DEVELOPMENT OF FINITE ELEMENT MODEL FOR POLYMER LATTICE STRUCTURE WITH DIFFERENT ASPECT RATIO

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DECLARATION

I declare that this project report entitled “Development Of Finite Element Model For Polymer Lattice Structure With Different Aspect Ratio” is the result of my own work except as cited in the references

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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 (Structure & Materials).

Signature :. ....

Name of Supervisor : DR RAFIDAH BINTI HASAN

Date : ....

DEDICATION

I dedicate this thesis to my beloved mother and father; Siti Melati binti Sufaat and Nasaruddin bin Najatuddin who have always been nearest in my heart although they are far away at hometown, Kemaman, Terengganu. Unlimited love towards both of you for patiently advice and give me passion in this life. I also dedicate this thesis to all my siblings (Aina, Ummi, Zaki, Aimi dan Muhayya) for being part of my life and also as one of the reason I want to be a better person in the future. Not to forget also my best friend, Muhammad Azrain bin Mohammad for showing me the true meaning of friendship and always there by my side during good and bad times. Hopefully all of us endowed with great success in this world and the hereafter.

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ABSTRACT

Lightweight material is more likely to be used in transportation industries such as aerospace, automobile, shipping and military since it can reduce the usage of energy and costs beside conserve the resources. Therefore, lattice structure that made up from ABS plastic was introduced and investigated in this project. The investigation will be based on development of numerical methods in the means of finite element (FE) methods in order to determine the behaviour of the lattice structure. Therefore, this project will design and develop FE model of lattice structure with different aspect ratio. In addition, the result from analysis using the software will then compared with experiment that will be obtained from another project. The designing phase of the lattice structure model is by using SolidWorks software with different aspect ratio; 0.18, 0.23 and 0.28 meanwhile ANSYS software is used for the analysis of the model under compression loadings. As expected, bigger aspect ratio gives higher compressive yield force. Furthermore, there are huge differences between the analysis and experiment data which is then discussed in the discussion chapter. Some recommendation is done in order to improve the result of this study in the future.

ABSTRAK

Bahan ringan adalah lebih cenderung untuk digunakan dalam industri pengangkutan seperti aeroangkasa, kereta penghantaran dan ketenteraan kerana mampu untuk mengurangkan penggunaan tenaga dan pengeluaran kos disamping dapat memelihara alam sekitar. Oleh itu projek ini memperkenalkan struktur kekisi yang diperbuat daripada ABS plastic. Penyelidikan akan dilakukan berdasarkan kepada pembangunan kaedah berangka dalam cara kaedah unsur terhingga (FE) untuk mengkaji sifat kekisi struktur. Oleh itu, projek ini akan mereka bentuk dan membangunkan model unsur terhingga struktur kekisi dengan nisbah aspek yang berbeza. Di samping itu, hasil daripada analisis perisian kemudian akan dibandingkan dengan eksperimen yang akan diperolehi daripada projek lain. Fasa mereka bentuk model struktur kekisi adalah dengan menggunakan perisian SolidWorks dengan nisbah aspek yang berbeza; 0.18, 0.23 dan 0.28 Sementara itu perisian ANSYS digunakan untuk analisis model di bawah beban mampatan. Seperti yang dijangka, nisbah aspek yang lebih besar memberikan kuasa hasil mampatan yang lebih tinggi. Tambahan pula, terdapat perbezaan yang besar antara analisis dan data eksperimen yang kemudiannya dibincangkan dalam bab perbincangan. Beberapa cadangan dilakukan dalam usaha untuk meningkatkan hasil daripada kajian ini pada masa akan datang.

