UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INVESTIGATION OF ENERGY ABSORPTION CAPACITY OF MILD STEEL CYLINDER SUBJECTED TO LATERAL CRUSHING

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

By

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DECLARATION

I hereby declared this report entitled "Investigation of Energy Absorption Capacity of Mild Steel Cylinder Subjected to Lateral Crushing" is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree in Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Satu bentuk struktur akan sentiasa mempunyai sifat mekanikal sendiri sebagai keupayaan untuk menahan sejumlah kekuatan sebelum kegagalan atau runtuh. Beban keruntuhan, kN dan jumlah penyerapan tenaga akan diambil kira untuk kajian ini. Kajian ini berkaitan dengan menyiasat kesan saiz struktur dan kelajuan menghancurkan ke arah kenderaan yang melibatkan kemalangan kereta. Terdapat 18 spesimen yang akan diuji yang terdiri daripada 6 spesimen dengan diameter 80 mm, 6 spesimen lain dengan diameter 100 mm dan 6 spesimen yang tinggal dengan diameter 120 mm. Spesimen-spesimen ini akan dikenakan pemuatan sisi menggunakan kelajuan menghancurkan yang berbeza iaitu 1 mm / min, 10 mm / min dan 20 mm / min. Kerja eksperimen dan berangka telah dijalankan untuk kajian ini untuk membandingkan hasil akhir. Keputusan teori penyerapan tenaga dan beban runtuh menunjukkan persetujuan rapat dengan hasil percubaan. Keputusan berangka didapati menyimpang untuk nilai beban runtuh, tetapi agak sama dengan ubah bentuk struktur dengan hasil eksperimen. Data yang diperolehi dalam disertasi ini diharapkan berfungsi dalam reka bentuk struktur pada masa akan datang.

ABSTRACT

A form of structure will always have it's own mechanical property as the ability to withstand a particular amount of force before failure or collapsing. The collapse load, kN and total energy absorption is to be taken into consideration for this study. This study is to investigate the energy absorption capacity of mild steel cylinder subjected to lateral crushing. There are total of 18 specimens to be tested which consists of 6 specimens with 80 mm diameter, another 6 specimens with 100 mm diameter and the remaining 6 specimens with 120 mm diameter. These specimens are to be subjected to lateral loading using different crushing speed which are 1 mm/min, 10 mm/min and 20 mm/min. Experimental and numerical work been conducted for this study to compare the final results. Theoretical results of energy absorption and collapse load showed a close agreement with the experimental results. Numerical results were found deviating for the collapse load value, but quite similar for the deformation of structure with the experimental results. Data obtained in this dissertation hoped serve in the design of structure in future.

DEDICATION

I would love to dedicate this report to my beloved parents. Thank you for everything and I hope that this achievement will fulfil their dreams and hope that you had for me when you chose to sacrifice everything just to provide me the best education you can possibly could.

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As the letter A is the first of all letters, so the eternal God is the first in this world. Praise to God for his blessings and divine guidance that this project was successfully completed.

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LIST OF ABBREVIATIONS

Al	-	Aluminium
EA	-	Energy Absorption
ED	-	Empty Double Tube
FD	-	Foam-Filled Tube
FE	-	Finite Element
FGF	-	Functionally Graded Foam
SEA	-	Specific Energy Absorption

