STUDY ON SINGLE STRUT FORMATION USING ADDITIVE LAYER MANUFACTURING

CHEE YING CHEN

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering (with Honours)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

© Universiti Teknikal Malaysia Melaka

DECLARATION

I declare that this project report entitled "Study On Single Strut Formation Using Additive Layer Manufacturing" is the result of my own work except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	CHEE YING CHEN
Date	:	....

© Universiti Teknikal Malaysia Melaka

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 Bachelor of Mechanical Engineering (with Honours).

Signature : ....

Name of Supervisor : DR RAFIDAH BINTI HASAN

Date : ....

© Universiti Teknikal Malaysia Melaka

DEDICATION

I dedicate this thesis to my beloved mother and father; Chong Chuai Kuan and Chee Yok Choy who have always been giving me spiritual support while they are living at hometown, Cheras, Kuala Lumpur. I am truly appreciate their loves and patients when educating me from time to time. I also dedicate this thesis to all my siblings (Chee Ying Thung and Cheay Ying Wei) for being part of my life. My family has inspired me always and made me to be a better person in the future. Apart from that, I dedicate this thesis to my course mates and friends as they are willing to help whenever I have troubles in my life. They are rational to correct my mistakes and also give me some valuable advices.

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to express my deep appreciation to my supervisor Dr. Rafidah binti Hasan, from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for guiding me very well throughout this project. Under her supervision, I had gained her guidance and inspiration that enable me to complete this final year project successfully.

Moreover, I would like to express my greatest gratitude to Prof. Dr. Ghazali Bin Omar as my panel seminar and also second report examiner. Next, I would like to express my deepest gratitude to Associate Professor Dr Mohd Ahadlin bin Mohd Daud as my second panel seminar. He had lent the Dino-Lite Pro for me as well in order to complete the microscopic examination in this project.

Furthermore, I would like to thank to Universiti Teknikal Malaysia Melaka (UTeM) especially the Faculty of Mechanical Engineering (FKM) for giving a fully support by allowing me to use their equipments and facilities during conducting my project.

In addition, I would like to express my sincere thanks to my friends and course mates for giving me their supports and advices in this project. Next, special thanks to my parents and my siblings for giving me their loves, supports and encouragements throughout this project.

© Universiti Teknikal Malaysia Melaka

ABSTRACT

The lattice-structure materials are suitable for lightweight structural applications as they have the properties of flexible and high stiffness. In a lattice-structure material, its basic unit is single strut which is a member that connects two nodes. Hence, understanding the single strut properties is important in lattice-structure material study. This study is conducted to analyse layer by layer formation of fabricated single strut using a 3D printer with several parameters. The chosen diameters of single struts are 1.2mm, 1.4mm and 1.6mm while the build angles are set as 0^o, 20^o, 35.26^o, 45^o, 60^o, 80^o and 90^o from a vertical line. All single struts are needed to be designed with suitable supports before proceed to fabrication stage. After three sets of 21 specimens are fabricated using CubePro 3D printer successfully, all single struts are analysed on their diameter using Dino-Lite Pro. The difference between measured diameter and designed diameter for each single strut is recorded. Next, the selected single struts with 35.26^o build angle are analysed on their surface roughness using Dino-Lite Pro and 3D non-contact profilometer. A graph of surface roughness versus strut diameter is constructed for both equipment used. Thus, the results show that all single struts have the accuracy of more than 86% when comparing the readings of measured diameter and designed diameters. The single strut with 1.2mm diameter for 35.26^o build angles has the lowest R_a (Roughness Average) value. The comparison between individual strut and struts arranged in lattice structure in physical test is recommended to be conducted for future study.