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LIST OF ABBREVATIONS

2D	Two Dimension
3D	Three Dimension
ABS	Acrylonitrile-Butadiene-Styrene
BCC	Body Centred Cubic
FCC	Face Centred Cubic
FE	Finite Element
FEM	Finite Element Method
UAV	Unmanned Aerial Vehicle

LIST OF SYMBOLS

A	=	Length of a strut
H	=	Hypotenuse of a unit cell structure
S	=	Length of two Strut
L	=	Length of a unit cell side
θ	=	Angle of strut to base of a unit cell
α	=	Angle of strut with respect to x-axis
β	=	Angle of strut with respect to y-axis
γ	=	Angle of strut with respect to z-axis
d	=	Diameter of strut
σ_{ult}	=	Ultimate Tensile Stress
σ_Y	=	Yield Tensile Stress
E	=	Modulus of Elasticity
ρ	=	Density
v	=	Poisson's ratio
E	=	Elastic Modulus
F_{CY}	=	Compressive Yield Force

CHAPTER 1

INTRODUCTION

1.1 Background

In certain industries such as aerospace, automobile, shipping and military, it is more likely to use lighter material in the main structure application. One of the important types of light material would be cellular structure. This is because of the porous structure that makes it lighter than solid structure since the usage of material is lesser. As a result, the cost of material can also be reduced if viewed from the perspective of economy. Moreover, lightweight cellular structure that is used in transportation will upgrade vehicle performance and safety, besides it also cut offs the transportation cost (Meisel et al., 2012). Furthermore, this type of structure offers many other advantages such as the ability to behave as thermal insulator and the energy absorber (Ashby et al., 2000). There are many type of cellular structure that can be found such as foams, honeycombs, truss structure and lattice structure. Each type of the cellular structure has its own advantages and disadvantages depend on the appropriateness of its usage in particular applications.

From previous study, finite element (FE) model has been used to simulate response of truss structures under variety of compressive loading. The FE model analysis was also used to predict the response of the lattice structure using beam elements to represent the whole structure by only analysing one unit cell of the lattice structure (Ushijima et al., 2010). However, most of the FE models for lattice structure as reported in previous studies were based on metallic materials such as stainless steel, titanium and aluminium. It is hardly to find study on the development of the lattice structure FE modelling which is based on polymer material. Therefore, there is potential to further explore in this area.

In this study FE model will be developed based on polymer lattice structure in body centred cubic (BCC) arrangement. Lattice structure is regular, periodic configuration or arrangement of trusses in an area or space to form a whole body structure. The type of cellular structure that involved in this study is the micro-lattice structure that made up from acrylonitrile-butadiene-styrene (ABS) polymers which is manufactured using three-dimension (3D) printer. The lattice structure will be designed in cube shape (20mm X 20mm X 20mm) that consist of four unit cells of lattice structure in a row which means that 5mm length for a unit cell while the length for all the struts in each unit cell must be equal. Thus the only manipulated variable in this study would be the diameter and type of arrangement of the strut. The variability in the strut's diameter will lead to different value of aspect ratio. The lattice structure must first be designed by using SolidWorks software and will be analysed by using ANSYS software under compressive loading. The result of the test will then be compared to several aspect ratio and experiment results to be discussed.

1.2 Problem Statement

Previously, there are many studies on micro-lattice structure manufactured from metals and alloys. In current proposed study, the material of the lattice structure is manufactured from acrylonitrile-butadiene-styrene (ABS) polymers which are one of the thermoplastic polymers. In order to investigate the mechanical behaviour of the lattice structure, numerical methods in the means of finite element (FE) methods are used. FE model can be developed to investigate how different geometrical parameters affect the mechanical properties of the lattice structure core (Schneider et al., 2015). The produced result is expected to reveal the overall compressive strength, deformation and other behaviour related to this study.

It is found that the polymer has an increasing usage especially in modern engineering applications. Usually, polymer is used in field that requires material which is light and strong such as in aerospace and automotive (Smith et al. 2013). In modern aerospace applications, polymer can be suggested as the main material of battery casing for unmanned aerial vehicle (UAV) which has an increasing importance in assisting human life. It is predicted that the battery efficiency can be increased since the total weight of the vehicle can be reduced when using micro-lattice structure in the components.

1.3 Objective

a) To design and develop the finite element (FE) model of lattice structure with different aspect ratio by using ANSYS software.

b) To compare the result from the analysis of the software with experiment.