CHAPTER 1

INTRODUCTION

1.0 Background

Cylindrical shell structures are widely used in the fields of civil and mechanical engineering., The use of shell structures in covering large span roofs, tall silos, large dams, pressure vessels, marine structures, airplane and space craft are just few examples. To successfully carry out buckling analysis of cylindrical shell structure, it is important to understand the factors influencing buckling and the energy absorption on the cylindrical structure. Energy absorption of a particular structure are affected by several factors such as type of material, thickness, speed of crush and the cross-sectional geometry. Few studies revealed that the sensitivity of the buckling behaviour of both plates and shells to the presence of defects highly depends on the loading condition. There are several type of loading has been done according to the specified purpose such as quasi-static loading, impact loading, and stress testing. These will obviously provide different results for different type of loading because the contact condition is not the same. The energy absorption of this specimens can be obtained from the graph of load (kN) versus extension (mm). From the graph, we could find the collapse load and also total energy absorption of the mild steel cylinder. The buckling behaviour of cylindrical shells under torsional loading absorbs less energy than that of a similar laterally compressed cylindrical shell (Estekanchi et. al, 2002). This project aims to investigate the energy absorption capacity of mild steel cylinder subjected to lateral crushing under quasi-static loading. The materials of cylinder are made from mild steel. There are total of 18 specimens to be tested which consists of 6 specimens with 80 mm diameter, another 6 specimens with 100 mm diameter and the remaining 6 specimens with 120 mm diameter. These specimens are to be subjected to lateral loading using different crushing speed which are 1 mm/min, 10 mm/min and 20 mm/min.

1.1 Problem Statement

Nowadays, increase in the number of transportation vehicles has resulted in a greater number of road accidents. Therefore, the crashing zone of a vehicle and the effect of crashing speed that contributes to the total energy absorption is the related study of this experiment. Collapse load is also to be identified in this study which means the ability of material to withstand it's strength and the point it losses them will be discovered and recorded. Finding of collapse load helps to know the material behaviour and the position of where it fails exactly Besides that, higher cost and more time is consumed to carry out a real test and to obtain the result. Numerical method is to be used for this study to save cost and time as mentioned earlier. This experiment will validate the results better since there will be comparison between numerical analysis and experimental analysis. This research focus on the energy absorption capacity of mild steel cylinder with different diameter subjected to lateral crushing.

1.2 Objective

This study will highlight on the following objectives:

1. To design and manufacture mild steel cylinder with different diameters.
2. To study the energy absorption capacity of 1 mm mild steel cylinders subjected to lateral crushing using different crushing speeds.
3. To analyse by comparing the theoretical, numerical and experimental data.

1.3 Scope

This is an experimental and numerical research work to determine effect of crushing speed on energy absorption of cylinders with different diameter subjected to lateral compression. The material used for the cylindrical structure is mild steel. This experiment and numerical research will be conducted by testing 18 specimens. The entire specimen are formed from mild steel plate and welded together. There are total of 18 specimens to be tested which consists of 6 specimens with 80 mm diameter, another 6 specimens with 100 mm diameter and the remaining 6 specimens with 120 mm diameter. This is to ensure that there is repeatability of experimental data. The entire specimen will undergo lateral compression test by using the Instron machine. The effect on the energy absorption of cylinder with various diameter subjected to lateral loading of crosshead speed will be analysed, and the result will be compared with the theoretical value.

CHAPTER 2

LITERATURE REVIEW

2.0 Background

Metallic cylindrical shells are common structural elements. They can be used as the dummy model of kinetic crash energy, in automobile and train structures. The energy absorption process of metallic shells subjected to lateral loading is based on the formation of plastic folds. In order to optimize the energy absorption behaviour of such metallic cylindrical shell structures, the influence of different induced folding modes is investigated with the help of experiments as well as numerical finite element (FE) calculations and a simplified analytical model (Miladi and Razzaghi, 2014). The load-deformation characteristics and the energy absorption capability resulting from different diameter and crushing speed are compared. All the specimens is tested based on the appropriate crushing speed. The experimental results are compared with the numerical results (Jiang et. al, 2006). In addition a simplified analytical model is developed, which is based on a detailed geometric idealisation of the folding process with stationary and moving plastic folds. It allows to predict the average crush force. The results of the analytical model confirm the tendencies found in experiments and FE simulations (Tay et. al, 2014).

