INVESTIGATION ON MECHANICAL PROPERTIES OF 3D-PRINTED SINGLE STRUT

MUHAMMAD FAKHRUR IQBAL BIN MUSLIM

**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

2019

DECLARATION

I declare that this project report entitled "Investigation on mechanical properties of 3D-printed single strut" 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 :..

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 Bachelor of Mechanical Engineering (with Honours).

Signature	: ....
Name of Supervisor	: ……………………...
Date	: ....

DEDICATION

I dedicate this thesis to my beloved mother and father, Muslim bin Md Said and Jamiah binti Chek who have always been giving me spiritual support while they are living at hometown, Alor Gajah, Melaka. I am truly appreciate their loves and patients when educating me from time to time. I also dedicate this thesis to all my siblings (Razi, Ikram, Maizatul Anis) 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.

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 Dr Mohd Basri bin Ali as my panel seminar and also second report examiner. Next, I would like to express my deepest gratitude to Dr. Mohd Azli bin Salim as my second panel seminar. All of them are helpful and gave a great cooperation to ease my journey during accomplishing this study.

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.

ABSTRACT

This study focusses in producing tensile test specimen and method for the determination on the elastic property of 3D printed ABS single strut specimen. Designs of miniture single struts include a slender straight design with nominal strut diameter of 1.6 mm, total length of 24 mm, 45 mm, 50 mm, 75 mm and 90 mm. Compliance correction method is applied for single struts with different gauge lengths of between 8mm to 30 mm. Design of specimen is referred to ASTM E8/E8M-13a standard specification while tensile test is performed with reference to ASTM D638 standard procedure by using shimadzhu EZ test (EZ-LX) machine.

ABSTRAK

Kajian ini memberi tumpuan dalam menghasilkan spesimen ujian tarik dan kaedah untuk menentukan keupayaan elastik untuk spesimen strut tunggal daripada ABS yang dicetak melalui 3D. Reka bentuk miniture strut tunggal termasuk reka bentuk lurus langsing dengan diameter strut nominal 1.6 mm, panjang keseluruhan 24 mm, 45 mm, 50 mm, 75 mm dan 90 mm. Kaedah pembetulan pematuhan digunakan untuk struts tunggal dengan panjang tolok yang berbeza antara 8mm hingga 30 mm. Reka bentuk spesimen dirujuk kepada spesifikasi standard ASTM E8 / E8M-13a manakala ujian tegangan dilakukan dengan merujuk kepada prosedur standard ASTM D638 dengan menggunakan mesin shimadzhu EZ (EZ-LX).

TABLE OF CONTENT

LIST OF FIGURES

LIST OF FIGURES FOR APPENDICES

LIST OF TABLES

LIST OF ABBEREVATIONS

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

LIST OF SYMBOL

n	=	Nodes
p	=	Struts
m_b	=	Mass of block
ρ_s	=	Density of the steel
L	=	Length of cell
d	=	Strut diameter
x	=	Reading of measured diameter
N	=	Number of readings in a single strut
σ	=	Standard deviation
$\bar{x}$	=	Mean (average data)
%	=	Percentage difference
l	=	Evaluation length
E_u	=	Uncorrected modulus of elasticity
E	=	Modulus of elasticity
C_a	=	Apparent compliance factor
C_m	=	Machine compliance factor
δ_T	=	Total elongation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Lattice structure is a lightweight material. Many studies have done to determine mechanical properties of this material produced from stainless steel, aluminium, copper and other metals. Its properties of high stiffness and strength to weight ratio caused it widely to be used for lightweight structural applications (Doyoyo and Hu, 2006).

Lattice-structure comprises of many struts connected to each other by nodes, in many architectural arrangements such as body-centred-cubic (BCC), face-centred-cubic (FCC) and hexagonal close packed (HCP). These availabilities of joint type offer flexibility in assembly methods of the strut-based lattice structure. Hence, due to flexible configuration, the complex geometries design would prefer to apply the strut-based lattice structure (Doyoyo and Hu, 2006).

A node is a joint where two or more struts meet, and a strut is a link or member that connects two nodes. Many feasible options can be considered to define volume for designing strut-based lattice structures as it has variation number of nodes and struts to be combined. Figure 1.1.1 shown an example of lattice structure which consist of nodes (n) and struts (p).

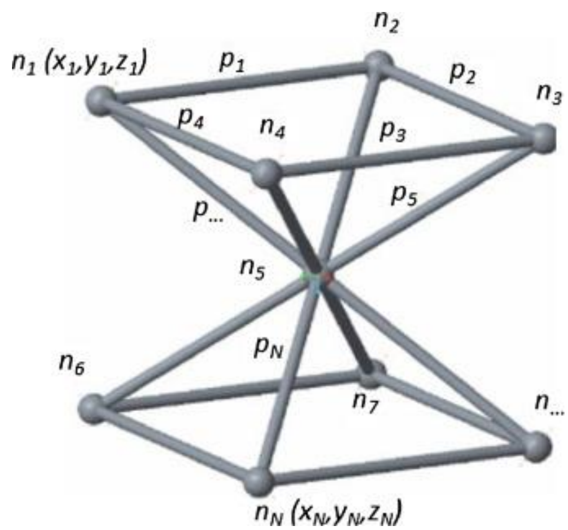

Figure 1.1.1: A strut-based lattice configuration with nodes n = 9 and struts p = 16.

