IMPACT CHARACTERISTIC AND ENERGY ABSORPTION OF AUXETIC FOAM-FILLED SQUARE TUBES

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I declare that this project report entitled "*Impact Characteristic And Energy Absorption Of Auxetic Foam-Filled Square Tubes"* is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date	:	January 2015

To my beloved parents and my dear brother, for their endless support and encouragement.

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ABSTRACT

Auxetic materials have recently been gaining popularity within the research community due to their enhanced mechanical properties, particularly energy absorption performances. Unlike conventional materials, they exhibit a negative Poisson's ratio when subjected to a uniaxial loading. This present research experimentally and numerically investigates the crush response and energy absorption performances of auxetic foam-filled square tubes under axial loading. For comparison, the crush response and energy absorption of empty and conventional foam-filled squares tubes have also been examined with respect to deformation modes and force displacement curve. Standard compression tests were conducted on a series number of thin-walled tube samples. In addition to this, the fabrication process of conventional and auxetic foam has also been described in this project report. An additional compression test on conventional and auxetic foam has also been conducted to observe the behavior of foam itself. It is evident that the auxetic foam-filled square tubes are superior to empty and conventional foam-filled square tubes in terms of energy absorption capacity. It shows that such tube is preferable as an impact energy absorber due to their ability to withstand axial loads effectively. Furthermore, it is found that the load capacity increases as the crush length increases. Parametric study shows energy absorption increases as aspect ratio increases whereas energy absorption decreases with increasing slenderness ratio. The primary outcome of this study is design information for the use of auxetic foam-filled square tubes as energy absorbers where impact loading is expected particularly in crashworthiness applications.

ABSTRAK

Bahan Auxetic baru-baru ini telah manjadi semakin popular dalam komuniti penyelidikan kerana sifat mekanikal nya dipertingkatkan, terutamanya persembahan sifat tenaga. Tidak seperti bahan konvensional, bahan ini menunjukkan nisbah Poisson yang negatif apabila dikenakan beban ekapaksi. Kajian iniyans dilakukan secara eksperimen dan berangka felah menyiasat kelakuan hentaman dan sifat penyerapan tenaga tiab yans diisikan bahan auxetic di bawah paksi beban. Sebagai perbandingan, sambutan menghancurkan dan tenaga penyerapan bagi tinb kasong dan konvensional diisikan tius juga telah diperiksa berkenaan dengan mod ubah bentuk dan lengkung anjakan. Ujian mampatan standard dijalankan ke atas beberapa siri sampel tiub berdinding nipis. Di samping itu, proses fabrikasi baban konvensional dan auxetic juga telah diterangkan dalam tesis ini. Ujian mampatan tambahan pada babam konvensional dan auxetic juga telah dijalankan untuk memerhatikan kelakuan baban itu sendiri. Ia adalah jelas bahawa auxetic yang telah diisi adalah lebih baik daripeda tiub kosong dan tiub berisi konvensional penyerapan tenaga. Ini menunjukkan bahawa tiub itu adalah lebih baik sebagai penyerap tenaga kesan kerana kemampuan mereka untuk menahan beban paksi berkesan. Tambahan pula, didapati bahawa kapasiti beban yang meningkat di mana panjangnya bertambah menghancurkan. Kajian parametrik menunjukkan penyerapan tenaga bertambah apabila nisbah aspek meningkat manakala penyerapan tenaga berkurangan dengan peningkatan nisbah kelangsingan. Hasil utama kajian ini adalah maklumat reka bentuk untuk penggunaan auxetic yang penuh dalam tiub sebagai penyerap tenaga di mana kesan dijangka terutamanya dalam aplikasi hentaman.