2.1 Introduction on Energy Absorption of Cylindrical tube

Energy absorber is to absorb kinetic energy upon impact and dissipate it in some other form of energy, ideally in an irreversible manner. Non-recoverable (inelastic) energy can exist in various forms such as plastic deformation, viscous energy and friction or fracture energy (Roberts, 2014). Circular or square sectioned tubes are one of the most commonly used structural elements due to their prevalent occurrence and easy of manufacturability (Rajak et. al, 2015). Circular tubes for example, can dissipate elastic and inelastic energy through different modes of deformation, resulting in different energy absorption responses. Such methods of deformation include lateral compression, lateral indentation, axial crushing, tube splitting and tube inversion which is outlined in the following sections. It is important to study their energy absorption characteristics and mean crushing loads so as to determine their applicability to practical energy absorption situations (Khalili et. al, 2015). The situations are such as energy absorbers in the aircraft, automobile and spacecraft industries, nuclear reactors, steel silos and tanks for the safe transportation of solids and liquids (Olabi et. al, 2007). The dynamic responses and the energy absorption characteristics of different configurations circular tubes i.e. empty double tube (ED), foam-filled double tube (FD) and foam-filled single tube (FS) were explored. The parameters that took into consideration are geometry parameters (such as tube length, tube outer diameter, tube wall thickness), material parameter (foam density) and loading parameters (load angle) are used to completely understand and quantify the deformation mode and the energy absorption behaviour of tubes (Niknejad et. al, 2015). The numerical simulations were validated using the experiment and the theoretical solutions taken from appropriate literatures in studying the effect of parameters for axial progressive collapse mode and global bending collapse mode (Djamaluddin et. al, 2015). The use of lightweight aluminium (Al) alloy foams is rapidly gaining popularity in automotive sector, aerospace, etc., which require crash energy absorption, weight reduction and sound damping capacity (Rajak et. al, 2016). With the development of complex thermo mechanical experiments, full-field displacement and strain measurements are often needed. In recent years, the development of robust, fast and affordable tools for full-field kinematic measurements prompts more and more experimentalists to resort to such techniques. The ductile fracture is in general governed by effective strain and stress triaxiality. Low triaxiality results in shear dimple rupture whereas high triaxiality results in void coalescence (Gustaffson et. al, 2016). The capability of an energy absorber in dissipating the impact energy depends on the extent of plastic deformation behavior of the metallic structures. Stroke length of energy absorber should be sufficient to absorb a large amount of impact energy. Long stroke and constant reactive force causes a higher absorbed energy. It is due to the fact that energy absorbed is equal to its magnitude times the displacement experienced along the acting line of the force. One of the main aims of energy absorber is to minimize the damages or injuries to the protected object. Hence, the kinetic energy should be dissipated with a longer time. The longer time that force prevails, the gentler is the arresting force required and the smaller is the injury sustained. The device should be designed to deform with good stability and repeatability, so as to ensure the reliability of the structure in its service. Phenomenon like catastrophic failure and Euler buckling should be avoided as these collapse modes affect the energy absorption efficiency of the structure significantly. Light weight property should be considered into the material selection for a quality energy absorber. It is because an increase in weight implies more consumption of fuel and more pollution of the environment. Recently, space frame design of car body using aluminium alloy demonstrated the commitment of automobile maker to design a quality energy absorber by not neglecting the environmental issues. Energy absorbers are usually disposable as it will only be used for once to deform and will be discarded. Metallic tubes are frequently used as energy absorbing devices. They deform plastically in several different modes such as inversion and folding. Each mode has an associated energy dissipation capacity. The tubular elements in energy absorbers can be confined in various ways so that when an impact does occur, they deform axially, laterally or in some combination. In the last few decades, several investigations have been carried out to study the response of metallic tubes for their use as energy absorbing elements. Earlier studies conducted on lateral collapse of round tubes differ in the mechanisms assumed for the analysis (Hao et. al, 2009).

2.2 Crashworthiness

The most important concept in vehicle collision cases is 'crashworthiness' the ability of a vehicle to prevent injuries to the occupants in the event of a collision. During a collision, a vehicle's occupants are subject to a number of forces that can result in injury, including rapid deceleration and rapid acceleration, depending on the direction of impact in the collision. Crashworthiness deals primarily with the "second collision" that results from these forces, in which the driver and passengers collide against the interior of the vehicle. An effective crashworthy vehicle design will distribute these injurious forces to have longer impact time and distance as possible, including by directing them to parts of the body that are more capable of withstanding them (Nagel and Thambiratnam, 2004a).