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

Certain process is needed in each fabrication method of lattice-structure material. There are various methods to produce lettice-structure material which are casting, wire bonding process, sheet metal forming and electron beam melting (EBM) (Rashed et al., 2016). One of the common method to produce lattice structure is casting method which is using injection moulding (Rashed et al., 2016). Wire bonding is generally considered the most cost-effective and flexible interconnect technology which is used to assemble the vast majority of semiconductor packages. Sheet metal methods is the process where producing lattice structure by press forming operation from a roll of sheet metal (Rashed et al., 2016). Otherwise in additive manufacturing (AM) techniques EBM is also one of the most selected method where the part is produced layer by layer (Rashed et al., 2016).

Additive layer manufacturing (ALM) or additive manufacturing (AM) is a modern fabrication process that can be use with wide range of materials to create product ranging from medical implants to parts of an aircraft wing. 3D printing is one of the categories in additive layer manufacturing available which the printed part is formed layer by layer (Gebhardt, 2003). The first step in fabricating parts by using this technology is to create the required geometry layer by layer, using computer aided design (CAD) data. Due to the high process flexibility and the possibility to produce parts with a high geometric complexity, AM technology is an advanced method that used widely

1.2 PROBLEM STATEMENT

Mechanical properties especially modulus of elasticity, yield strength and maximum strength of lattice structure materials can be obtained through stress-strain diagram. In case for lattice-structure materials arrangement, compression test is one of the simplest methods to obtain the stress-stress diagram. However, using compression test will not give the failure strength and failure strain data. Tensile test is preferred to provide the failure data. For micro-lattice structure as a whole, tensile test experiment will need a specially designed and fabricated jig to hold the specimen. To simplify this, it is suggested that tensile test on single strut specimen need to be done.

Stress-stress diagram for single strut can provide some information related to the basic failure of lattice structure material. For ABS lattice-structure fabricated using 3D printer, mechanical properties from tensile test has not yet been conducted. Thus, this study is looking for such data.

1.3 OBJECTIVE

To investigate mechanical properties of 3D printed single strut with selected parameter using tensile test.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Design of single strut for tensile test specimen using Solidworks with selected parameter.
2. Fabrication of single strut tensile test specimen using CubePro 3D printer, from ABS material.
3. Conduct tensile test experiment for single strut by using Shimadzu table top machine.
4. Analyse mechanical properties of single strut using compliance correction method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the background of this study will be researched in order to have better understanding of fundamental knowledge before proceed for further progress. All topics are which relevant with this study are discussed based on the journal articles and academic book. Besides that, all materials from previous research which related to this study will be described as well.

2.2 Lattice-structure and Strut

Struts is the basic units which will be connected to each other to form lattice structure. The connection between struts are called nodes, the point where struts meet together in the structure. In a fixed volume, there are various types of configuration where strut-based lattice structure can be designed with variation of node position. Material used in the lattice-structure can be saved as it has high stiffness to weight ratio. Hence, the problem of forming in any complex geometries can be eliminated when the strut-based lattice structure is applied (Doyoyo and Hu, 2006).

Large number of formations of strut-based lattice structure in a fixed volume can be deformed when the number of nodes and struts are not fixed. Node position and strut diameter also can be the variable in a specific volume besides the alteration of number of nodes which can produce large number of results (Syam et al., 2017). Strut-based lattice structure can be in numerous form such as cubic truss and octetruss as shown in Figure 2.2.1.

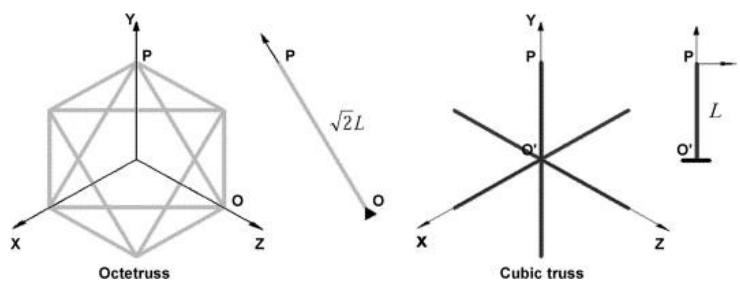

Figure 2.2.1: Octetruss and cubic truss.

(Source: Doyoyo and Hu, 2006)

2.3 Methods in Producing Lattice-structures

Common process to manufacture lattice-structures are through casting, sheet metal forming or wire bonding process. These regular assemblies are time-consuming and furthermore limited the complexity of lattice-structure designs. These methods are just used to produce lattice-structure materials with simple setup on a macroscale (Tang et al.2017).

In casting process, ceramic casting slurry is used to coat a pattern of wax or polymer lattice-structure. This ceramic is a mold and the wax or polymer is the expelled through the process of melting. The liquid metal with high fluidity can be utilized to fill in the vacant shape of the mold to form lattice-structure material. Wide range of shapes of lattice structure can be formed by using this method as any shape can be produced according to the designed mold. Through out this process, the produced lattice-structure material had severe porosity and this method is time consuming and costly. Example of octet-truss lattice structure produced from casting process is shown in Figure 2.3.1.

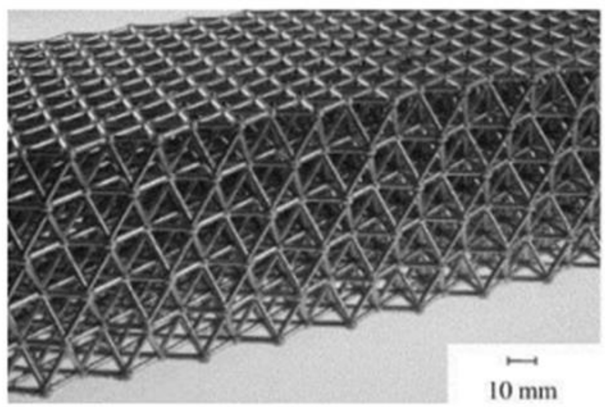

Figure 2.3.1: Octet-truss lattice structure.

(Source: Rashed et al., 2016)