# EFFECT OF NODE ENHANCEMENT ON STRENGTH OF BODY-CENTERED-CUBIC (BCC) POLYMER LATTICE–STRUCTURE MATERIAL

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**A report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering**

**Faculty of Mechanical Engineering**

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## DECLARATION

I declare that this research project entitled "Effect of Node Enhancement on Strength of Body-Centered-Cubic (BCC) Polymer Lattice-Structure Material" is the result of my own work except as cited in reference.

| | | |
|---|---|---|
| Signature | : | |
| Name | : | AHMAD WAHI BIN AB.RAHMAN |
| Date | : | |

**APPROVAL**

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

| | | |
|---|---|---|
| Signature | : | |
| Name of Supervisor | : | DR.RAFIDAH BINTI HASAN |
| Date | : | |

## DEDICATION

Dedicated to my beloved father and mother,

my friends and family members.

For their encouragement and supports throughout the research.

# ABSTRACT

The lattice-structure is used to enhance the strength of light-weighted material and 3D printing is a suitable method to produce light-weighted lattice-structure. This research focuses on the compressive strength of 3D printed polymer lattice-structure for lattice-structure without enhancement, fillet and ball enhancement with 1.4 mm and 1.6 mm diameter. The Acrylonitrile Butadiene Styrene (ABS) polymer is used as the 3D printed material in this research. Lattice-structures without enhancement and with enhancement have been designed by using Solidwork software. The 3D printed lattice structure specimens are then tested by using Instron universal test with ASTM D695 standard as reference. The result reveals that the specimen with ball enhancement has increased the young modulus for 1.6 mm diameter. The data and results from compression test which are then analysed by using hypothesis test show that the specimen fabricated with ball enhancement, 70 µm layer resolutions, solid print strength, honeycomb print pattern and 1.6 mm strut diameter has experienced different young modulus value as compared to that without enhancement.

## *ABSTRAK*

*Struktur kekisi digunakan untuk meningkatkan kekuatan dan mampatan bahan mentah yang ringan dan percetakan tiga dimensi (3D) adalah cara pembuatan kekisi yang sesuai. Kajian ini telah dijalankan untuk mendapatkan kekuatan dan mampatan struktur kekisi yang dicetak oleh pencetakan tiga dimensi (3D) bagi struktur kekisi tanpa penambahbaikan nod, penambahbaikan bebola dan filet dengan 1.4 mm dan 1.6 mm diameter. Acrylonitrile Butadiene Styrene (ABS) polimer telah digunakan sebagai bahan percetakan 3D dalam kajian ini. Struktur kekisi tanpa penambahbaikan dan dengan penambahbaikan telah direka dengan menggunakan perisian Solidwork. Selepas itu, spesimen kekisi yang dicetak telah diuji dengan menggunakan mesin Instron bagi ujian mampatan mengikut Standard ASTM D695 sebagai rujukan. Hasilnya telah menunjukkan spesimen dengan penambahbaikan bebola mempunyai pertambahan modulus young untuk 1.6 mm diameter. Data dan keputusan dari ujian mampatan kemudian yang dianalisis dengan menggunakan ujian hipotesis telah menunjukkan bahawa spesimen yang dicetak dengan penambahbaikan bebola, 70 µm sebagai solusi lapisan, keadaan pepejal sebagai kekuatan cetakan, susun atur honeycomb sebagai corak cetakan dan 1.6 mm diameter strut mempunyai perbezaan modulus young apabila dibandingkan dengan spesimen tanpa penambahbaikan.*

## ACKNOWLEDGEMENT

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Lastly, special thanks to all my friends and family members for their encouragement and supports in completion this research.

