EFFECT OF ASPECT RATIO ON STRENGTH OF LATTICE STRUCTURE MANUFACTURED USING 3D PRINTER

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DECLARATION

I declare that this project report entitled "Effect Of Aspect Ratio On Strength Of Lattice Structure Manufactured Using 3D Printer" is the result of my own work except as cited in the references

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Date : 27/06/2016

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of degree of Bachelor of Mechanical Engineering (Structure&Materials)

Signature : ....

Name of Supervisor : DR. RAFIDAH BINTI HASAN

Date : 27/6/2016

DEDICATION

Dedicated to my beloved mother and father,

Azlina binti Ahmad & Baharudin bin Baba

My supporting siblings,

Nurlyana & Nurhanisha

and

My entire friends in UteM

For their encouragement

ABSTRACT

These lattice structures possess exceptional mechanical strength resulting in highly efficient load supporting systems. The lattice structure has been receiving of interest to a variety application areas and industries including automotive, shipping and aeronautic. The metallic or polymer micro lattice material is a type of periodic material which can be categorized as lightweight and energy-absorbing structure. The aim in this study is to analyse the strength of polymer lattice structure with different ratio that is 0.185, 0,231 and 0.277. The lattice structure was designed using the SolidWork software and fabricated using CubePro 3D printer machine. The Instron 5585 Compression Test machine was using to analyse the strength of each lattice structure. As a result, lattice structures with aspect ratio 0.231 showed the better result in term of constrain the impact force and fit the criteria of a good absorption impact structure.

ABSTRAK

Struktur kekisi menunjukkan kekuatan mekanikal yang amat luar biasa dalam menjadi sistem sokongan yang cekap. Stuktur kekisi ini juga mendapat perhatian dalam pelbagai kegunaan dalam bidang industri termasuk automotif, perkapalan dan aeronautik. Struktur kekisi logam atau polimer adalah jenis struktur bahan berkala yang boleh dikategorikan sebagai bahan yang ringan dan struktur yang menyerap tenaga. Tujuan utama kajian ini adalah untuk menganalisa kekuatan struktur kekisi polimer dengan berlainan aspek nisbah iaitu 0.185, 0.231, dan 0.277. Struktur kekisi ini direka bentuk menggunakan perisian SolidWork dan difabrikasi menggunakan mesin percetakan 3D CubePro. Mesin pemampat Instron 5585 digunakan untuk menganalisa kekuatan setiap struktur kekisi. Sebagai keputusannya, struktur kekisi dengan aspek nisbah 0.231 menunjukkan keputusan yang memberangsangkan dalam menahan daya impak dan memenuhi kriteria sebagai struktur yang bagus dalam menyerap daya impak.

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LIST OF ABBEREVATIONS

3D	3 Dimensions
ABS	Acrylonitrile Butadiene Styrene

LIST OF SYMBOLS

A	=	Angle of strut from base
B	=	Length of strut
D	=	Length of unit cell
L	=	Hypotenuse
F	=	Height of one unit cell
C	=	Length base of one unit cell
ρ	=	Density
E	=	Elastic Modulus
kg	=	kilogram
m	=	meter

CHAPTER 1

INTRODUCTION

1.0 Background

Cellular material or micro lattice material has been receiving interest from a variety application areas and industries including automotive, shipping and aeronautic. The metallic micro lattice material is a type of periodic material which can be categorized as lightweight and energy-absorbing structure. The applications of metallic micro lattice materials in areas such as the cores of sandwich panels, thermal insulation, packaging and some automotive parts are due to their strength properties and superior specific stiffness. It is found that previous studies on micro lattice were developed and manufactured from metallic structure.

In this study, the micro lattice structure will be developed from polymer material. Polymer is a material which made up of several types of alloying elements such as epoxy, phenolic and polyester. It can be processed in various ways and comes with different colours. The polymer micro lattice structure will be designed with three different aspect ratios to study their strength under particular load applied. Therefore, one solid cube with size 20mm × 20mm × 20mm will be used as a controlled variable to compare the strength with that of micro lattice structure block specimen according to their ratio.

