UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## Faculty of Mechanical Engineering

# AXIAL CRUSHING OF THIN-WALLED TUBE WITH HOLE UNDER QUASI-STATIC LOADING

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**Master of Mechanical Engineering**
**(Applied Mechanics)**

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# AXIAL CRUSHING OF THIN-WALLED TUBE WITH HOLE UNDER QUASI-STSTIC LOADING

**MINAH MOHAMMED FAREED ABD-A AL-DABBAGH**

**A dissertation submitted**
**in fulfillment of the requirements for the degree of master of Mechanical Engineering**
**(Applied Mechanics)**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

**DECLARATION**

I declare that this dissertation entitles "Axial Crushing of Thin-Walled Tube with Hole under Quasi-Static Loading" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....................................................................................

Name : MINAH MOHAMMED FAREED ABD-A AL-DABBAGH

Date: : 4/9/2016........

**APPROVAL**

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Applied Mechanics).

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## DEDICATION

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this search.

To the great prophet Mohammed (Allah peace be upon him) ... a prophet of mercy and the light of the Worlds

To whom God has given the prestige and dignity... who taught me to tender without waiting... to whom I bear his name proudly... my father's beloved (God's mercy), I ask God Almighty to have mercy and to reward him paradise, My beloved mother, which is my gates to paradise, she removes all my worries by her smile. I did not get to what I am now without her duaa, I pray for Almighty God to save and protect my dear mother

All the love... To my dear husband, to who helped me to achieve my dream step by step when he gave me the love and time, God rewards you. My beloved kids (Mustafa and Marah) I ask the Almighty God to save and protect both of them for me.

To my beloved sister (Zena) and her daughters (Aya and Fatima), your duaa, love and support that helped me and meant a lot to me. To my dearest brothers (Zaid, Mokhallad, and Mustafa), I ask God to keep and protect both of them for me.

For all friends especially (Jumadi Chuli) who have encouraged me during my study, thank you all.

**ABSTRACT**

Thin-walled tube is one of the energy absorbing structure utilized to dissipate energy and increase the efficiency of crashworthiness. During the accident, thin-walled tube dissipates the kinetic energy of the structure and converts it into other form of energy. Thus, this gives enough energy dissipation before hitting the human. This study examines the circular and square thin-walled tubes of mild steel subjected to axial crushing test by using Instron machine. These tubes include imperfection (round holes) located at three different locations. The theoretical results obtained from mathematical equations for the circular and square tubes crushing have been compared to the experimental results and a good agreement has been achieved between the theoretical and experimental results. The analysis of load-displacement characteristics includes the peak load, energy absorption capacity, mean crushing load, crush force efficiency (CFE), and specific energy absorption (SEA) results. The diameter, location and number of the holes were varied to investigate the effect of these parameters to the load-displacement characteristics. The location of round hole is located in 3 different level in the tube. As a result, the circular tube is capable of providing better decrease peak load and higher absorbed energy compared to the square tube.It was found that the better specimen is the circular tube with multi-hole, due to it has the excellent result in decrease the peak load reached to 16 %, it was concluded that value of the peak load is optimum in circular thin-walled tube. While the value of energy absorption slightly decreases in all specimens with holes compared with tube without hole. The location of holes in circular tube has the effect on the type of deformation. However, it does not affect the deformation in the square tube the location unaffected on the deformation. At the end, the modifications performed on the original tube shows an improvement in the load-displacement characteristics. The information obtained in this study will serve as a guide to better design the thin-walled tube in the future.