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## LIST OF ABBEREVATIONS

| | |
|---|---|
| 2D | 2 Dimensional |
| 3D | 3 Dimensional |
| ABS | Acrylonitrile Butadiene Styrene |
| BCC | Body-centered-cubic |
| CAD | Computer Aided Design |
| EBM | Electron Beam Melting |
| EIA | Electronic Industries Association |
| FCC | Face-centered-cubic |
| FDM | Fuse Deposition Modelling |
| SLM | Selective Laser Melting |
| SLS | Selective Laser Sintering |
| STL | Stereolithography |

# LIST OF SYMBOL

| | | |
|---|---|---|
| $\alpha$ | = | significant level |
| DF | = | Degree of Freedom |
| F | = | Test Statistic for F-test |
| n | = | Number of Sets |
| $S$ | = | Standard Deviation |
| $t$ | = | Test Statistic for t-test |
| $\mu$ | = | Mean |
| $\sigma$ | = | Variance |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Lattice-structure is a newly developed material which have high potential to be used in lightweight component such as drone. Lattice-structures are arranged in a periodical cellular structure. Example of other cellular structures are honeycombs and foams. Lattice-structure materials have good thermal and acoustic insulation properties as well as provide good energy absorption characteristics (Gibson and Ashby, 1997). Many researches prefer using lattice-structure material as compared to honeycombs and foams because the arrangement of structure are more compact and less miserable (Ushijima et al., 2016 ). Thus, the lattice-structure material has received considerable research attention because the advantages in providing light, stiff, and strong material compared to foams (Ashby et al., 2000). The lattice structure are usually arranged in body-centered cubic (BCC) and face-centered cubic (FCC) architecture. By using 3D printing technology which is one of the additive layer manufacturing process, one can produce lattice structure blocks down to tiny lattice structure which scales $10^{-6}$, which is micro in size (Mines, 2008).

Additive manufacturing is usually used to fabricate or manufacture parts from computer aided design (CAD). 3D printing is one of the additive manufacturing that gives high geometric complexity, customizability and metal grading to the fabrication of parts (Rosen, 2007). There are many useful products that have been fabricated by using 3D printing technology, for example, in automotive and aerospace industry such as car bumpers and spare parts for an airplane (Rehme, 2010). The 3D printing technology is started by drawing the design in Computer Aided Design (CAD) software for example Solidwork and Catia. The 3D printer will receive data of the design and generate the desired product layer by layer.

In this research, effect of node enhancement on strength of body-centered cubic (BCC) polymer lattice structure material will be studied. The lattice-structure with node enhancement will be fabricated by using Cube Pro 3D printer. The strength of polymer lattice-structure blocks with and without node enhancement will be analysed and compared.

## 1.2 PROBLEM STATEMENT

Strength of polymer lattice-structure with BCC configuration has been determined from previous researches. However, there are stress concentration area parts in original BCC lattice-structure design. It is thought that further improvement can be done in order to produce lattice-material with less stress concentration areas. Thus, new designs of BCC lattice-structure material with node enhancements are proposed and will be compared with the specimens without node enhancement structure.

## 1.3 OBJECTIVES

The objective of this study is to study the effect of node enhancement design on compression strength of BCC polymer lattice-structure material manufactured by using FDM machine which is one of the additive layer manufacturing.

## 1.4 SCOPE OF PROJECT

The scope of this research are:

1. Design of BCC lattice-structure blocks with node enhancement parts and areas by using Solidwork, a software of computer-aided design.
2. Fabrication of BCC lattice-structure blocks using CubePro 3D printing machine and acrylonitrile butadiene styrene (ABS) filament.
3. Compression test of lattice-structure blocks to test the strength by using Instron 5585 universal test machine.
4. Hypothesis test on the results to analyse the effect of node enhancement on the BCC polymer lattice-structure.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In this chapter, past researches and studies about lattice-structure, 3D printing, ABS polymer, and compression test will be studied. The goal of studying past research projects is to gain a knowledge, theories and methodologies about 3D printing. By studying the past researches, the data and result obtained will be compared in order to support the findings in present research.

## 2.2 LATTICE-STRUCTURE MATERIAL

Lattice-structure material is a cellular structure which is made up of struts in crisscrossed formation (Bourzac, 2014). Thus, due to the struts arrangement, several studies have focused to develop lattice-structure on application of light weighted materials to be applied in the construction of bridge and building for example. Lightweight structural application is suitable to use lattice-structure material because of strength-to-weight scaling and strong stiffness (Zheng et al., 2014). In aeronautics field, the body of aeroplane was built from lattice-structure material as the weight is save up to 40% from present material as shown in Figure 2.1.