The micro lattice structures will be designed by using Solid Work software and specimen will be fabricated by using CubePro 3D printer which is available in Faculty of Mechanical Engineering Laboratory. This equipment offers a cost effective process as compared with the expensive investment in prototyping injection mould tool. The micro lattice structures will be tested by using Instron 5585 compression test machine according to ASTM D6641 standard which is used for test method for compressive properties of polymer. The ASTM D6641 standard is given in **Appendix A**.

1.1 PROBLEM STATEMENT

Previous studies on strength analysis of micro lattice structure were based on specimen from metallic material. In this research the micro lattice specimen will be constructed using polymer material which is known as lightweight material and low in cost as compared to metallic material. The development of lattice structure from polymer material using 3D printer is found to be an effective solution, if the lightweight lattice structure material is planned to be widely used in engineering applications.

1.2 OBJECTIVE

1. To design the micro lattice structure with different aspect ratio using Solid Work software and fabricate the lattice structure using 3D printer.
2. To evaluate the strength of micro lattice structure with different aspect ratio using Instron 5585 compression tester machine.

1.3 SCOPE

1. Design of the micro lattice structure with different aspect ratio using Solid Work software.
2. Exploration of 3D printer capabilities and micro lattice structure by using CubePro 3D printer.
3. Strength analysis of micro lattice structure using the Instron compression tester machine by following ASTM D6641 standard.

CHAPTER 2

LITERATURE REVIEW

2.1 Cellular and lattice structure

Cellular solids, such as foams are widely used in engineering applications. In these applications, it is important to know their mechanical properties and the variation of these properties with the presence of defects. Several models have been proposed to obtain the mechanical properties of cellular materials (Deshpande, 2001). A cellular solid is made up of an interconnected network of solid struts or plates which form the edges and faces of cells. The simplest form of cellular structure is a two dimensional array of polygons which pack to fill a plane area like the hexagonal cell of the bee. Moreover, for this reason we call such two-dimensional cellular material as honeycomb. More commonly, the cells are polyhedral which pack in three dimensions to form cellular materials which are called foams (Amin, 2008). Example of polymeric foam is shown **Figure 2.0**

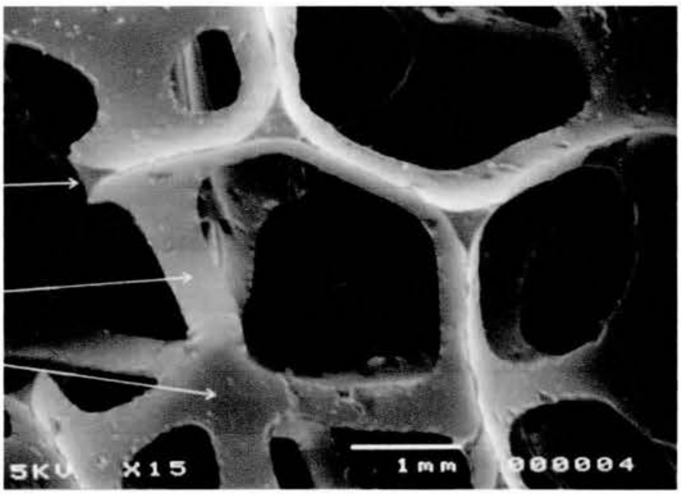

Figure 2.0: Polymeric Foam of Rapid Prototype Structure

(Source: Mills, 2006)

Polymeric foams and lattice structure which are used for good cushioning, packaging and insulation for structure can be good energy absorbers during impact loading (Amin, 2008). Some lattice structure systems can be good sound dampers and afford thermal isolation opportunities if the structures were fabricated using plasticity material (Ashby, 1997). There is a growing interest in extending shock protection concepts developed for low-velocity impacts such as component packaging, head impact protection and vehicle occupant injury prevention during automobile accidents (Wadley, 2007). In **Figure 2.1,** the example of lattice structure after impact loading test is shown.