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LIST OF ABBREVIATIONS

EA	-	Energy Absorption
SEA	-	Specific Energy Absorption
CFE	-	Crush Force Efficiency
EAT	-	Empty Aluminium Tube
CFFT	-	Conventional Foam-Filled Tube
AFFT	-	Auxetic Foam-Filled Tube

CHAPTER 1

INTRODUCTION

1.1 Introduction

Higher requirements of improving the crashworthiness efficiency of vehicle structures have drawn growing attention to minimize injuries of drivers and passengers in crashing events. The utilization of the energy absorption devices with high crashworthiness capacity and desirable deformation characteristics has become more and more prevalent. In this respect, energy absorbers allow the vehicle structures to maximize absorption of the kinetic energy yielded during the impact process and to minimize the impact forces transferred from vehicle structure to occupants. Over the past decades, research interests in crashworthiness have resulted in a series of systematic investigations into crash responses of various thin-walled tubal structures with different cross-sectional geometries and wall materials via analytical, experimental and numerical approaches. From the energy absorption point of view, tubal structures are capable of carrying substantial loads for leading to desired deformation, which are much higher than the corresponding ultimate or buckling loads (Abramowicz & Wierzbicki, 1988).

Advanced materials are playing an increasingly important role in improving crashworthiness of thin-walled structures. Auxetic material as a filler of tubes is considered as new candidates for energy absorbers.

1.2 Background of the Study

Materials can be divided into two basic categories: structural or functional. Development of structural materials is focused on improving their mechanical or physical properties, often with a saving in weight or cost. By contrast, functional materials are designed to detect and/or respond to events or stimuli that occur during their lifetime. These materials often display novel and counterintuitive behavior. Materials that contract when heated, and those that expand when subjected to hydrostatic pressure. For example is a remarkable class of materials known as auxetic materials (Evans, 1991(b)), when stretched lengthways, these materials get fatter rather than thinner.

As well as this unique characteristic, auxetic materials have enhanced mechanical and physical properties, which mean that they can actually be classified as both structural and functional materials.

The key to auxetic behavior is a value known as Poisson's ratio. It determines how the thickness of the material changes when it is stretched lengthways. When an elastic band is stretched the material becomes thinner, giving it a positive Poisson's ratio. Indeed, most solids have a Poisson's ratio of around 0.2–0.4. Poisson's ratio is determined by the internal structure of the material. For example, consider a two-dimensional honeycomb deforming by hinging of the ribs forming the network (see Figure 1.1). For the conventional hexagonal geometry (see Figure 1.1(a)), the cells get longer in the x-direction and close up along the y-axis when the material is stretched along the x-axis, giving a positive value for Poisson's ratio. Modifying the honeycomb cell geometry to adopt a 're-entrant' structure (see Figure 1.1(b)) means that the network gets longer in both the x- and y directions when it is stretched, giving it a negative Poisson's ratio and making the material auxetic (Almgren, 1985).

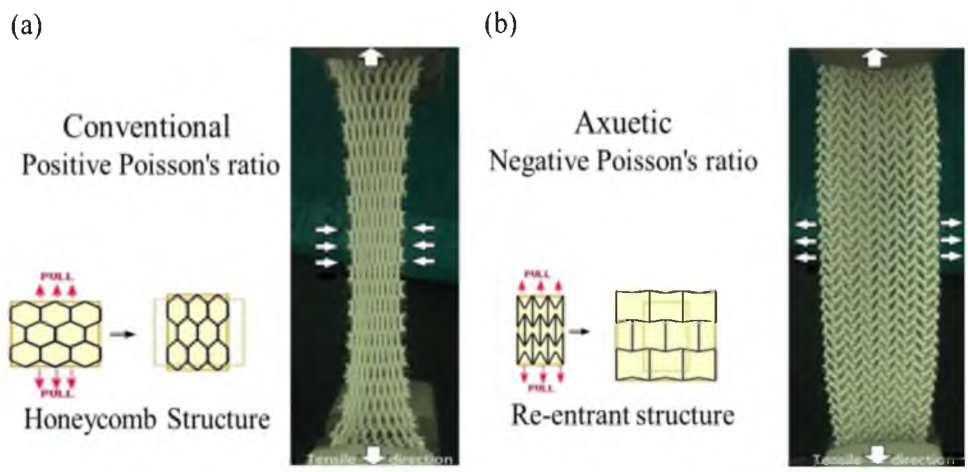

Figure 1.1 (a) Honeycomb structure with positive Poisson's ratio, (b) Re-entrant structure with negative Poisson's ratio (www.hkrita.com).