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Bahan struktur kekisi sesuai untuk aplikasi struktur ringan kerana mereka mempunyai sifat fleksibel dan kekakuan yang tinggi. Dalam struktur kekisi, unit asasnya ialah strut tunggal yang merupakan satu sambungan yang menghubungkan dua nod. Oleh itu, memahami sifat-sifat strut tunggal adalah penting dalam kajian bahan struktur kekisi. Kajian ini dijalankan untuk menganalisis lapisan pembentukan strut tunggal yang dibuat daripada pencetak 3D dengan beberapa parameter. Garis pusat yang ditentukan untuk strut tunggal adalah 1.2mm, 1.4mm, dan 1.6mm, manakala sudut membina ditetapkan sebagai 0^o, 20^o, 35.26^o, 45^o, 60^o, 80^o, dan 90^o dari garis menegak. Setiap strut tunggal diperlukan untuk direka dalam bentuk yang sesuai sebelum meneruskan ke peringkat fabrikasi. Setelah berjaya menghasilkan tiga set 21 spesimen dengan menggunakan pencetak 3D CubePro, semua strut tunggal dianalisis pada garis pusat dengan menggunakan Dino-Lite Pro. Perbezaan antara garis pusat yang diukur dan garis pusat yang ditetapkan untuk setiap strut tunggal juga dicatatkan. Seterusnya, strut tunggal dengan sudut 35.26^o yang dipilih dianalisis pada kekasaran permukaan mereka dengan menggunakan Dino-Lite Pro dan 3D non-contact profilometer. Graf kekasaran permukaan melawan saiz garis pusat strut ditunjukkan untuk kedua-dua peralatan yang digunakan. Oleh itu, keputusan menunjukkan bahawa semua strut tunggal mempunyai ketepatan melebihi 86% apabila membandingkan bacaan garis pusat yang diukur dan garis pusat yang ditentukan. Strut tunggal dengan garis pusat 1.2mm untuk 35.26^o sudut membina mempunyai nilai Ra (Purata Kekasaran) terendah. Perbandingan antara strut individu dan strut yang diatur dalam struktur kekisi dalam ujian fizikal adalah dicadangkan pada masa depan.

© Universiti Teknikal Malaysia Melaka

TABLE OF CONTENTS

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES FOR APPENDICES

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

© Universiti Teknikal Malaysia Melaka

LIST OF ABBEREVATIONS

ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
Avg D	Average Diameter
BCC	Body Centered Cubic
CAD	Computer-Aided Design
CATIA	Computer Aided Three-dimensional Interactive Application
CO_2	Carbon Dioxide
EBM	Electron Beam Melting
FDM	Fused Deposition Modelling
PLA	PolyLactic Acid
R_a	Roughness Average
SEM	Scanning Electron Microscope
SLM	Selective Laser Melting
STL	Standard Tessellation Language

© Universiti Teknikal Malaysia Melaka

LIST OF SYMBOL

n	=	Nodes
p	=	Struts
m_b	=	Mass of block
ρ_s	=	Density of the steel
L	=	Length of cell
N_1, N_2, N_3	=	Number of cells along the width, length and height directions
d	=	Strut diameter
x	=	Reading of measured diameter
N	=	Number of readings in a single strut
σ	=	Standard deviation
$\bar{x}$	=	Mean (average data)
x_e	=	Experimental value (measured diameter)
x_a	=	Actual value (designed diameter)
%	=	Percentage difference
l	=	Evaluation length
Z(x)	=	Profile height function

© Universiti Teknikal Malaysia Melaka

CHAPTER 1

INTRODUCTION

1.1 Background

Lattice-structure materials utilize the design principals of efficient, lightweight macroscale structures, to mesoscale material architectures. By having the properties of high stiffness and strength-to-weight scaling, the lattice-structure materials are suitable for lightweight structural applications. The basic unit of lattice-structure material is single strut. The assembly methods of the strut-based lattice structures are flexible because of the availability of the joint type. Hence, the complex geometries designs would prefer to apply the strut-based lattice structures due to its flexible configurations (Doyoyo and Hu, 2006).