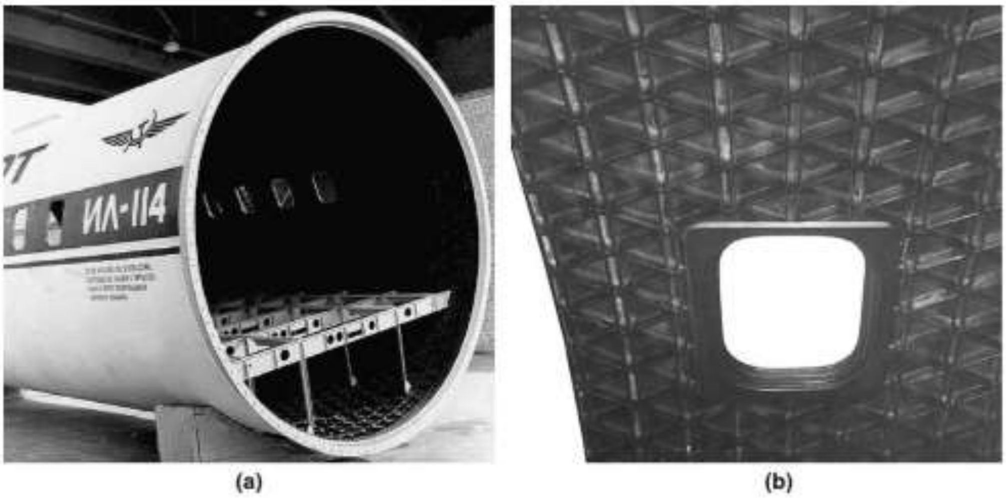


Figure 2.1: Lattice usage for aeroplane body (a) and the window frame (b) (Vasiliev and Razin, 2006)

Based on the past researches, many studies has been done about lattice-structure material performance compare to solid material. Research has been made that diamond truss lattice-structure with hollow part is more stronger compared to solid structure (Queheillalt et al., 2005). Some of lattice-structure groups are honeycomb and foam which are also known as cellular structure. Honeycombs are known as anti-bending beam, catalyst supports, heat insulation, noise barrier and energy absorber due to design of high-out-plane compression (Bitzer, 1997). Many researches has carried out experiments on honeycombs based on its mechanical properties and behaviour. One of them is bending and torsion model by twisting on each edge of the cell walls (Chen, 2011) as shown in Figure 2.2.

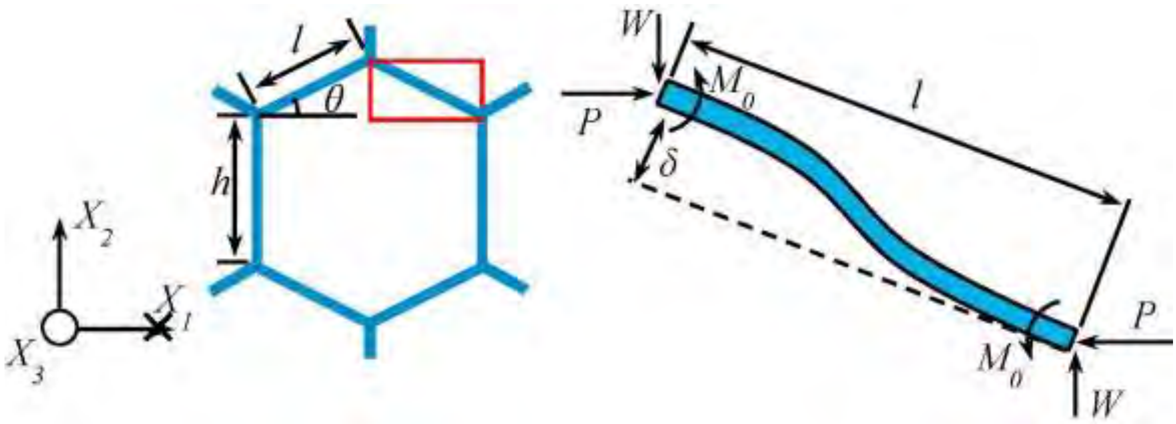


Figure 2.2: Bending mode of honeycomb (Ruoshui and Jyhwen, 2017)

