EFFECTS OF PROCESS PARAMETERS ON STRENGTH OF POLYMER LATTICE STRUCTURE MANUFACTURED BY USING 3D PRINTER

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PSM REPORT
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DECLARATION

I declare that this research project entitled "Effects of Process Parameters on Strength of Polymer Lattice Structure Manufactured by Using 3D Printer" is the result of my own work except as cited in reference.

Signature : YHoe.
Name : NG WAI HOE
Date : 12 JUNE 2017

APPROVAL

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

Signature : Rafidah

Name : DR RAFIDAH BINTI HASAN

Date : 13/6/2017.

ABSTRACT

The lattice structure is used to enhance the strength of light-weighted material and 3D printing is a good method to produce light-weighted lattice structure. This research focuses on the compressive strength of 3D printed polymer lattice structure using different combinations of process parameters which are layer resolution, print strength, print pattern and strut diameter. The Acrylonitrile Butadiene Styrene (ABS) polymer is used as the 3D printing material in this research. The 3D printed lattice structure specimens are then tested by using Instron compression test with ASTM D695 standard. The result reveals that specimen with identification (ID) of 07SoH12 has the highest strength compared to the others. The data and results from compression test are then inserted into Minitab software to obtain the optimization of the experiment and the S/N ratio shows that the specimen fabricated by using the combinations of 70 μm layer resolutions, almost solid print strength, cross or honeycomb print pattern and 1.2 mm strut diameter has the highest strength.

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LIST OF ABBREVIATIONS

3D	3 Dimensional
ABS	Acrylonitrile Butadiene Styrene
ASTM	American Society for Testing and Materials
BCC	Body Centered Cubic
CAD	Computer Aided Design

CHAPTER 1

INTRODUCTION

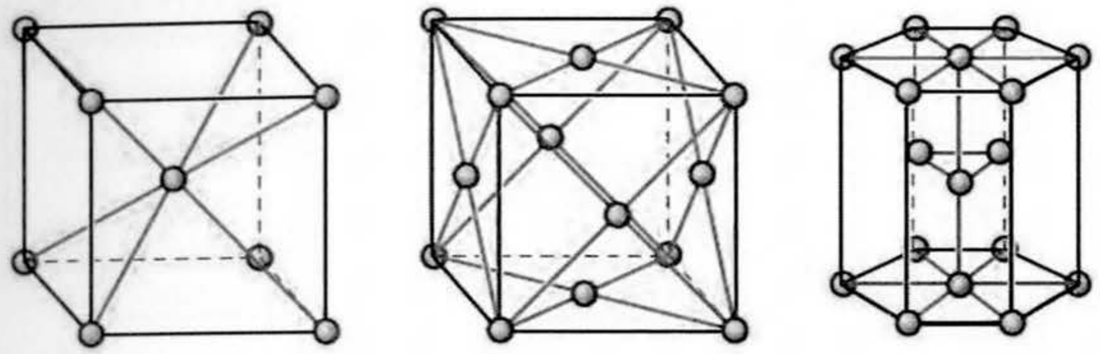
1.1 BACKGROUND OF STUDY

In recent years, there has been an increasing interest in 3D printing technology. 3D printing, also known as the additive manufacturing process, is used to fabricate and manufacture three-dimensional solid objects by inserting computational data into a 3D printer. At the beginning of this industry, 3D printing technology was used to manufacture prototypes (Wohlers, 2015). But after some modifications and improvements, it can be used to print useful products for real life usage. There are many fields using 3D printing technology to produce useful products. For example, the medical field uses the 3D printer to print of human organs for organs implantation. Besides that, automotive and aerospace fields use 3D printing to manufacture automotive parts such as car bumpers and spare parts for an airplane. Basic working mechanism of 3D printing is started with designing process using Computer Aided

Drawing (CAD) software or 3D scanning process of the object in order to obtain its parameters. After receiving the data from the computer, the 3D printer will continue with the process of layering down melted materials layer by layer until the product is made.

The lattice structure is a three-dimensional open cellular structure. This structure is made up of straight struts with uniform thickness, consistent joint angle and it is in a symmetrical arrangement. The lattice structure can be designed using several arrangements, such as body-centered cubic (BCC), face-centered cubic (FCC) and hexagonal close-packed (HCP) structures as shown in Figure 1 (Mahan, 2016). Besides that, there are also different methods and manufacturing processes that can be used to fabricate lattice structure blocks, such as investment casting, deformation forming and brazing. However, in recent years, there are many researchers trying to manufacture lattice structure blocks by using an additive manufacturing process, which is 3D printing technology. One of the advantages of using 3D printing is because it can manufacture a tiny lattice structure which scales 10^{-6}, which is micro in size (Abdul Hadi, 2015).

