AN ENERGY ABSORPTION CHARACTERIZATION OF IMPROVED CIRCULAR THIN-WALLED TUBES UNDER DYNAMIC LOADING

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by

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LIST OF ABBREVIATIONS

ASTM	American society for testing and materials
C	Circular tube designation
CFE	Crush force efficiency
CON	Conical tube designation
DOE	Design of experiment
FE	Finite element
FEA	Finite element analysis
GA	Genetic algorithm
M	Modification tube designation
NIP	Number of integration point
NODOUT	Nodal displacement
PVC	Polyvinylchloride
RCFORC	Resultant interface forces
RSM	Response surface methodology
S	Square tube designation
SEA	Specific energy absorption
STR	Straight tube designation
UTM	Universal testing machine

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LIST OF SYMBOLS

cm^3	Centimeter cubic
C	Cowper'symonds constant
D	Tube diameter
E	Elastic modulus
E_a	Energy absorption
$E_{kinetic}$	Kinetic energy
F_{mean}	Mean crushing force
F_{peak}	Peak load
G	Shear modulus
g	Gravity constant
g	Gram
GPa	Gigapascal
J	Joule
kg	Kilogram
kN	Kilonewton
l	Original length of the tube
m	Mass
mm	Millimeters
mV	Milivolts
N	Newton
P	Crushing load
p	Cowper'symonds constant
t	Tube thickness
T_{melt}	Melting temperature
T_{room}	Room temperature
T^{*m}	Homologous temperature
v	Poisson's ratio
δ	Deformation length

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$\dot{\varepsilon}$	Strain rate
ε_p	Effective plastic strain
$\dot{\varepsilon}*$	Dimensionless strain rate
σ_0	Mean plastic flow stress
σ_y	Yield stress
ρ	Mass density
%	Percentage

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Ciri-ciri Penyerapan Tenaga Oleh Tiub Bulat Berdinding Nipis Melalui Beban Dinamik

ABSTRAK

Tiub berdinding nipis adalah salah satu daripada alat penyerap tenaga yang direka untuk melesapkan tenaga dan meningkatkan kecekapan struktur bagi menahan hentakan dalam peristiwa hentaman. Semasa pelanggaran, tiub berdinding nipis akan melenyapkan tenaga kinetik di dalam sesuatu struktur dengan cara menukarkan tenaga kinetik kepada tenaga yang lain, sekali gus mengurangkan kesan yang dialami oleh penumpang. Penyelidikan ini mengkaji tiub berdinding nipis yang dihentak menegak secara dinamik dengan menggunakan penguji pelepasan beban. Model elemen unsur terhingga untuk penghentakan tiub telah dibentuk dengan menggunakan perisian LS-DYNA dan keputusan yang baik telah diperoleh antara model unsur terhingga dan keputusan eksperimen. Kajian parametrik ke atas tiub berdinding nipis telah dilakukan dengan menggunakan model unsur terhingga yang telah disahkan. Ciri-ciri penyerapan tenaga yang dianalisis termasuklah kapisiti penyerapan tenaga, beban tinggi terawal, penyerap tenaga spesifik (SEA) dan kecekapan beban pelanggaran (CFE). Bentuk, bahan dan geometri tiub divariasikan untuk menyiasat kesan menggunakan parameter ini terhadap ciri-ciri penyerapan tenaga. Hasilnya, tiub berbentuk bulat mampu menghasilkan ciri-ciri penyerapan tenaga yang lebih baik berbanding tiub berbentuk segiempat. Tiub yang diperbuat daripada tiga bahan yang berbeza iaitu aluminium aloi AA6061-T6, karbon keluli S1214 dan magnesium aloi AZ31B-O telah digunakan dalam LS-DYNA. Didapati bahawa magnesium aloi AZ31B-O sangat berpotensi untuk dijadikan sebagai bahan dalam pembuatan tiub berdinding nipis selain daripada aluminium aloi dan karbon keluli memandangkan ia mempunyai keputusan yang sangat bagus dari segi beban tinggi terawal, SEA dan CFE. Walaubagaimanapun, apabila sesuatu aplikasi tidak menitik beratkan kerosakan struktur dan tidak melibatkan manusia, karbon keluli adalah terbaik kerana dapat menyerap lebih banyak tenaga dan mempunyai purata beban perlanggaran yang tinggi. Faktor bagi panjang, diameter dan ketebalan tiub terhadap ciri-ciri penyerapan tenaga juga telah dikaji. Kesimpulannya, beban tinggi terawal dan CFE adalah optimum bagi tiub yang lebih tebal dan besar. Kapasiti penyerap tenaga adalah optimum bagi tiub yang lebih tebal, besar dan panjang, sementara keputusan SEA adalah optimum untuk tiub yang lebih tebal, kecil dan pendek. Akhir sekali, pengubahsuaian yang dilakukan terhadap tiub asal telah meningkatkan ciri-ciri penyerapan tenaga berbanding tiub asal. Kombinasi antara tiub berbentuk kon dan penutup berbentuk rata telah dicadangkan sebagai modifikasi tiub yang terbaik kerana ia memberikan keputusan yang cemerlang untuk beban tinggi terawal, CFE dan SEA serta memberikan keputusan yang sederhana untuk kapasiti penyerapan tenaga. Maklumat penyelidikan yang disediakan dalam kajian ini akan menjadi panduan untuk merekabentuk tiub berdinding nipis pada masa yang akan datang.