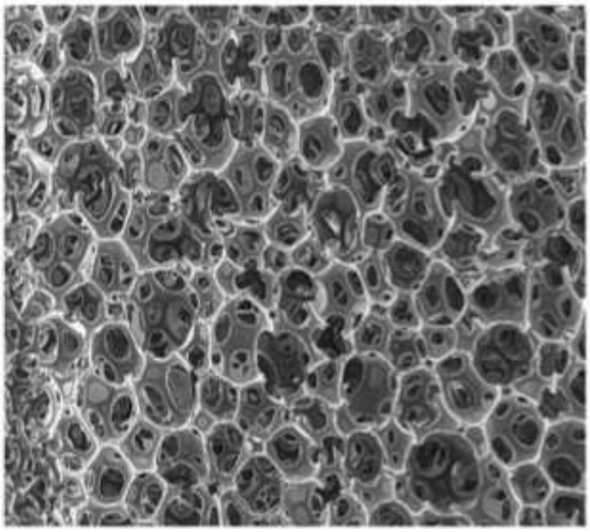

Figure 2.3 Foam cellular structure (Bashirzadeh and Gharehnaghdi, 2009)

Besides, foam as shown in Figure 2.3, is another cellular structure that is gaining interests from the researchers. Foam has been used in applications of automotive seat foam, fire resistance properties, furniture and sound insulation due to physical properties (Kirk and Othmer, 1997 ). Lattice structure provides a high mechanical performance compare to open-cell foam as it has a higher nodal connectivity, stiffness and strength although from same material (Ashby et al. 2000). There are many types of lattice as shown in Figure 2.4 that offer strength and stiffness with various nodal connectivities.

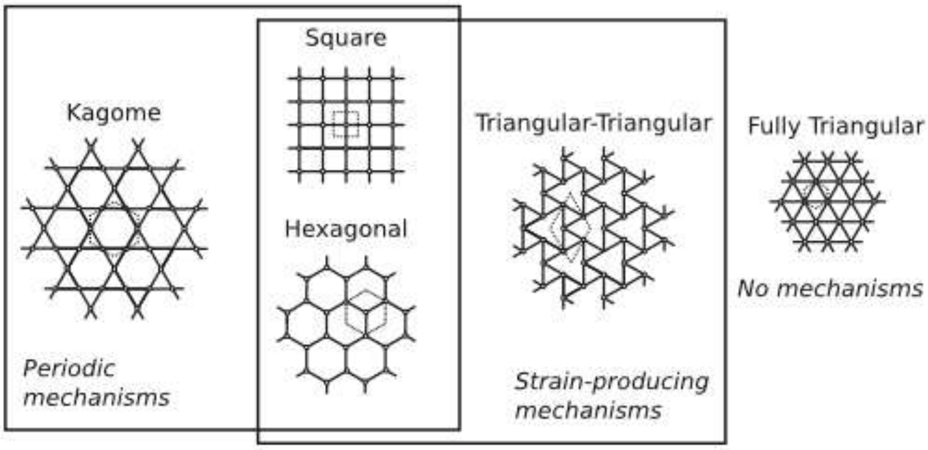


Figure 2.4: Type of lattice-structure (Fleck et al. 2010)

Lightweight material has been increasing in industrial demand especially in manufacturing technology such as shape morphing technology which is expected to change the shape due to temperature and pressure (Wadley et al. 2003). Attention to lattice has been increased because of its function and mechanical properties. For example, Kagome is the most used in manufacturing industry because of its four nodal connectivity which has been used in shape morphing compared to triangulated and hexagonal (Hutchinson et al. 2003). Lattice which is commonly arranged in Body-Centered-Cubic (BCC) is shown in Figure 2.5. The center mass of the BCC is located at the centred of the cell compared to Face–Centered-Cubic (FCC) which is located at the face of the unit cell as shown in Figure 2.6.