Auxetic materials are interesting both because of their novel behavior and because of enhancements in other material properties that are related to Poisson's ratio. For example, hardness can be increased in an auxetic material (see Figure 1.2). When an object hits an auxetic material and compresses it in one direction, the auxetic material also contracts laterally material 'flows' into the vicinity of the impact. This creates an area of denser material, which is resistant to indentation. Importantly, elasticity and hence auxetic behavior does not depend on scale. Deformation can take place at the macro-, micro- or even molecular level; this means that we can not only consider auxetic materials, but also auxetic structures.

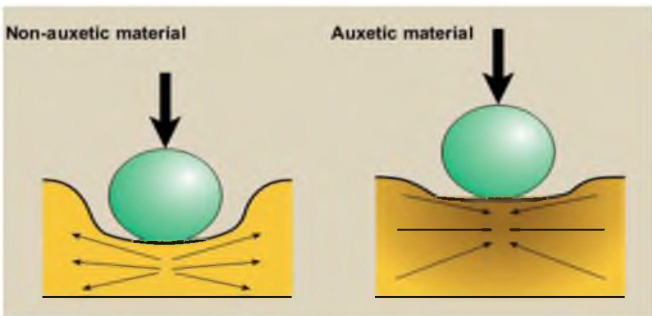

Figure 1.1 Reaction of conventional and auxetic materials into the vicinity of the impact

1.3 Problem Statement

Thin-walled tubes with different filler are widely used as energy absorbing structural components in high-volume automotive and aviation industries. Large deformation occurred when exposed to the crash event, so auxetic material as filler has been paid attention by automotive industries with the aims of weight reduction and increasing energy absorption capacity. A large number of experimental works has been done on auxetic materials, fabricated with a number of modified methods. In the present research, attempt has been done to do analytical and finite element modeling, modifying the fabrication process, also effect of foam as filler on thin-walled tubes have investigated the energy absorption capacity.

1.4 Objective

The primary objective of this thesis is to examine the crush response and energy absorption capacity of auxetic foam-filled square tube under axial loading

1.5 Scopes of the Study

The scope of this project includes the following aspects:

a) Develop preliminary models of thin walled tubes (empty and foam filled)
b) Fabrication of auxetic foam and testing samples
c) Conduct quasi-static compression test on the samples
d) Develop detailed FE model and validate the FE model
e) Conduct a series of parametric study on energy absorption of empty and filled tubes with respect to varying geometry

1.6 Importance of the Study

As the advancement in automotive technology, number of accident is in rise, this automatically increases the importance over the safety of the drivers and passengers. This made automotive engineers to develop structures which can reduce or eliminate the effect of accident on occupant.

Tubular structures provide the widest range of possible energy absorbing systems for any simple structure. Apart from their use as energy absorbers, their common existence as structural elements implies in strict energy absorption capability in the largest part of the vehicles structures. This study focuses on energy absorption capacity of foam-filled tube on vehicles.

1.7 Structure of the Thesis

Chapter 2 involves some of the literatures reviewed and provides the reader with a general understanding of the auxetic material and crashworthiness concepts, are introduced in Chapter 2, the methodology used in this research and the established process of fabricating auxetic foam, experimental tests, and simulation are explained in Chapter 3.

Comparison of energy absorptions of empty tube, conventional foam-filled tube and auxetic foam-filled tube for two different geometries and validation of finite element analysis with experimental tests are presented in Chapter 4.

Finally a conclusion is made in Chapter 5 through comparison of energy absorptions of empty tube, conventional foam-filled tube and auxetic foam-filled tube.

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