Crashworthiness features, which are designed to minimize occupant injuries, prevent ejection from the vehicle, and reduce the risk of fire, include: seat belts; crumple zones, and airbags (including side impact protection) (Nagel and Thambiratnam, 2002). The Finite Element model Ford Festiva and a weak-post W-beam guardrail were used for analyzing the oblique impact situation with a high impact speed and a small angle. For this specific situation the dynamic responses of the vehicle and the guardrail during impacts were investigated to study their structural interactions. The simulation results of the modified vehicle model and guardrail model were reasonable in comparison with the crash test data under the similar impact conditions (Wu et. al, 2004). Quasi-static and dynamic axial crushing tests have been performed on circular thin-walled sections made of three materials: 304 stainless steel, aluminium alloy 6063-T6, and mild steel. The stainless steel, aluminium alloy and mild steel shells have moderate diameter-to-thickness ratios and were examined over a range of different axial lengths that encompassed both classical progressive buckling and the global bending modes of failure. The tests were conducted at a standardised energy of 9 kJ, approximately, with a few tests repeated at a higher energy of 18 kJ. The shells were impacted at velocities up to 13.4 m/s with masses up to 502 kg. Standard collapse modes developed in the tubes and the associated energy absorbing characteristics have been examined and compared with previous studies on mild steel. Quasi-static and dynamic tensile test results on the materials are also reported and the critical slenderness ratios at the transition between the two principal modes of failure are identified. The effects of strain hardening, strain rate as well as inertia effects due to the individual characteristics of the three materials are explored (Hsu et. al, 2004). In the collision process, thin-walled structures not only bear axial load but can also be subjected to oblique loads of different angles. Under oblique loading, the energy absorption, (EA) characteristics of thin-walled tubes decrease sharply, and the combined mode of axial progressive and global buckling is produced. Compared to axial progressive collapse, the global buckling mode is unstable. Therefore, the design of thin-walled structures that can absorb more energy and produce a stable deformation under oblique load has attracted more attention. Crashworthiness of thin-walled structures with different shapes under oblique load. The crashworthiness of thin-walled structures with different cross-sectional shapes under axial and oblique loading (Tarlochan et. al, 2010).Conical tubes exhibit good crashworthiness under oblique load. These thin-walled structures have the same wall thickness, but their inherent weakness is that they are not able to make full use of the material to meet the requirements for lighter weight (Gao et. al, 2016). Foam-filled thin-walled structure has been widely used in impact engineering such as vehicle crashworthiness for its excellent energy absorption and extraordinary light weight. Thus, a lot of work on studying the energy absorption characteristics of foam-filled thin-walled structures by employing experimental, analytical and numerical methods has been extensively investigated. Foam-filled thin-walled structures can absorb more dynamic impact energy than the corresponding hollow thin-walled structures. The energy absorption of a foam-filled thin-walled structure is larger than the sum of the energy absorptions of individual filled foam and thin-walled structure. The improvement is due to an interaction between the foam and the thin wall. Among those different kinds of foam-filled thin-walled structures, the foam-filled tapered thin-walled structure has been gradually become a very attractive subject because it not only has excellent energy absorption capacity but also performs superior balance of crashing stability. However, the investigations on foam-filled thin-walled structures in the existing literature mainly focus on the uniform density foams. Recently, for some foam-filled thin-walled structures, the functionally graded foam (FGF) material is considered to replace the uniform foam (UF) material. The energy absorption characteristics of FGF-filled square tubes in comparison with the UF-filled square tubes. It is found that the crashworthiness of FGF-filled tube is better than that of the corresponding UF-filled tube. In their work, the density of the filled foams of FGF-filled tubes changes along the axial direction of the tube. The energy absorption characteristics of two kinds of functionally lateral graded foam (FLGF) filled square tubes. FLGF-filled square tube has better energy absorption than UF-filled square tube with the same weight. Nonlinear finite element code LS-DYNA to investigate the crashworthiness of the FGF-filled square tubes, in which the foam density changes along both the axial and lateral directions of the tubes. It shows relative improvement of 12% in specific energy absorption levels of FGF-filled structures over their uniform density counterparts with the same mass. Based on the above investigations, it can be found that the crashworthiness of FGF-filled thin-walled structures is usually better than that of their uniform density counterparts. FGF-filled tapered thin-walled structures are likely to be a good alternative energy absorber in vehicle engineering, because UF-filled tapered thin-walled structure performs better crashing stability. However, to our best knowledge, the FGF-filled tapered thin-walled structures had never been presented or investigated before (Yin et. al, 2014). The energy absorption of thin-walled aluminium tubes used as crash boxes in the body structure of a vehicle has been optimized. In order to achieve this, various cross-sections of extruded aluminium were chosen and their behaviour under dynamic impact loading was investigated. The crash boxes were made from aluminium alloy 6060 temper T4. Finite element software LS-DYNA in ANSYS was used for modelling. For each cross-section, the results of dynamic crushing load versus crushing distance was obtained from the FE simulation and the results were compared with the experimental and numerical work on a square crash box in the literature. Parameters such as the crush force efficiency and the specific energy of various crash boxes were compared with the relevant ones for the square crash box and the most efficient crash box was recommended (Ghasemnejad et. al, 2007).