In this research, properties of body-centered cubic (BCC) lattice structure blocks manufactured by the 3D printer will be studied. There are several combinations of 3D printing process parameters will be used to fabricate lattice structure blocks. The specimens will be manufactured by using Cube Pro 3D printer, and the material used is Acrylonitrile Butadiene Styrene (ABS) polymer.



body-centred cubic (bcc) face-centred cubic (fcc) hexagonal close-packed (hcp)

Figure 1.1 Examples of Common Lattice Structures

Source : https://global.britannica.com/science/crystal/Types-of-bonds

1.2 PROBLEM STATEMENT

Properties of lattice structure blocks can be affected by its materials, cell geometry and also manufacturing processes. For lattice structure blocks manufactured by using 3D printing technology, its strength can be affected by the process parameters. There are several process parameters in a CubePro 3D printer, such as layer resolution, print strength and print patterns. In this study, different combinations of process parameters will be used to manufacture lattice structure blocks in the purpose of getting the best combination of process parameters that can produce lattice structure block with the highest strength.

1.3 OBJECTIVES

The objectives of this study are:

1. To study the effects of process parameters (layer resolution, print strength, print pattern and strut diameter) on strength of lattice structure manufacture by using Cube Pro 3D printer.
2. To study the behavior of lattice structure under compression test.

1.4 SCOPE OF PROJECT

The scopes of this research are:

1. Design of lattice structure by using Solidwork, a computer-aided design software.
2. Selection of combinations of 3D printing process parameters by using Minitab software and Taguchi method.
3. Manufacturing and fabrication of lattice structure blocks by using Cube Pro 3D printer with Acrylonitrile Butadiene Styrene ABS polymer as the material.
4. Testing of the strength of lattice structure blocks which are fabricated with different combinations of process parameters by using Instron compression test machine with ASTM D695 standard.
5. Analysis of results and data by using Signal-to-Noise ratio in Minitab software.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, past researches and studies about micro-lattice structure, ABS polymer, Taguchi method, 3D printing, compression test and compression standards will be studied. The purpose of studying past research projects is to establish a framework about 3D printing topic to ensure that the knowledge, theories and methodologies are up to date. Besides that, the data and result obtained from past researches are important for comparison in order to support present research.

2.2 CELLULAR LATTICE STRUCTURE

In recent years, several studies have focused on the application of light weighted materials in engineering industries. The light weighted material is a new type of material that is made up of nanoscale struts in crisscrossed formation also known as cellular structures (Bourzac, 2014). These types of materials are useful in the automotive and transportation industry because its light weighted properties help to reduce the energy consumption during the operation of machines or engines. The cellular structure is a structure that consists of an interconnected network of solid struts forming the edges and faces of cells. There are several types of cellular solid structures in two or three dimensional, such as the honeycomb-like structure and the foam-like structure. The most important property of a cellular structure is the relative density of the structure and is defined by the ratio of cellular solid density to the density of the material. As the relative densities are increased, the cellular wall becomes thicker. In other words, relative density is equivalent to the volume fraction of a solid. Table 2.1 shows the relative densities of some examples of natural and artificial cellular structure materials.

Table 2.1 Examples of Cellular Structure Materials and its Relative Densities (Gibson, 1997).

Material	Relative Densities
Special ultra-low density foam	0.001
Polymeric foam for packaging	0.05 – 0.20
Corks	0.14
Softwood	0.15 – 0.40
Porous Solid	> 0.30

According to a research paper conducted by Erjavec (2011), the relationship between mechanical properties and the relative density of the cellular structures is studied. The honeycomb structure as shown in Figure 2.1 is a very common two-dimensional structure and it is mainly used in load bearing structures. For the foam structure as shown in Figure 2.2, it is a three-dimensional structure and it is widely used to absorb impacts and energy. From the results obtained by Erjavec, the mechanical properties of honeycomb structures are dependent on the direction of loading. The in-plane properties depend on the relative density and cell geometry, whereas the out-of-plane properties depend only on the relative density. Mechanical properties of foam structure are dependent on loading direction and its relative density.