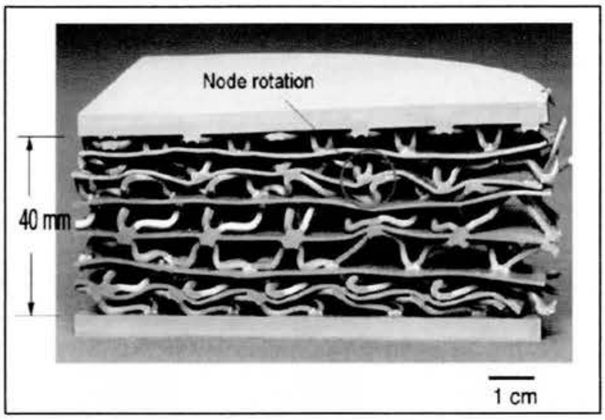

Figure 2.1: Lattice structure after impact test.

(Source: Wadley et al, 2007)

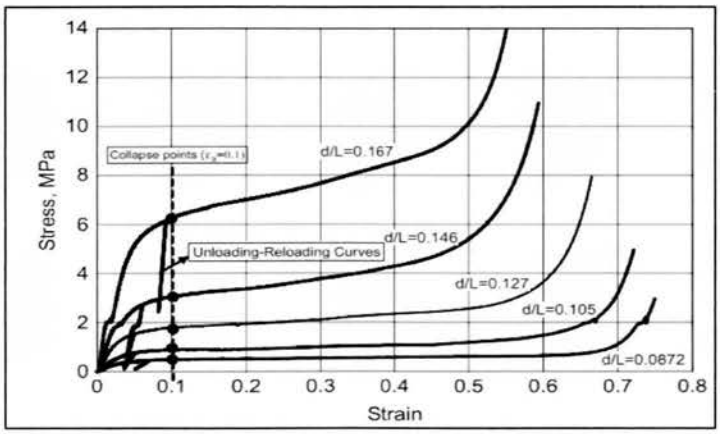

Figure 2.2: Result of strength lattice structure with different aspect ratio

(Source: Gumruk and Mines, 2013)

Based on **Figure 2.2** the lattice structure strength was related to their aspect ratio. The pyramidal structure in this project was fabricated with different aspect ratio to investigate the effective properties of lattice material. From **Figure 2.2**, it is shown that smaller relative density of lattice structure will make the collapse stress and elastic stiffness increase. Besides that, plastic collapse region increase with decrease of aspect ratio or relative density. Average strut diameter will be calculated by using definition of relative density and mass of lattice block. The thicker the struts mean that the relative density of lattice structure will be increased. It is found that the load carrying capability of the structure is affected by the number of vertical reinforcements, strut edge size and cell size. Peak and collapse stress values increase almost linearly with relative density (Sabina, 2014).

Furthermore, relative density and strut geometry of lattice structure was important because that was related with the plastic yielding behaviour. If relative density is smaller than critical value, the micro compression buckling of strut will dominate the macro tensile loading or macro failure mode (Gumruk and Mines, 2013). Based on previous articles, mechanics properties of lattice structure received attention to analyse the effective stiffness of three dimensional stretching that will be dominated by lattice structure. In this project, the pyramidal lattice structure were made up of polymer materials that were fabricated using rapid prototype to investigate their strength subjected to compression loading.

2.2 Polymer

Based on **Figure 2.3**, polymers are made up of many molecules all bond together to form really long chains and produced a complicated structures. In addition, the responses of things that are made of polymers are depending on how their atoms and molecules are connected. A linear polymer is made up of one monomer after another, hooked together in a long chain. This process causes the polymerization that is the method of creating a synthetic polymer by combining many small monomer molecules into chain held together by covalent bonds. There are two major forms of polymerization, step growth polymerization and chain growth polymerization. The main difference between the two types of polymerization is that in chain growth polymerization, monomer molecules are added to the chain one at a time.