## *ABSTRAK*

*Tiub berdinding nipis adalah salah satu menyerap struktur tenaga yang digunakan untuk menghilangkan tenaga dan meningkatkan kecekapan crashworthiness. Semasa pelanggaran itu, tiub berdinding nipis menyebarkan tenaga kinetik struktur dan menukarkan kepada bentuk tenaga yang lain. Dengan ini,tenga dapat terserap sebelum melanggar manusia. Kajian ini melihat tiub berdinding nipis bulat dan persegi keluli lembut yang dikenakan bebanan paksi oleh mesin Instron. Tiub-tiub ini juga ditebuk dengan lubang bulat pada 3 lokasi yang berbeza.Keputusan teori yang diperolehi daripada persamaan matematik untuk tiub bulat dan tiub segi tepat dibandingkan dengan keputusan eksperimen dan didapati ia hampir sama.Analisa ciri-ciri beban-anjakan ini adalah termasuk beban puncak, kapasiti penyerapan tenaga, beban purata kecekapan kuasa menghancurkan (CFE) dan penyerapan tenaga tentu (SEA).Garispusat, lokasi dan bilangan lubang diubah untuk melihat kesan parameter ini dengan ciri-ciri beban-anjakan. Lokasi lubang bulat diletakkan pada 3 paras yang berbeza-beza. Hasilnya, tiub bulat mampu menyediakan penurunan beban puncak yang lebih baik dan tenaga yang diserap lebih tinggi berbanding dengan tiub persegi Kajian ini menjumpai bahawa spesimen tiub bulat dengan pelbagai lubang adalah lebih baik dan boleh menurunkan beban puncak sehingga 16%.Walaubagai pun, nilai serapan tenaga akan berkurangan.Lokasi lubang pada tiub bulat mempunyai kesan terhadap jenis ubah bentuk. Walau bagaimanapun, ia tidak memberi kesan kepada perubahan bentuk dalam tiub persegi lokasi terjejas pada ubah bentuk. Pada akhirnya, pengubahsuaian dilakukan ke atas tiub asal menunjukkan peningkatan dalam ciri-ciri beban-anjakan. Maklumat yang diperolehi dalam kajian ini akan menjadi panduan untuk lebih baik mereka bentuk tiub berdinding nipis pada masa hadapan.*

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Most importantly, I am forever grateful my family who understands the importance of this work, none of this would have been possible without their patience and help.

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## LIST OF ABBREVIATIONS

| Abbreviation | Specification |
|---|---|
| ASTM | American society for testing and materials |
| C | Circular tube designation |
| Sq | Square tube designation |
| CFE | Crush force efficiency |
| SEA | Specific energy absorption |
| UTeM | University of Technical Malaysia Melaka |
| FKM | Faculty of Mechanical Engineering |
| Sp | Specimen |
| WH | Without hole |
| H | Hole |
| T | Top |
| M | Middle |
| B | Bottom |
| MH | Multi-hole |
| IEA | Impact energy absorption |
| Expt | Experimental |

# LIST OF SYMBOLS

| Symbol | Specification |
|---|---|
| *mm* | Millimetres |
| *m* | Mass |
| *N* | Newton |
| *P* | Crushing load |
| *t, h* | Tube thickness |
| $P_{max}$ | Peak load |
| $P_{mean}$ | Mean crushing load |
| *D* | Tube diameter |
| $E_a$ | Energy absorption |
| *L* | Tube length |
| *KJ* | Kilojoule |
| *kN* | Kilo newton |
| *Kg* | Kilogram |
| $\delta$ | Deformation length |
| $\sigma_y$ | Yield stress |
| % | Percentage |
| *R* | Radius |
| $M_0$ | Fully plastic bending moment per unit length |
| *A* | The contact area of the top cross-section |
| $\eta$ | Structural effectiveness |
| $\Phi$ | Hole diameter |
| $\sigma_u$ | The ultimate tensile strength |
| *k* | Dimensionless constant |
| $E_e$ | Energy efficiency |

| | |
|---|---|
| $H$ | Half-length of the buckled fold |
| $\lambda$ | Plastic folding |
| $\phi$ | Relative density |
| $b_e$ | Effective width |
| $\delta_t$ | Total crushing distance |
| $A_0$ | Overall section area |
| $C_1, C_2$ | Constant to determine the number of holes |
| $V$ | Crush structure volume |
| $b, c$ | Width of square tube |
| $E_s$ | Specific energy absorption |
| $\rho$ | Density of structure |

# CHAPTER 1

# INTRODUCTION

## 1.1 Safety and motivation

Every year more than million people die and 20 to 50 million more are exposed to injury by vehicle accident around the world (Hyder et al., 2013). This number of death will reach nearly 2 million in 2020 (Krug, 2012). The importance of the safety of passengers and vehicles as well as the high cost of maintenance of vehicles are the reasons that motivate engineers and automotive designers to design safe vehicle structure (especially cars) that absorb most of the energy during the collision, by converting the kinetic energy into another type of energy that cause less damage. In other words, the vehicle will absorb the bulk of the energy while the passengers will absorb a minimum energy to achieve maximum protection for passengers.