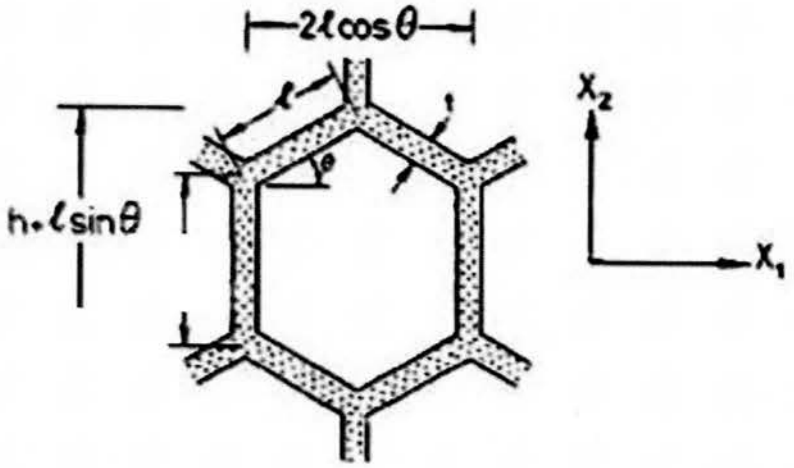


Figure 2.1 Honeycomb Cellular Structures (Erjavec, 2011)

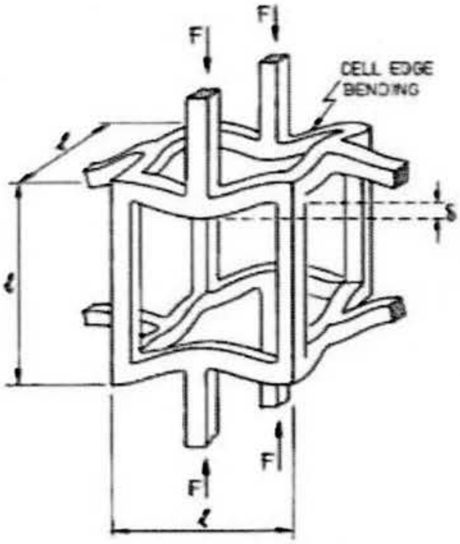


Figure 2.2 Foam Cellular Structures (Erjavec, 2011)

Solid materials may be classified according to the regularity with which atoms or ions are arranged with respect to one another. A crystalline material is one in which the atoms are situated in a repeating or periodic array over large atomic distances (Callister, 2007). In describing crystal structures, it is more convenient to subdivide the structure into smaller repeating entities called unit cells. The lattice structure is an array of unit cells made up of struts connecting two nodes between each rigidly bonded or pin-jointed. The material, cell shape and relative density are the affecting factors that determine the mechanical properties of cellular materials (Mahshid, 2016).

In a study conducted by Rehme and Emmelmann in the year 2006, the effects of uniaxial compressive test on cellular structures with eight different cell types were investigated. This research involved finding optimal unit cell types in order to maximize the collapse strength and minimize the overall achievable density. From the research conducted, a cell type named F_2CC-Z had the best ratio for collapse strength-to-density. This unit cell consisted of rods in a vertical direction and double-faced diagonals as shown in Figure 2.3. The presence of vertical struts enhanced the strength of a lattice structure (Rehme, 2006).

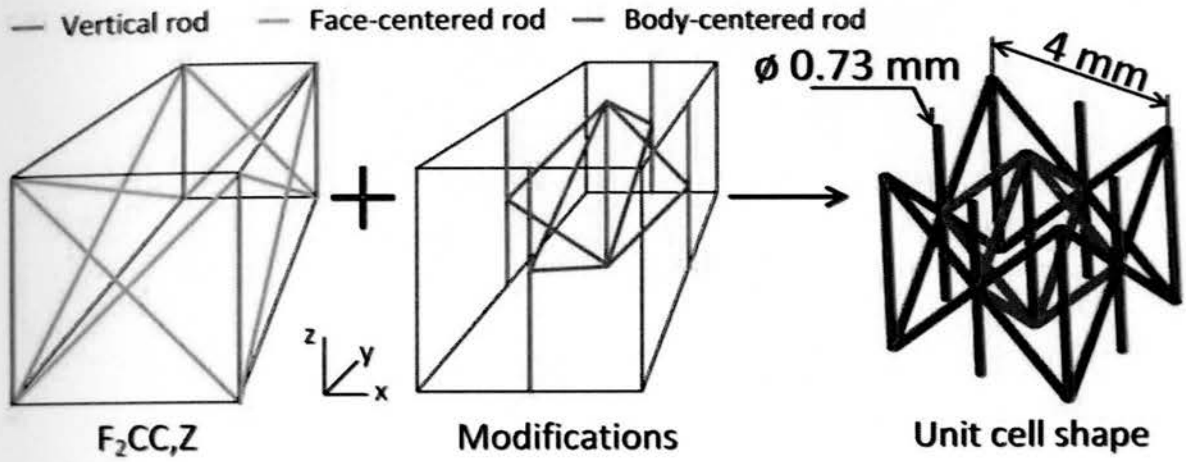


Figure 2.3 F_2CC-Z Lattice Structure (Rehme, 2006)