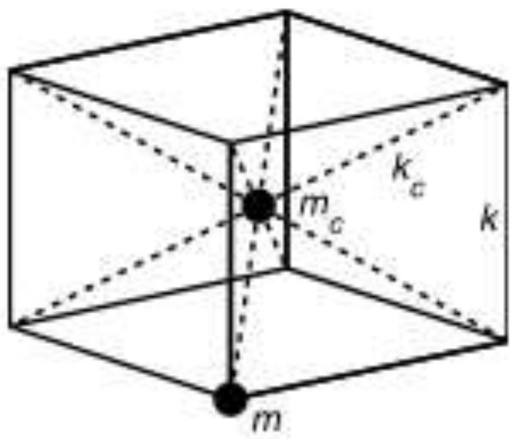


Figure 2.5: BCC lattice-structure (Taniker and Yilmaz, 2013)

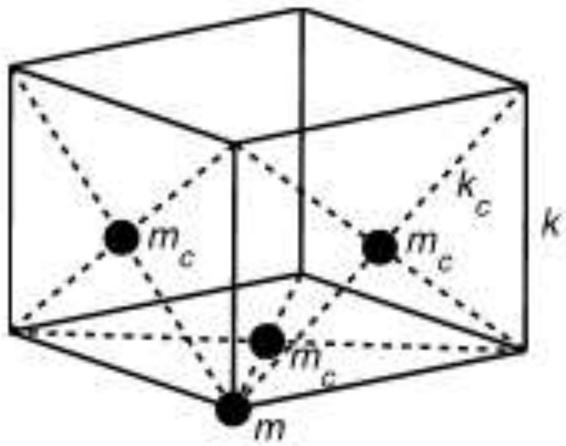


Figure 2.6: FCC lattice structure (Taniker and Yilmaz, 2013)

There are study about the properties of body-centered-cubic (BCC) done by Ushijima et al. (2011) predicted that specific stiffness $E*$ and strength $\sigma*$ values of selective laser melting (SLM) stainless steel body centered cubic (BCC) micro-lattice structure increase with increasing *d/L* (strut diameter over cell size), and there is no optimum as shown in Figure 2.7.

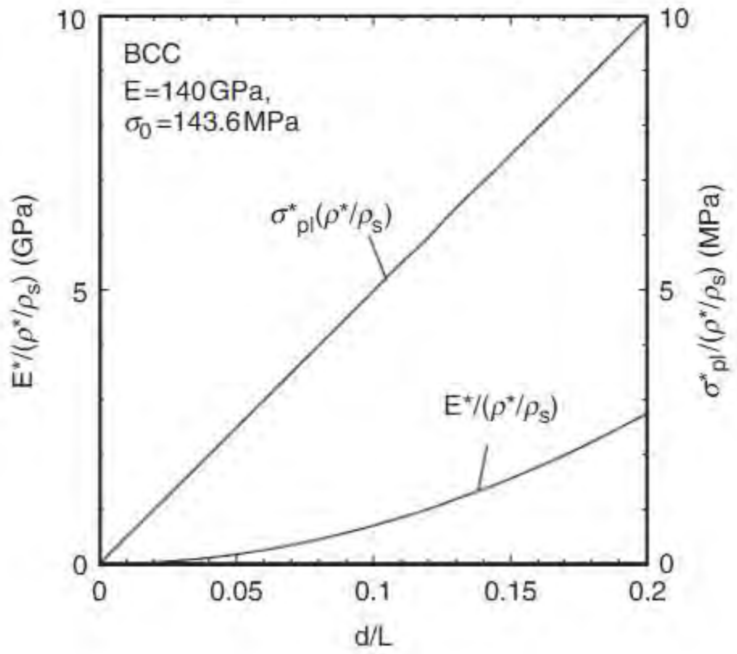


Figure 2.7: Graph of specific stiffness $E*$ and strength $\sigma*$ values versus *d/L* (strut diameter over cell size (Ushijima et al. 2011)

## 2.3 ADDITIVE LAYER MANUFACTURING

In recent years, several studies have focused on the development of the application of lattice-structure material. There are many methods to produce lattice-structure material. One of the method to produce lattice-structure material is casting. Casting is a conventional method among cut, assemble, weld, bond and wire-mesh methods which are used in producing lattice-structure-material. These method is less effective compare to innovative method which is chemical etching and additive layer manufacturing (Hooreweder et al., 2017). Lattice-structure material with length scales on the order millimetres can be assembled by using additive manufacturing technologies (Yan et al., 2012).