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An Energy Absorption Characterization of Improved Circular Thin-Walled Tube under Dynamic Loading

ABSTRACT

Thin-walled tube is one of the energy absorber devices designed to dissipate energy and increase the efficiency of a crashworthiness structure in an impact event. During an accident, thin-walled tube dissipates the kinetic energy of the structure and converts the kinetic energy into the other form of energy thus minimize the impact experienced by the occupant. This research examines the thin-walled tube subjected to axial dynamic crushing experiment by using a drop weight impact tester. A nonlinear finite element model for the tube crushing has been developed by using LS-DYNA software and a good agreement has been achieved between the finite element model and experimental results. The parametric studies of the thin-walled tubes have been performed by using the validated FE model. The analysis of energy absorption characteristics includes the energy absorption capacity, initial peak load, specific energy absorption (SEA) and crush force efficiency (CFE) results. The shape, material and geometry of the tube are varied to investigate the effect of using these parameters to the energy absorption characteristics. As a result, circular tube is capable to provide better energy absorption characteristics compared to the square tube. The tubes designed by three different materials which are aluminium alloy AA6061-T6, carbon steel S1214 and magnesium alloy AZ31B-O has been developed in LS-DYNA. It was found that the magnesium alloy AZ31B-O is highly potential to be created as the thin-walled tube material instead of aluminium alloy and carbon steel since it has excellent result in initial peak load, SEA and CFE. However, when the applications neglect the damage of the structure and does not involving human, carbon steel is the best material as it can absorb most energy capacity and high mean crushing force. The effect of length, diameter and thickness of the tube to the energy absorption characteristics has been investigated. It was concluded that initial peak load and CFE are optimum in thicker and larger tube. Energy absorption capacities are optimum in thicker, larger and longer tube while SEA result is optimum in thicker, smaller and shorter tube. At the end, the modifications performed on the original tube shows an improvement in the energy absorption characteristics compared to the current tube designs. A combination of conical tube with flat end cap was proposed as the best modified tube since it has excellent results on initial peak load, CFE and SEA with moderate results on the energy absorption capacity. Research information provided in this study will serve as a guide to design the thin-walled tube in the future.

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CHAPTER 1

INTRODUCTION

1.1 Project background

Crashworthiness can be defined as the ability of a structure to prevent occupant injuries during an impact [1]. Many manufacturers especially in producing vehicles and moving part such as automotive, aircraft, ships, railway couches, lift and others machinery aim to make an improved crashworthy structure to increase the occupant safety during an accident or collision. Energy absorber is the main component to increase efficiency of a crashworthiness structure. During an accident, energy absorber dissipates the kinetic energy of the structure and converts the kinetic energy into the other form of energy thus minimize the impact experienced by the occupant. The impact energy is converted into strain energy through structural deformation. In general, the efficiency of the energy absorber is optimum when the system can provide maximum energy absorption, stable progressive collapse mode, lower initial peak crushing load, longer deformation length, deformation in concertina mode with shorter length of fold and produce a large number of fold. The studies of crashworthiness have been at interest to many researchers in the past until this date [2-5].

Some example of energy absorber structures are thin-walled tube, sandwich structure, egg-box material, lattice structure and cellular material. However, the application using the thin-walled tube as energy absorber received the most attention from the researchers

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because it is easy to produce and the structure proved to absorb more energy capacity at large deformation of the tube.

