FINITE ELEMENT MODELLING ON SINGLE AND NESTED MILD STEEL TUBES UNDER QUASI- STATIC LATERAL LOADING

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A report submitted
In fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering with Honours

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this project report entitled "Finite Element Modelling on Single and Nested Mild Steel Tubes Under Quasi-Static Lateral Loading" is the result of my own work except as cited in the references.

Signature : ....

Name : Cheong Chi Cheng

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature : ....

Name : Associate Professor Ir. Dr Sivakumar A/L Dhar Malingam

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Thin-walled structures are widely utilized in various engineering industries applications such as aircraft, ships, motor vehicles, building construction, tank, pressure vessel, etc. Different geometries or cross-section shapes of thin-wall structures are primarily utilized for energy absorption, such as circular, square, rectangular, and hat-section. The energy absorbed by the thin-walled structure can prevent occupant injuries and intrusion of the crash object during the impact in a collision. The impact of structure is not limited to the axial direction, but it may occur laterally. Over the past few years, the number of road accidents had slightly increased in Malaysia. Due to the rise in deaths, engineers and automotive designers have tried to control the impact load through several passive energy absorption mechanisms. In the automotive industry, the single tube structure was traditionally used as the crash tube or energy absorber, which had poor performance and easily deforms during an impact. Therefore, comprehensive studies and research need to be carried out into the design and development of energy absorbers to improve the energy absorption performance and enhance the safety of a vehicle structure. Besides that, nested thin-walled tubes are considered an alternative to energy absorption structures utilized in various industries, including aerospace, automotive and military. There are three different types of nested tube systems investigated in this study, which included Circle- Circle Tube (CCT), Circle-Square tube (CST), and Circle-Rectangular Tube (CRT). The purpose of this study is to identify the deformation behaviour and the energy absorption of the single and nested mild steel tube systems under quasi-static lateral loading. Besides that, Finite Element Analysis (FEA) was used to validate the experiment result that obtained from other authors to ensure that in order to obtain accurate and precise results. The results presented that the energy absorption performance of nested mild steel tubes is superior as compared to the single mild steel tube. Among the tube systems, the Circle-Square Tube (CST) leads to outstanding energy absorption due to the existence of the inner quadrangular tube. The results revealed that the inner tube inside the nested tube systems had increased the strength of the structure and thus improved the amount of total energy absorption.

ABSTRAK

Struktur berdinding tipis digunakan secara meluas terutama dalam pelbagai aplikasi industri kejuruteraan seperti pesawat, kapal, kenderaan bermotor, pembinaan bangunan, tangki, kapal tekanan, dan lain-lain. Geometri yang berbeza atau bentuk keratan rentas struktur dinding tipis terutama digunakan untuk penyerapan tenaga seperti pekeliling, persegi, segi empat tepat, dan keratan topi. Tenaga yang diserap oleh struktur berdinding tipis dapat mengelakkan kecederaan penghuni dan pencerobohan penghuni objek yang terhempas semasa kesan dalam perlanggaran. Kesan struktur tidak terhad pada arah paksi, tetapi ia mungkin berlaku secara sisi. Sejak beberapa tahun kebelakangan ini, jumlah kemalangan jalan raya sedikit meningkat di Malaysia. Kerana peningkatan kematian, jurutera dan pereka automotif telah berusaha untuk mengawal beban impak melalui beberapa mekanisme penyerapan tenaga pasif. Dalam industri automotif, struktur tiub tunggal secara tradisional digunakan sebagai tabung kerosakan atau penyerap tenaga, yang mempunyai prestasi buruk dan mudah cacat semasa hentaman. Oleh itu, kajian dan penyelidikan yang komprehensif perlu dijalankan ke dalam reka bentuk dan pengembangan penyerap tenaga untuk meningkatkan prestasi penyerapan tenaga dan meningkatkan keselamatan struktur kenderaan. Selain itu, tiub berdinding tipis bersarang dianggap sebagai alternatif kepada struktur penyerapan tenaga yang digunakan dalam berbagai industri, termasuk aeroangkasa, automotif dan tentera. Terdapat tiga jenis sistem tiub bersarang yang disiasat dalam kajian ini, yang merangkumi Circle-Circle Tube (CCT), Circle-Square tube (CST), dan Circle-Rectangular Tube (CRT). Tujuan kajian ini adalah untuk mengenal pasti kelakuan ubah bentuk dan penyerapan tenaga sistem tiub keluli ringan tunggal dan bersarang di bawah pemuatan lateral kuasi-statik. Selain itu, Analisis Unsur Terhingga (FEA) digunakan untuk mengesahkan hasil eksperimen yang diperoleh dari penulis lain untuk memastikannya agar dapat memperoleh hasil yang tepat and persis. Hasil kajian menunjukkan bahawa prestasi penyerapan tenaga tiub keluli ringan bersarang lebih baik berbanding dengan tiub keluli ringan tunggal. Di antara sistem tiub, Circle-Square Tube (CST) membawa kepada penyerapan tenaga yang luar biasa kerana adanya tiub segi empat dalam. Hasil kajian menunjukkan bahawa tiub dalam sistem tiub bersarang telah meningkatkan kekuatan struktur dan meningkatkan jumlah penyerapan tenaga.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) and Faculty of Mechanical Engineering to conduct this project that benefits the students in various of aspects. Besides that, the help of our coordinator of this project, Dr Fadhil bin Syahrial in assisting the student throughout this project period is also greatly appreciated.