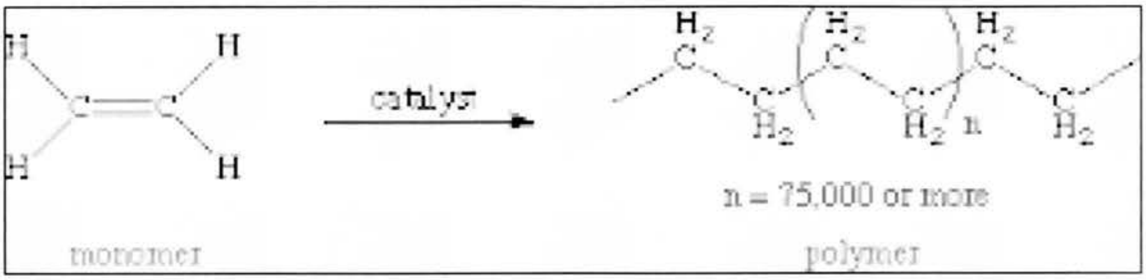

Figure 2.3: Process of polymerization

(Source: Pathiraja and Raju, 2003)

Table 2.1: List of common polymer and their uses

Polymer	Uses
Polyethylene low density (LDPE)	Grocery bags
Polyethylene high density (HDPE)	Detergent bottles, toys
Polystyrene (PS)	Toys, foam
Poly vinyl chloride (PVC)	Piping, decking

(Source: www.compositeabout.com, 2015)

Polymer material is a material that can be recycled and eco-friendly. Plastic material can be recycled by melting process as well as the polymer material. These polymers can be molded or extruded into desired shapes. There are two main types of plastics: thermoplastics and thermosetting polymers. Thermoplastics can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that they can be made into new plastics products (Hayelom, 2014).

The fracture strength of polymers is much lower than metals. Fracture initiates when there are cracks at flaws and scratches that involves breaking of covalent bonds in the chains. Thermoplastics also have the same properties like polymers in term of brittle and ductile fracture. The brittle fracture will occur at low temperatures while ductile fractures occur at high temperatures. The polymer lattice structure absorb twice impact energy after normalizing process (Qizhen et al, 2008). In **Figure 2.4**, show the result impact test of polymer lattice structure after normalizing process.

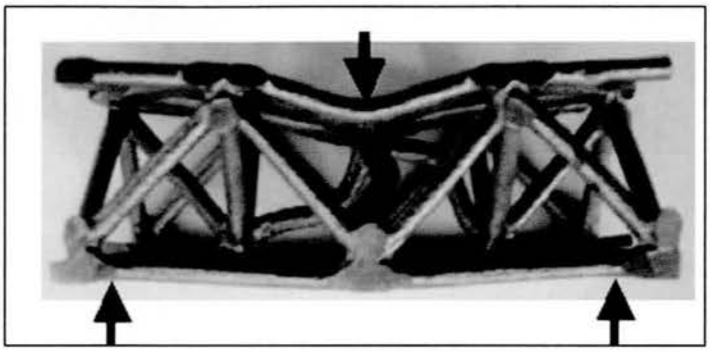

Figure 2.4: Polymer lattice structure while impact test

(Source: Qizhen et al, 2008)

In this current project, the lattice structure is constructed in the arrangement of body centre cubic (BCC) using polymer based materials in order to study the response of loading. In other studies, some utilize open cell polymer templates for investment casting, chemical vapor deposition (INCO Ltd, 1998) or slurry coating (Frame, 2000). Others utilize hollow spheres (Jackel 1983) or aggregates of soluble particles into which metals can be injected and solidified (Chen et al, 2001). Polymer is a substance that can be diluted. Therefore, the polymer which is in a liquid form can be injected into a mold or formed using rapid prototype as shown in **Figure 2.5(b)**. Based on the **Figure 2.5(a)**, the method produces a polymer lattice structure mold process is quite difficult because it requires the skill to make molds and its cost is relatively high compared to the process of rapid prototype.