For designing strut-based lattice structures, a lot of feasible options can be proposed within a defined volume as a lattice structure has variation number of nodes and struts. An example of lattice structure with its nodes (n) and struts (p) is shown in Figure 1.1. A node is a point where two or more struts join, while a strut is a connection or member that links two nodes (Syam et al., 2017).

© Universiti Teknikal Malaysia Melaka

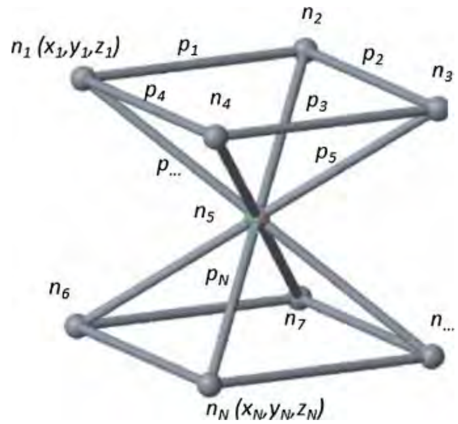

Figure 1.1: A strut-based lattice configuration with nodes n = 9 and struts p = 16.

(*Source: Syam et al., 2017)*

There are many methods in fabricating lattice-structure material, such as casting, sheet metal forming, wire bonding process, selective laser melting (SLM) and electron beam melting (EBM) (Rashed et al., 2016). Casting is one of the conventional methods to produce lattice structures by using injection molding and the mold is made by ceramic (Rashed et al., 2016). Sheet metal forming produces lattice structures by press forming operation from a roll of sheet metal (Rashed et al., 2016). SLM and EBM are both methods that using additive manufacturing (AM) techniques where the part is produced layer by layer. For SLM process, its raw material used is metal powder and the part is formed by depositing a thin powder layer and scanning by the laser (Gebhardt, 2003).

Additive layer manufacturing is an innovative method to fabricate lattice-structure materials. 3D printing is also an additive manufacturing (AM) which the printed part is formed layer by layer. By using AM technology, the design of lattice structure is needed to be drawn using a CAD software before proceed to printing machine. AM technology is an advanced method because it has high process flexibility and the possibility to produce parts with a high geometric complexity (Reinhart and Teufelhart, 2013).

© Universiti Teknikal Malaysia Melaka

1.2 Problem Statement

Understanding the single strut properties is important in lattice-structure material study. This is because, single strut is the basic unit of lattice-structure material. Different arrangement of struts can produce different architecture of lattice-structure material. Moreover, by producing lattice-structure material using additive layer manufacturing, many controlling parameters affect the properties of material. In this study, fabricated single struts using additive manufacturing are studied, in terms of its layer by layer formation. This is because there is no study done on investigating single strut using CubePro machine. Hence, the formation of single strut using material of polymer acrylonitrile butadiene styrene (ABS) and CubePro machine (Figure 1.2) will be examined at different diameter sizes and build angles.

Figure 1.2: CubePro machine at Rapid Prototyping Laboratory.

© Universiti Teknikal Malaysia Melaka

1.3 Objective

The objective of this study is to analyse layer by layer formation of fabricated single strut using fused deposition modelling (FDM) machine with several parameters.

1.4 Scope of Project

The scopes of this project are:

1. To design single strut using CATIA (an acronym of computer aided three-dimensional interactive application) at different size and angles.
2. To fabricate single struts using CubePro 3D printer and material of polymer acrylonitrile butadiene styrene (ABS).
3. To evaluate the formation of single strut and relate it with process parameters using microscopic examination, which is optical microscope and profilometer.

1.5 Summary of Chapter 1

In conclusion, the fabricated single struts using additive manufacturing are studied in order to quantify the single strut as a basic unit of lattice structure. By conducting this study, the formation of single strut with different diameter sizes and build angles can be evaluated. The next chapter will describe about the literature review of this study.