2.3 Energy absorption of cylindrical tube subject to lateral compression

Several researchers have analysed analytically the compression of a tube between rigid platens and proposed a deformation mechanism to describe the lateral compression process. The compression of a mild steel tube subjected to quasi-static lateral loading has been analyzed. A rigid perfectly plastic material model was used to predict the load-deformation response. The authors improved the strain hardening prediction by replacing the localised hinges with an arc in which its length changes with deflection (Deruntz et. al, 2011). It may be possible to maximise the energy absorbing capacity by choosing appropriate tube dimensions. Instron machine is used to compress the aluminium and mild steel laterally. (Gupta et. al, 2005), led an extensive test and computational examination of round metallic tubes subjected to semi static sidelong stacking. Examples broke down comprised of both mellow steel and aluminum tubes with various distance across to-thickness proportions. A quarter cross segment of a common tube was partitioned into zones to help portray the distortion component as it was subjected to expansive plastic misshapenings. Settled frameworks comprise of round tubes or curved formed containers of various measurements which are set inside each other and their tomahawks being parallel. Pressure of these frameworks is accomplished through two unbending level platens, one put at the highest point of the safeguard and another at the base of the safeguard to be broke down. Dialog is made on how the round tubes were framed into curved shapes and how such a changed shape can show more noteworthy pound efficiencies than their roundabout formed partners. A numerical procedure by means of the limited component strategy is utilized to mimic the stacking and reaction of such gadgets and henceforth, examination of numerical and exploratory power redirection reaction is introduced (Morris et. al, 2007). Introducing more plastic hinges into the structure is a way of increasing the specific energy absorption capacity (Olabi et. al, 2007). An attempt was made to explain this inconsistency on the basis of the formation of plastic hinges and the validity of strain rate parameters used in the Cowper Symonds relation (Olabi et. al, 2006). It was found that the optimised energy absorbers exhibited a more desirable force-deflection response than their standard counterparts due to a simple design modification which was incorporated in the optimised design. It is particularly important when a thin-walled member works as an energy absorber. This factor has not been taken into consideration so far in the case of crushing behaviour of the tubular absorbers mentioned above. Thus, within the presented work, the authors discuss the problem of initial crushing load and post-failure behaviour of tubular structure subjected to lateral impact, taking into account in the theoretical analysis the strain rate. Evaluation of the initial crushing (yield) load of the single tube allows one to determine approximately the corresponding load of the multi-member structure. Thus, the main aim of the present analysis was to specify and verify simple algorithms of the initial crushing load and post-failure equilibrium path of a single tube, laterally impacted (Kotelko et. al, 2013). Lateral compression of single circular tubes has been analyzed both experimentally and numerically by several researchers on lateral crushing of circular