Fig. 1.1 shows the applications of energy absorber in the crash box element of the cars. Fig. 1.1(a) illustrates the overall body structure safety cage and Fig. 1.1(b) focuses in the crash box element of an AUDI A8 manufactured in year 2011. It is clearly shown that the car crash box element uses the square shape of thin-walled tube structure as the energy absorber to resist the impact when accident occurs.

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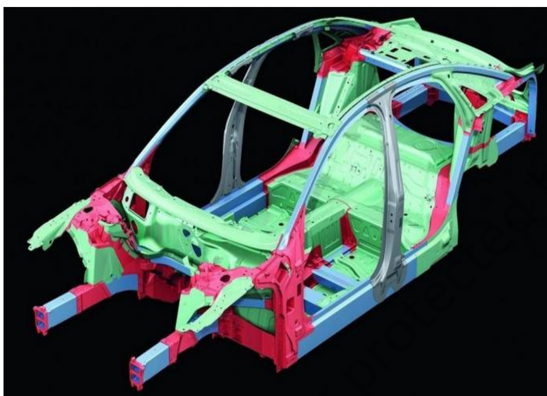
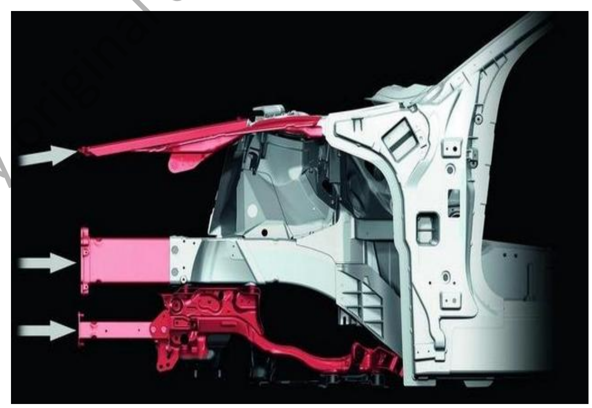
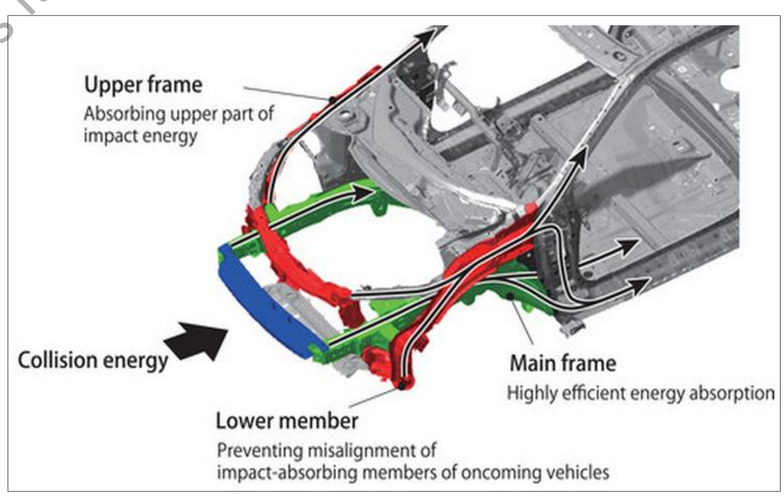


(a)



(b)



(c)

Fig 1.1: Body structure safety cage and crash box element; (a) Overall structure for AUDI A8, (b) Crash box element of AUDI A8 and (c) Crash box element in Honda CR-Z [6].

Besides that, Fig. 1.1(c) shows the combination of main frame, upper frame and lower member used as energy absorber in Honda CR-Z. The thin-walled tube of the main frame designed to absorb most kinetic energy during the collision by deformation of the structure and dissipate the energy to the other members. Regarding to this matter, many researchers focused in improving the efficiency of this structure either by using experimental or simulation analysis methods [7-8].

A lot of methods and modifications had been done by the previous researchers in order to analyze and improve the energy absorption characteristics of the thin-walled tube structure [9-10]. One of the methods used various shapes of the cross section of the thin walled tube such as circular, triangular, square and hexagon that are employed in thin-walled structure [9, 11]. Furthermore, new material development technology has encouraged researchers to use variety of materials available to improve the performance of energy absorption characteristics.

