, the operating load for splitting tube was rather lower. However, from the resulting large stroke in splitting condition, the total energy absorbed could often be high as in the other methods. Furthermore, crack propagation mechanism helps the load displacement diagram to be steadier that shows it is important factor in energy absorber designing (Ronzegar and Karimi, 2016).

Stronge et al. (1986), investigated splitting behavior of square tube with a flat die experimentally. Three main energy dissipation mechanism were reported in this process, they are:(i) the learning energy related to splitting and crack propagation, (ii) the plastic deformation related to the plastic bending and stretching of curls and (iii) the function energy between the tube and die. Lee et al. (1999), has studied that trigger mechanism that are located at the pitch length of the folding wave enhance the energy absorption capability of the tube.

Niknejad et al. (2012), found that the folding process of the tubes could be controlled by the introduction of grooves with different distance and hence achieved the desired load uniformity. Similar finding were obtained by separate study by Zhang and Huh (2009), investigating longitudinally groove square tubes. Zhang et al. (2009), also have designed a new trigger mechanism attached to the structure and the novel design has proven to improve the energy absorption and lower the initial peak force. Trigger mechanism in the