Secondly, I would like to express my deepest gratitude to my supervisor, Associate Professor Ir. Dr Sivakumar A/L Dhar Malingam, for all the kindness in guiding me to complete my project report. My supervisor's assistance helps me gain a great insight into the engineering field by sharing his experience. He always times to answer my questions patiently and help me figure out those matters. I very much appreciated his valuable guidance and advice while guiding me in this project.

In a nutshell, I would like to express my greatest appreciation to my friend and family for their continuous support. It will be somehow stressful to work on this project due to the workload and strict timeline. Their support encouraged me to face the hardship, which I overcame with more determination, persistence, and a good attitude in order to complete this degree.

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FEA	Finite Element Analysis
SEA	Specific Energy Absorption
FE	Finite Element
FEM	Finite Element Method
ST	Single Tube
CCT	Circle-Circle Tube
CST	Circle-Square Tube
CRT	Circle-Rectangular Tube

LIST OF SYMBOLS

E	=	Energy absorption capacity
P	=	Compression load
δ	=	Displacement or current attainable crush distance
δ_{max}	=	Maximum attainable crush distance
P_m	=	Mean crush load
P_{max}	=	Maximum crush load
P_l	=	Limit load
P_e	=	Elastic load
δ_e	=	Elastic deflection
m	=	Mass of the energy
S_E	=	Stroke efficiency
D	=	Outer diameter of the energy absorber
e_E	=	Energy efficiency
F_{max}	=	Maximum force
L_o	=	Original length of the energy absorber device
W_{eff}	=	Work effectiveness
F	=	Crushing load
E_s	=	Energy absorbed under quasi-static loading
E	=	Young’s modulus
v	=	Passion’s ratio
t	=	Thickness
P_{avg}	=	Average crushing force
P_A	=	Crushing force in stage A
P_A	=	Crushing force in stage B

CHAPTER 1

INTRODUCTION

1.1 Background

Thin-walled structures are widely used in various engineering industries. Many industrial applications are commonly used in aircraft, ships, motor vehicles, building construction, tank, pressure vessel, etc. Thin-walled structure have various geometrical shapes such as circular, square, rectangular, hat-section and so on. Thin-walled tubes have been known to be exceptionally excellent impact energy absorbers due to their ability to crush in a stable, progressive axial manner (Ahmad, 2009). Besides that, the thin-walled structure absorbs different amounts of energy depending on its geometry. In the field of engineering, cylindrical shape is commonly used for a thin-walled structure due to the simple geometry and easy manufacturability. Due to different types of loading conditions (e.g., lateral, and axial loading), the cylindrical thin-walled structure able to absorb the various type of energy which result in different kinetic energy dissipation (Lafta et al., 2020).

In the early 1920s, steel has been widely used in automobile industry (Miller et al., 2000). Over the last decade, the researchers had spent their time on extensive research and development of advanced steels that are safer, stronger, greener, more fuel-efficient and cost competitive (Samodajev, 2019). Nowadays, mild steel is extensively utilized for many applications due to its lightweight, low cost, outstanding ductility and toughness (Odio et al., 2014). Mild steel is predominantly used in different engineering application such as automobile body components, structural shapes (I-beam, channel and angle iron), pipelines, buildings, bridges, tin can and so on (Callister Jr & Rethwisch, 2018; Singh, 2016).