Therefore, to provide safety to passengers during accidents, one should find out which are the places that are prone to damage during a collision, where these places are controlled on the amount of energy absorbed to be dissipated within an area of collision and prevent the arrival of impact energy to the passengers or reduce this energy to get as little damage as possible. As shown in Figure 1.1 the bigger percentage of damage due to accident is in the frontal part of the car that reaches 48 %. This value explains the importance of the component of the car structure and how to make the structure plays a vital role to attenuate the propulsive force and prevention of this force of access to occupants.


Figure 1.1: Percentage of damage direction due to accident (How to safety, 2014).

Thin-wall structures tubes have been extensively used as these energy absorbers that most commonly exist as either square or circular cross-sections (Jones 1989; Qi Chang et al., 2012; Zhou et al., 2011). These structures are called the frontal longitudinal, where such structures permanently deform to mitigate the crash energy and forces transmitted to the vehicle, reducing the deceleration experienced by the passengers as demonstrated in Figure 1.2.

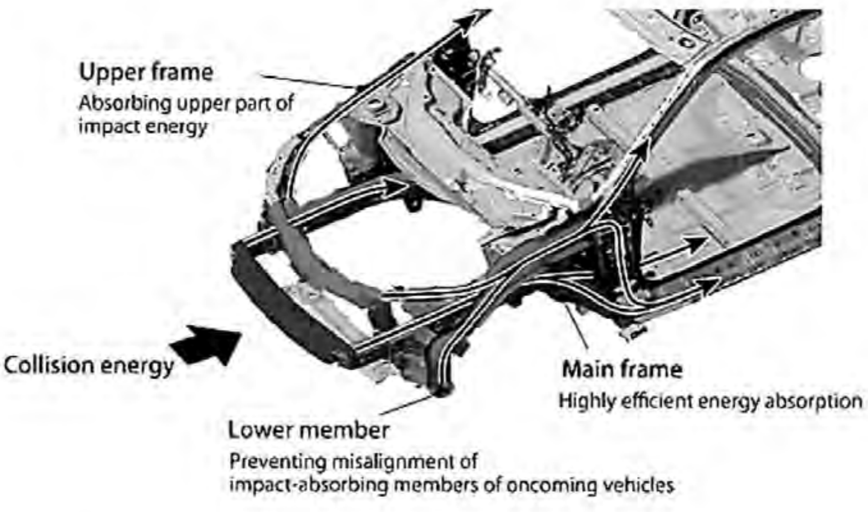


Figure 1.2: Transfer of collision energy in car structure (Crash box element in Honda CR-Z, 2010).

This structure should have the ability to form folds during accident, these folds can be obtained from a thin-walled tubular structure with imperfection (grooves, trigger, tend, and hole) because this imperfection helps to accelerate the fold forming at the same point of imperfection, which means that the imperfection is used to control the location of the forming fold during the collision. Thus, to decrease damage should put the imperfection in the frontal structure of the vehicle or in crush distance as in same Figure 1.3, this imperfection will work on accelerating the dissipate of kinetic energy that led to minimizing the number of death and injury by providing safe occupants' compartment. These imperfection can be found on any components of the vehicle, which may be the bumper, pillars, in the early design of the chassis and frontal side rail. They can be made in different shapes or from different tubular structure, (circular or square tube) and a specular tubular such as steel (stainless steel and cold mild steel) or aluminum can be selected. The thin-walled structure solves the problem of heavy weight and moreover when holes are put on the structure, it will increase the drop in the mass and make the structure absorb energy early as the fold forming is expedited.

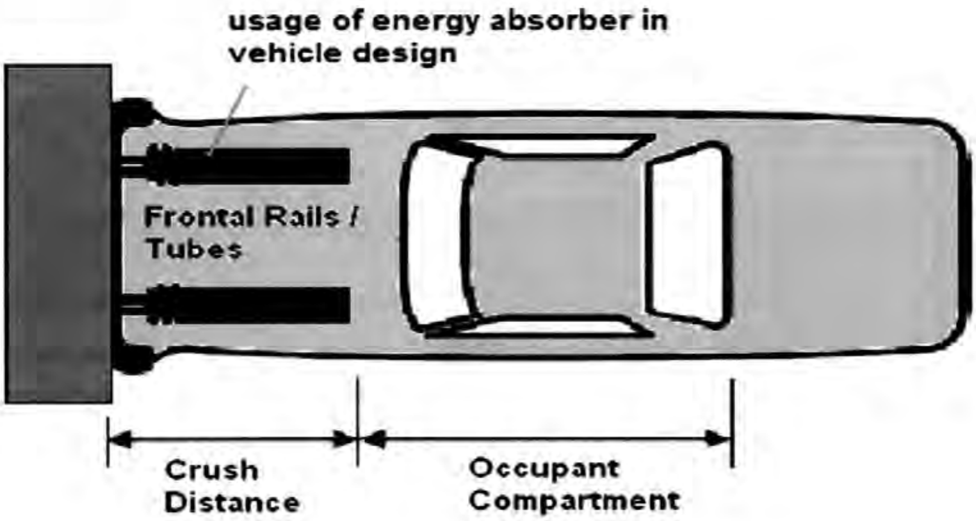


Figure 1.3: Frontal rails tubes put in crash distance (Qi Chang et al., 2012)