© Universiti Teknikal Malaysia Melaka

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The background of this study is needed to be studied in order to have better understanding before proceed for further progress. In this chapter, the relevant topics with this study are explained based on the journal articles and academic book. Moreover, the researches that related to this study are discovered from the journal articles and described in this chapter as well.

2.2 Lattice-structure and Strut

Lattice-structure is formed by a number of struts and nodes. Node is a joint where struts meet together while strut is the basic unit of lattice structure and also as a connection between nodes. For designing strut-based lattice structure, it can be designed in various types of configuration due to the variation of node positions in a fixed volume. Lattice-structure has high stiffness-to-weight ratio, which means its materials used can be saved. Hence, the strut-based lattice structures are being applied in complex geometries designs as the problem of forming can be eliminated (Doyoyo and Hu, 2006).

There is a large number for the formation of strut-based lattice structure that can be designed within a fixed volume when the number of nodes and struts are not fixed. Since the

© Universiti Teknikal Malaysia Melaka

variation of the number of nodes and struts can lead to obtain a large number of options results, the node positions and strut diameters can be variable in a specific volume as well (Syam et al., 2017). Strut-based lattice structure can be in various shape such as cubic truss and octetruss as shown in Figure 2.2.

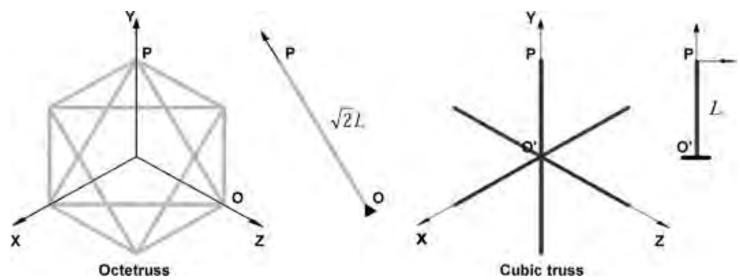

Figure 2.2: Octetruss and cubic truss.

(Source: Doyoyo and Hu, 2006)

2.3 Methods in Producing Lattice-structures

Traditionally, lattice-structures are manufactured through casting, sheet metal forming, or wire bonding processes. These conventional manufacturing processes are time-consuming and also limited the complexity of lattice-structure designs. These methods are only used to manufacture lattice-structure materials with simple configuration on a macroscale (Tang et al., 2017).

For casting process, a pattern of wax or polymer lattice-structure is coated with ceramic casting slurry. This ceramic is a mold and the wax or polymer is then removed through the process of melting. The liquid metal with high fluidity can be used to fill in the empty mold in order to form lattice-structure material. By using this method, a wide range of shapes of lattice structure can be formed as it depends on the shape of the mold that can be designed to be desired

© Universiti Teknikal Malaysia Melaka

shape. Figure 2.3.1 shows octet-truss lattice structure produced from casting process. With this casting process, the manufactured lattice-structure material had severe porosity and this method is expensive and time-consuming (Rashed et al., 2016).

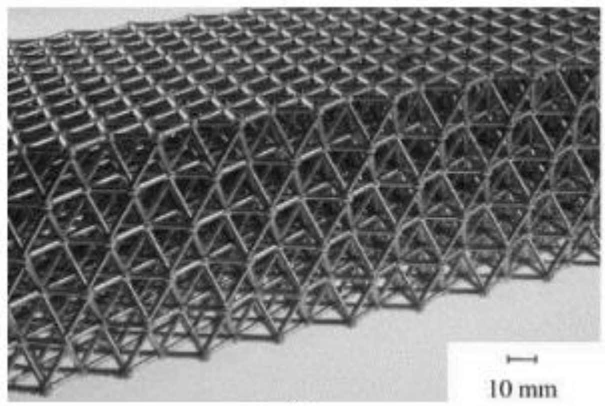

Figure 2.3.1: Octet-truss lattice structure.