1.2 Problem Statement

The impact of vehicle structure is not limited to the axial direction, but it may occur laterally (Ahmad, 2009). The Star (2020) newspaper reported that the number of road accidents had slightly increased over the past few years in Malaysia. A total of 23,208 road accidents were recorded throughout the operation, an increase of 11% compared to Ops Selamat 2019 (The Star, 2020). Due to the rise in deaths, engineers and automotive designers have tried to control the impact load through several passive energy absorption mechanisms (Szwedowicz et al., 2014). The energy absorbed by the structure can prevent occupant injuries and intrusion of the crash object during side impact in a collision (Safari et al., 2018). In the automotive industry, the single tube structure was traditionally used as the crash tube, which requires absorbing the kinetic energy during an impact in a collision (Usta et al., 2018). However, the single tube structure shown poor performance and easily deforms under compression loading (Sofi et al., 2019). Therefore, comprehensive studies and research into the design and development of energy absorbers are required to improve the energy absorption performance and enhance the safety of a vehicle structure. A wide range of studies and future research need to be conducted to meet the optimum energy absorption structure. In this study, a single cell tube and three different nested mild steel tube structure under quasi-static lateral loading will be examined using simulation work in Finite Element Analysis (FEA).

1.3 Objective

The objectives of this project are as follows:

i. To study the deformation behaviour of the single and nested mild steel tubes under lateral loading through Finite Element Analysis (FEA).

ii. To investigate the energy absorption of the single and nested mild steel tubes under quasi-static lateral loading.

iii. To compare the energy absorption capacity between the three different type of nested tubes system.

1.4 Scope of Project

The scopes of this project are:

i. The single and nested mild steel tubes will be modelled using ABAQUS software.

ii. Three different nested mild steel tubes structures, which made up of stacked group of circulars, square, and rectangular tubes are used to determine the energy absorption under lateral compression at a loading rate of 5mm/min using simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter shows the critical and comprehensive review of the published research literature relevant to this project. The background literature to date is significant to the research carried out in this thesis. All established theories and findings are discussed to enhance insight for conducting this research. Literature not only just generally summarizes all the related past research but should contrast and related all theories and studies.

2.2 Structural Crashworthiness

Crashworthiness can generally describe a vehicle structure's ability to withstand impact load to protect its survival space without taking any risk of injuries or death to the occupants in the event of the collision. Ambrosio (2014) states that the term 'structural crashworthiness' is used to describe a structure's impact performance when it is in collision with another object. When crushing with another object, the structure must be deformable in order to absorb the kinetic energy generated by the collision. Through the decades, researchers had worked hard towards developing technologies to improve the crashworthiness performance of structural. In the automotive industry, crashworthiness had been considered as a precondition to be an essential issue when design automobile structures.

Additionally, the vehicle structure must have the ability to prevent intrusion of the crash object into occupied space to reduce the risk of injuries or death to the occupants (Safari et al., 2018). Figure 2.1 and 2.2 illustrates the fundamental concept of crashworthiness performance for automobiles and aircraft under crash condition. According to Ma et al. (2020), the force-displacement curve response of the automobile body in the crash condition is essential to evaluate crashworthiness, as shown in Figure 2.3. Besides that, the front and rear crumple zones of a structure are designed to absorb the impact energy, reducing peak damaging forces from being transmitted to the vehicle and occupants during the impact event (Ganilova & Low, 2018; Nagel & Thambiratnam, 2002). As a result, the crashworthiness design has become a primary safety requirement for occupant-carrying automobiles and aircraft.

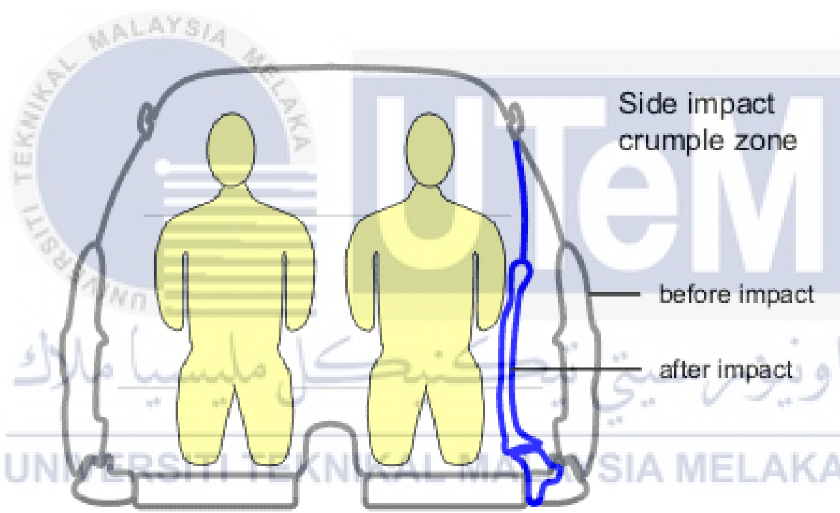

Figure 2.1: Fundamental concept of crashworthiness on automobile under lateral crash impact

(Car safety features, 2021)