In addition to safety, there are many design aims which revolve around the same ring, as illustrated in Figure 1.4. These design aims are very important to meet the requirements of the consumer, and the acceptable design car should meet safety needs and all other design aims at the same time.

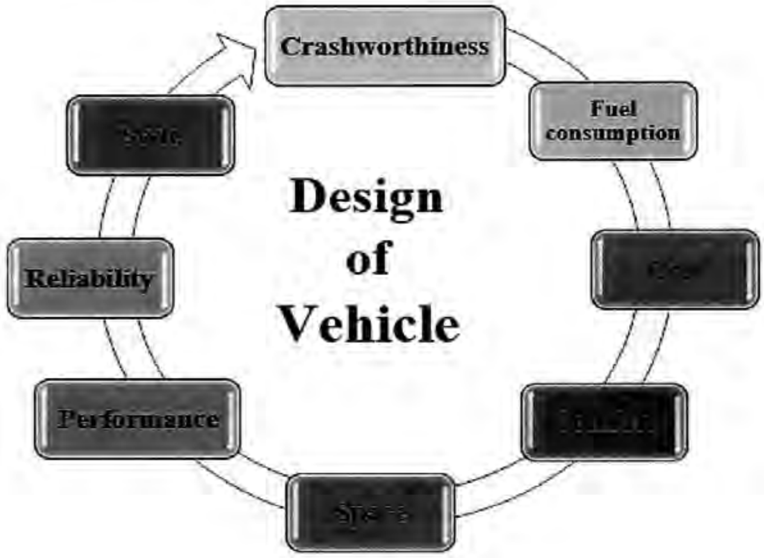


Figure 1.4: Design aims for good structure of vehicle

During the last decades, many works have been done to modify the existing energy absorption or to make new models; many studies have been done on the various forms of tubes such as circular, square and elliptical tubes to investigate the better absorption of energy (Marzbanrad et al., 2009). Many research conducted tested the impact on different types of materials such as aluminum, stainless steel and mild steel (Hsu and Jones, 2004). The pioneering work of the crushing of the thin-walled circular tube has performed and developed the theoretical formula of the mean load (Alexander, 1960). Meanwhile, some authors addressed the square tube containing holes to study the effect of the holes to reduce the peak load and increase energy absorption (Szwedowicz et al., 2014). Another studies have addressed the honeycomb shape and investigated it is effect on the absorption of energy, where some authors have studied the empty honeycomb (Wu and jiang, 1997). Meanwhile, some studied the aluminum foam-filled honeycomb (Xu et al., 2012), whereas others examined the honeycomb with the cover on top and bottom ends (Griskevicius et al., 2010).

In addition to what has been mentioned, many attempts have been carried out by scientists to find out the effect of the tube's dimensions such as the thickness, length, and diameter of the tube and some variables such as speed, load and the direction of collapse on the amount of energy absorbed and the reduction of the peak load.

The aim of all these attempts is to get a better load-displacement characteristic to evaluate the energy absorption capacity of crash, as well as the crash force efficiency (CFE), a reduction in the peak load crash and the act of saving the lives of passengers and reducing the damage by providing the safety conditions.

## 1.2 Problem statement

A lot of works have been developed in the past by engineers and researchers to investigate the thin-walled tube as a structure that has the ability to absorb the energy and decrease the value of the peak load (DiPaolo and Tom 2006; Abramowicz 2003; Guillow et al., 2001; Yob et al., 2016). The safety of occupants and the vehicle depend on the value of the absorbed energy and drop peak load value during the accident. Therefore, the structures should have the ability to absorbed higher energy and the higher decrease in peak load via adding some imperfections to achieve less damage and injuries. Studies related to thin-walled tubes with the existence of round holes are still lacking and more experimental attempts are needed. Thus, this study will investigate the effects of the