(Source: Rashed et al., 2016)

For sheet metal forming method, a roll of sheet metal is went through perforation punch to form the shaped holes such as hexagonal or diamond. The elongated perforated sheet is treated with annealing process to soften the struts before proceed to punching process. The perforated sheet is then bent by the combinations of punch and die. This punching process allows the perforated sheet to be corrugated. Hence, a simple lattice-structure material can be manufactured through these processes from a sheet metal. Figure 2.3.2 shows the processes of sheet metal forming method (Rashed et al., 2016).

© Universiti Teknikal Malaysia Melaka

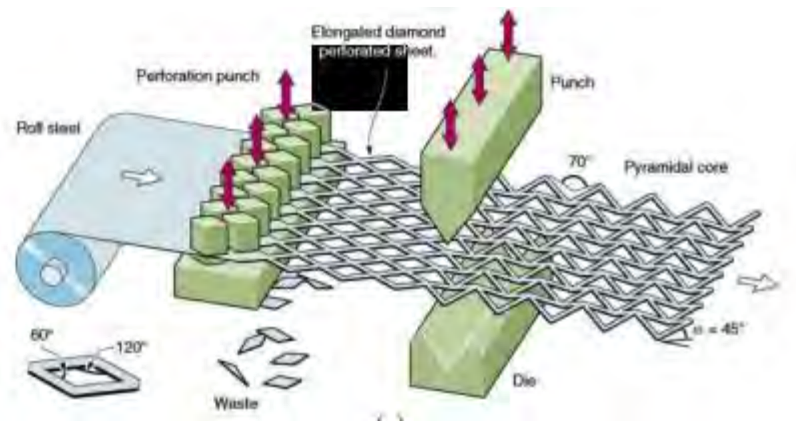

Figure 2.3.2: Sheet metal forming process.

(Source: Rashed et al., 2016)

However, the introduction of additive manufacturing (AM) technologies had reduced the limitations in producing lattice-structure materials. AM technologies manufacture a part layer by layer and enables the design of lattice-structure materials in complex configuration. A complex lattice-structure can be produced in ease through AM technologies and also in variation of geometrical scales such as microscale, mesoscale or macroscale (Reinhart et al., 2012).

2.4 Additive Layer Manufacturing

Generally, the first process of AM technology is to design and build a 3D modeling using a CAD (Computer-Aided Design) software. This drawing is later converted into a “STL” (Standard Tessellation Language) file format which originates from 3D Systems. A computer program can read the STL file to create slices from the model for data preparation. This data is inserted into a program of an AM machine for producing the designed parts. Post processing is needed to carry out for removing support structure or surface finishing (Kessler et al., 2016).

© Universiti Teknikal Malaysia Melaka

3D printing is one of the additive layer manufacturing technologies. There are different types of 3D printing and can be classified by depending on the raw materials such as solid-based, liquid based or powder based (Gebhardt, 2003). A lattice-structure material or single strut can be fabricated by using 3D printing which is done within one process only where the part is generated layer-by-layer (Kessler et al., 2016).

There was a study on producing strut shape of lattice-structure using SLM (Selective Laser Melting) method. It was a powder-based AM technology and its raw material used was metal powder. During SLM process, a thin powder layer was deposited, and CO_2 (carbon dioxide) laser was irradiated to the powder surface successively until final part was produced based on CAD data. It focused on few types of cross sectional shape of struts and its reached quality. The examined shapes were circular, elliptical, square, triangular and rhombus. By producing these struts, the limitations of SLM process were evaluated. For example, the limitation for circular cross section was the nominal diameter which smaller than 0.15mm cannot be fabricated (Kessler et al., 2016). Figure 2.4 shows the fabricated struts with different diameters.

Figure 2.4: Fabricated struts with different diameters.

(Source: Kessler et al., 2016*)*

© Universiti Teknikal Malaysia Melaka