2.2.1 ARCHITECTURE OF LATTICE STRUCTURE MATERIALS

The body-centered cubic structure is a cubic unit cell with atoms located at all eight corners and a single atom at the cube center. The center and corner atoms connected one another along the cube diagonals and formed lattice struts. Lattice struts structures are commonly used as structures of light weighted material. There are some examples of lattice strut structures commonly used, such as body-centered structure (BCC), face centered structure (FCC) and also pyramidal Kagome structure (Wadley, 2005). In Figure 2.4, the common lattice structure, body centered cubic BCC structure is shown. However, in Figure

2.5, the strut structures of tetrahedral, pyramidal and 3D Kagome are shown and all these struts structures are not that common compared to BCC and FCC structures.

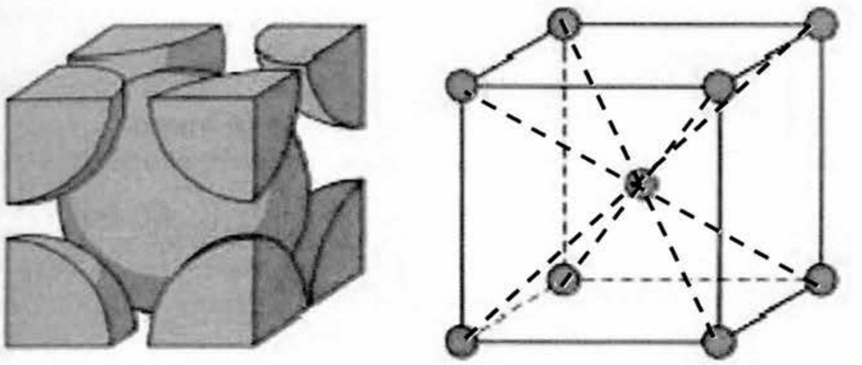


Figure 2.4 Body Centered Cubic BCC Structure (Callister, 2007)