On the other hand, some modifications had been performed by combining different types of energy absorber in a single structure. Since the result of the research proved that using combination of geometry and making modification on the energy absorber can improve the energy absorption characteristic, some of the car manufacturers applied this invention in their production [10, 13]. For example, Peugeot from France, a well-known car manufacturer tried to improve their occupant safety by modification of the energy absorber in their new car model (Peugeot 3008) in 2011 [13]. Fig. 1.2 shows two conical energy absorbers positioned between the impact absorption beam and chassis leg to control the deformation of the thin-walled tube in the event of collision.

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Fig. 1.2: Modification made to the thin-walled tube of Peugeot 3008 [13].

1.2 Problem statement

A lot of works have been developed by previous researchers and engineers to investigate the thin-walled tube as an energy absorption structure [2-5]. Since investigation in thin-walled structure is very wide-ranging, researchers still do not find the best energy absorber because their result shows both advantages and disadvantages in their designs [14-15]. With the growth of material development in industries, the application of using the new materials as the energy absorber has created a challenge to the researchers and engineers especially to produce both lightweight and high strength structure.

The design of the energy absorber still need more attention by researchers because there are big numbers of geometry, shape and modification can be performed in designing the structure. However, perfection can be achieved through further study and analysis of the energy absorber. For this concern, this study is made to design an improved thin-walled structure by using a new material and some modifications to determine and improve the energy absorption characteristics in thin-walled tube structure as the energy absorber.

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1.3 Objectives

The main objectives of this research are listed as follows:

a) To develop a nonlinear finite element model for deformation of circular and conical thin-walled tubes during dynamic axial loading.

b) To validate the nonlinear finite element model with experimental results.

c) To perform parametric studies for tubes under dynamic loading and modify the current tube designs to enhance the energy absorption characteristics.

1.4 Scopes

In the initial stage of this research, the specimens of thin-walled tube are tested under dynamic axial loading experiment. LS-DYNA finite element analysis software will be used to simulate the experimental test and the results obtained by LS-DYNA are compared with experiment results for the verification and validation purposes. In addition, LS-DYNA software will be also employed to perform the parametric studies and modification of the thin-walled tubes. The application of using various materials, shapes, geometries and loading conditions of thin-walled tube are discussed in the parametric studies. The main findings from the parametric studies are referred in designing several modified thin-walled tubes. The thin-walled tube with greatest energy absorption characteristics will be proposed at the end of the research.

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1.5 Significance of study

The main contribution of this study is to provide additional research information of thin-walled tube application as energy absorber. This research is expected to get the energy absorption characteristics of improved thin-walled tubes under dynamic axial loading. Since the improved thin-walled tube will be more efficient for the energy absorber, it can be used as the new structure for the application in industry, military, automotive or manufacturing. Thus, the aim to increase the performance of crashworthiness and protect structures from serious damages when subjected to dynamic loading can be achieved.

Besides that, the effects of using various shapes of thin-walled tube to the energy absorption capacity are observed in this study. Furthermore, the study on using various geometries such as thickness, length and diameter of the thin-walled tube will help to provide a design guideline for the engineers, researchers and designers to create the most efficient thin-walled tube in the future. In addition, the results of combining various shapes of thin-walled tubes as a single structure also presented in this study.

This research also presents the effects of using various tube materials on the energy absorption characteristics. The aim is to obtain a light weight and high strength tube that can absorb most kinetic energy during the accident. In fact, the weight reduction in the automotive application improves the performance of vehicle by reducing the fuel consumption, thus reducing the effect of global warming.

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1.6 Thesis outline

This thesis is divided into five chapters. Chapter 1 introduces the overview of the research and also justifies the problem faced by the previous researchers. The objectives and scopes of the research are also presented in this chapter. This chapter ended by description of the significance of study and the contributions of this research.

Chapter 2 explains some of theories regarding to the crashworthiness and impact. The important terms in energy absorption characteristics are also explained in this section. The evolution regarding the research topic that performed by previous researchers are presented in the literature review.

Chapter 3 presents the methods used from the beginning of the research until the data analysis stage. The detail procedures for experiment and simulation using Finite Element Analysis (FEA) are fully described in this section.

Chapter 4 presents the overall results and analysis. Discussions on the results are explained throughout this chapter. Some new modification designs that improved the energy absorption characteristics also have been introduced.

Chapter 5 concludes the overall findings obtained from the study. It is hoped that light can be shed on the recommendations stated in this chapter in providing some ideas to the researcher for further study in this area.

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