1.4 Scope of Project

a) Model development for finite element (FE) simulation (using ANSYS) of micro-lattice unit cell.

b) Analysis of BCC micro-lattice unit cell with different aspect ratio and strut arrangement.

c) Comparison of FE analysis with results of experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

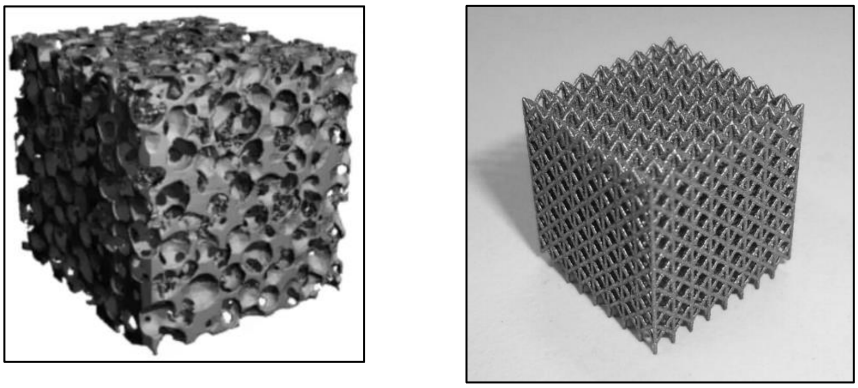
Reviewing the background of this study is vital in the process of getting the ideas and understanding it before going further in progress. This chapter will go through the topics that related are to this study such as the contextual of specimens used and its materials background. Furthermore, this section will also discover more about the investigation related to this study including engineering test and introduction of software used for the analysis. All information is gathered from reasonable sources such as journal articles, online websites, magazines and academic books.

2.2 Cellular Structures

Cellular structures have been widely used in many engineering fields and the usage depends on its advantages and disadvantages in each type of cellular structures. One of the advantages of cellular structure can be light in weight. Due to this kind of advantage, it can attract variety of industries especially automobile, shipping, military and aerospace (Smith et al., 2013). Cellular structure is light in weight due to its lesser amount of material to build up the structure as compared to full solid structure. Besides that, its porous structure will give good ventilation system, hence leading the structure to be a good heat insulator. Therefore, some other advantages that can be obtained from cellular structures are superior sound proofing characteristics and low thermal conductivity (Smith et al., 2013).

Furthermore, it has been shown that, cellular structures such as foams are suitable to be used in wide range of applications such as energy absorption, thermal and acoustic management and biocompatible inserts (Ashby et al., 2000). This is due to its networked structure which enabling it to transmit more energy from one cell to another; thus make it good in energy absorber.

Basically, cellular structures are divided into two categories which are stochastic (random) and periodic cells arrangement. Stochastic cells arrangement is traditional cellular structure with random and unpredictable structures as shown for example by foam structures in Figure 2.1(a). Therefore, it is hard to conduct the analysis and topology towards the structure during any mechanical test. Consequently, it is difficult to predict the mechanical properties and the yield surfaces are always built with the help of experiments (Huang, 2003). In the other hand, periodic cells arrangement which result from regular cells arrangement does not have this kind of problem. Periodic cells arrangements with regular unit cell that consist of straight struts are having mechanical properties which are predictable and designable (Deshpande et al., 2001). Furthermore, periodic cells arrangement can be categorized as a unit cell that is repeated either in two-dimension (2D) or three-dimension (3D) (Gümrük & Mines, 2013). The example of 2D repeated unit cells are honeycomb. Meanwhile, lattice structures are the example of 3D repeated unit cells as presented in Figure 2.1(b).



(a) (b)

Figure 2.1: Cellular Structure: (a) Stochastic Structure; (b) Periodic Structure

(*Source: (a) Jinnapart & Kennedy, 2011; (b) Brandt, 2015)*

2.2.1 Lattice Structures

Lattice Structures are modern type of cellular structure which resulting from periodically cells arrangement. Two elements are needed in order to build a unit cell of lattice structure, which are crystal basis and lattice geometry. The lattice geometry plus the crystal basis equals the lattice structure (Mitchell, 2006). The crystal basis is the arrangement of atoms that is particular to the mineral being considered and each of it is called a unit cell. Meanwhile, lattice geometry is point in crystal with specific arrangement of atoms reproduced many times in the crystal (Evan & Grove, 2004). This unit cells are repeated over and over again in 3D to make up a whole body of lattice structures.