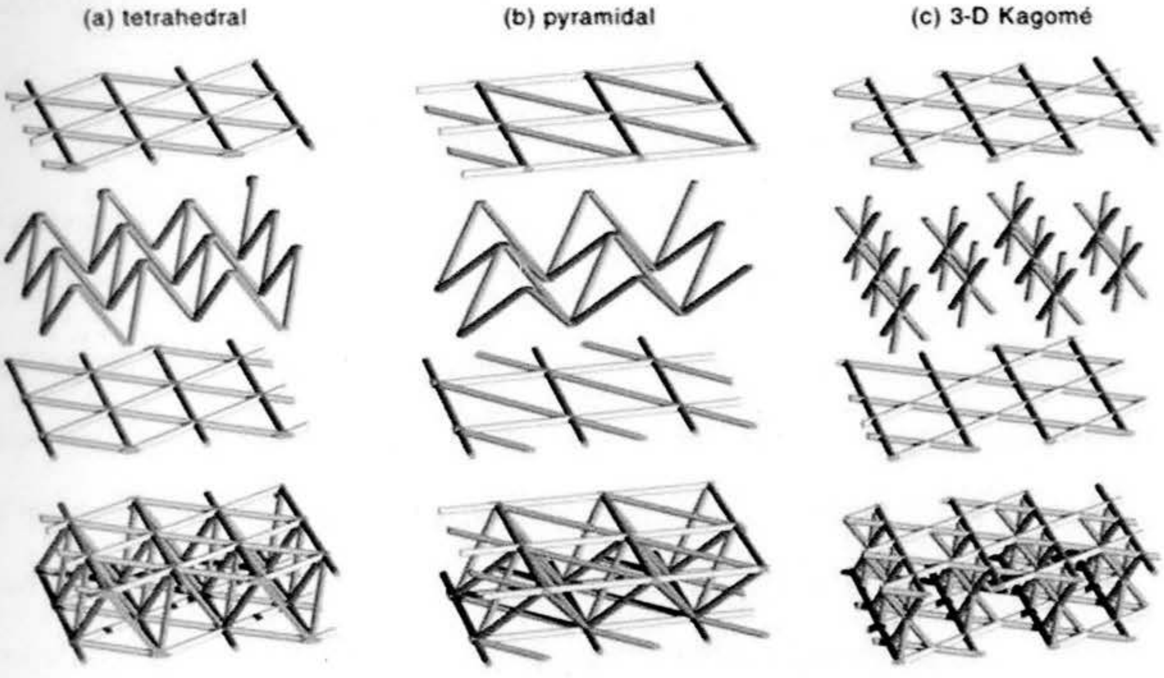


Figure 2.5 Tetrahedral, Pyramidal and 3D Kagome Strut Structures (Wadley, 2005).

2.3 TAGUCHI METHOD

Nowadays, the Taguchi method is widely used by engineers to determine the factor level and to evaluate possible factor interaction in order to design and plan for experiments or manufacturing processes. By using the Taguchi method, researchers are allowed to initiate an experiment with many different factors on a few levels instead of conducting experiments with all combinations of affecting factors (Kacker, 1991). Because the Taguchi method has reduced the number of experiments that needs to be conducted; it has helped in cost reduction and time consumed for experiments.

2.3.1 ORTHOGONAL ARRAYS

An orthogonal array is a fractional factorial matrix, where all the factors affecting the experiment are arranged in columns and the factor level combinations are designed in rows to be used for the experiment runs. These arrays help to minimize the number of experiments and it gives the full information about the factors that affect the experiment performance. There are several types of orthogonal arrays and it is basically classified by a specific number of independent variables and levels. An orthogonal array designed the factor levels equally; therefore each factor can be assessed independently. Table 2.1 shows a level 9 L_9 orthogonal arrays where there are nine experiments with different combinations of factors to be conducted (Kacker, 1991).

Table 2.2 Table of $L_9 (3^4)$ Orthogonal Array (Kacker, 1991)

Experiment	Variable 1	Variable 2	Variable 3	Variable 4	Performance Parameters
1	1	1	1	1	R_1
2	1	2	2	2	R_2
3	1	3	3	3	R_3
4	2	1	2	3	R_4
5	2	2	3	1	R_5
6	2	3	1	2	R_6
7	3	1	3	2	R_7
8	3	2	1	3	R_8
9	3	3	2	1	R_9

2.3.2 SIGNAL-TO-NOISE RATIO

In the Taguchi method, the Signal-to-Noise (S/N) ratio is used to evaluate deviation and robustness from the target of a response and process variation. The measure of robustness in the Taguchi method is used to identify the control factors that reduce variability in an experiment or a process by minimizing the effects of uncontrollable factors also known as the noise factors. Higher values of the signal-to-noise ratio (S/N) helps to identify the control factor settings that minimize the effects of the noise factors. The signal-to-noise ratio measures how the response varies relative to the nominal or the target value under different noise conditions. From the Minitab support website http://support.minitab.com/, it shows that the Minitab software offered four types of signal-to-noise ratios as shown in Table 2.3.

Table 2.3 Signal-to-Noise Ratios and the Descriptions

Signal-to-noise ratio	**Goal of the experiment**	**Data characteristics**	**Signal-to-noise ratio formulas**
Larger is better	Maximize the response	Positive	$S/N = -10 * \log(\Sigma(1/Y^2)/n)$
Nominal is best	Target the response and you want to base the signal-to-noise ratio on standard deviations only	Positive, zero, or negative	$S/N = -10 * \log(\sigma^2)$
Nominal is best (default)	Target the response and you want to base the signal-to-noise ratio on means and standard deviations	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero	$S/N = 10 \times \log((\bar{Y}^2) \div \sigma^2)$ The adjusted formula is: $S/N = 10 \times \log((\bar{Y}^2 - s^2 \div n) \div s^2)$
Smaller is better	Minimize the response	Non-negative with a target value of zero	$S/N = -10 * \log(\Sigma(Y^2)/n))$

Source : http://support.minitab.com/en-us/minitab/17/topic-library/modeling-statistics/doe/taguchi-designs/what-is-the-signal-to-noise-ratio/

2.4 ADDITIVE MANUFACTURING

Additive manufacturing, also known as 3D printing, is the process of making a three-dimensional object from a drawn model. This technology is operated by using the additive