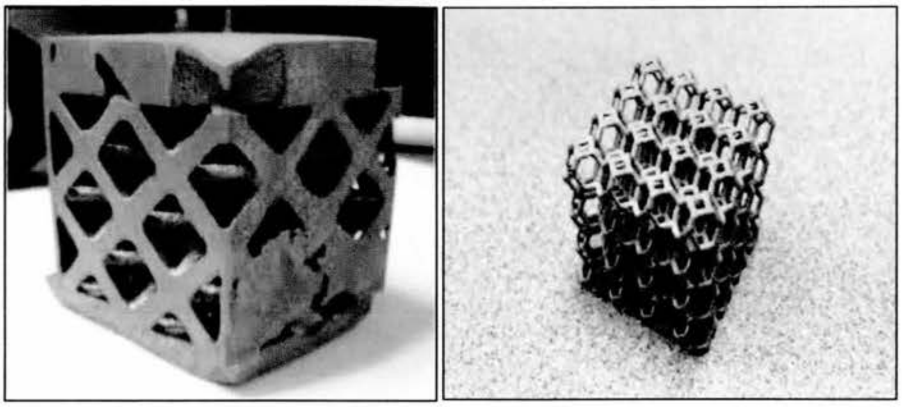

Figure 2.5: (a) Polymer lattice structure using moulding process (b) Polymer lattice structure using rapid prototype process

(Source: ((a) www.symposium.engr.utexas.edu (b) www.3dprint.com), 2015)

2.3 3D printing

3D printing is also known as rapid prototyping form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. Moreover in the **Figure 2.6**, 3D printing is a mechanized method where 3D objects can be quickly made on a reasonably sized machine connected to a computer containing blueprints for the object. The 3D printing concept of custom manufacturing is exciting to nearly everyone because the revolutionary method for creating 3D models with the use of inkjet technology saves time and cost by eliminating the need to design, print and glue together separate model parts. From this technology, you can create a complete model in a single process using 3D printing (Tyagi, 2014)

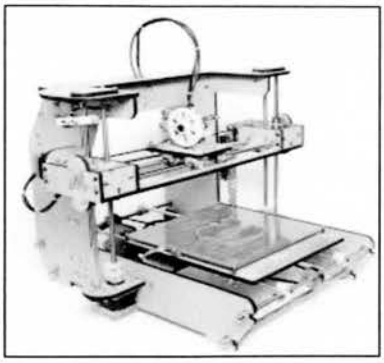

Figure 2.6: Typical 3D printer

(Source: www.3ders.org, 2015)

3D Printers are machines that receive digital data by printing layer by layer that will produce physical 3D models. The physical models of objects can be made either by designing with a CAD program or scanning with a 3D Scanner. It has been receiving attention from variety of industries including architecture, engineering and construction, automotive, aerospace, dental and medical industries, footwear, industrial design, consumer products, education and jewellery (Siddharth and Regina, 2014).

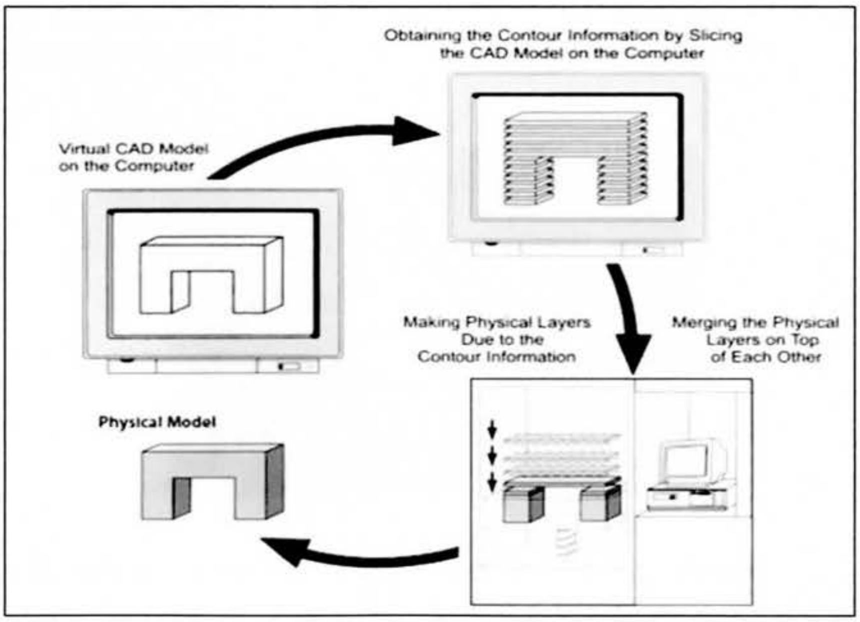

Figure 2.7: Working process 3D printer

(Source: www.wiki.aalto.fi.com,2015)