There are several types of arrangements that can be found in lattice structures and some are from crystal structure in certain material. As for the first example, diamond crystal structures which are from diamond, silicone or germanium element. Furthermore, diamond crystal structures are faces-centered cubic (FCC) atom arrangement as shown in Figure 2.2.

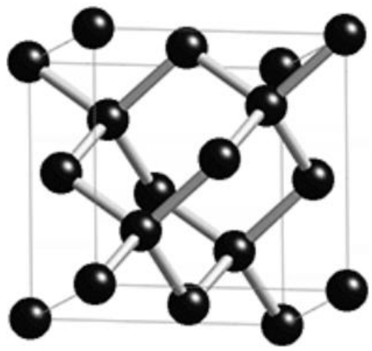
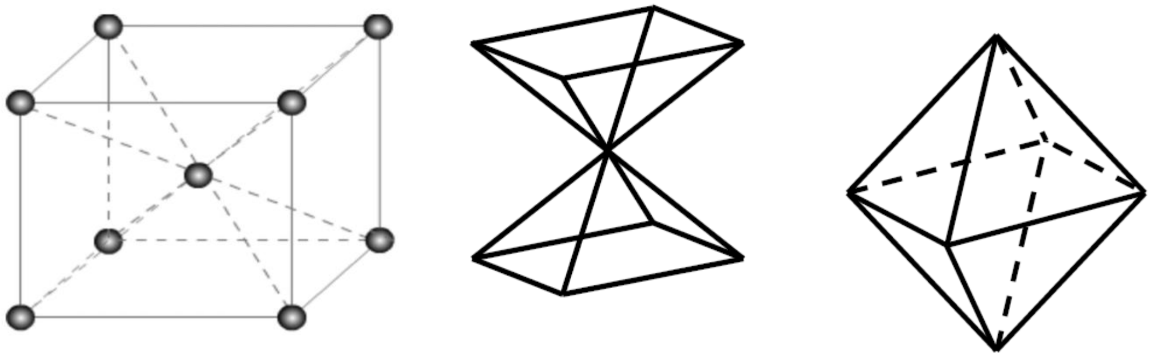


Figure 2.2: One Unit of Diamond crystal structure

(*Source: Eppstein, 2015)*

Type of crystal structure that is used in this study is pyramidal structure which is also known as body-centered cubic (BCC) arrangement. This kind of structure can be found in caesium chloride compound. Based on the geometry coordinate of this structure, caesium is known as crystal basis of this structure which located at the center of the unit cell with coordinate [0, 0, 0]. Meanwhile, eight atom of chloride located at the edge of the unit cell with coordinate [1/2, 1/2, 1/2] and known as lattice geometry (Mitchell, 2006). Another type of cell arrangement that will be used in this study is octahedral structures which are also in BCC arrangement. Actually, octahedral is similar like pyramidal structures which can be obtained by shifting the unit cell of pyramidal structure with the neighbouring unit cell. Refer Figure 2.3 for more information.



(a) (b) (c)

Figure 2.3: (a) One Unit Cell of BCC arrangement; (b) Pyramidal Structure; (c) Octahedral Structure

(*Source: (a)Excellup, 2014; (b) & (c) Fan et al., 2008*)

In order to form a mechanical lattice structure of BCC, edges in this structure are connected with each other by using straight struts. Therefore, a packed of one unit cell of BCC will become a cubic lattice structure. Since these structures are made up from periodically cells arrangement, the stress applied in certain situation will be distributed evenly throughout the strut which lead the structure to be stronger and tougher compared to stochastic cell arrangements. Periodic structures have superior mechanical properties including energy absorption, strength and stiffness compared to stochastic structures (Meisel et al., 2012).