INVESTIGATION ON MECHANICAL PROPERTIES OF ADDITIVE MANUFACTURED BONE SCAFFOLD

This report submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering

(Manufacturing Design) (Hons.)

by

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DECLARATION

I hereby, declared this report entitled "Investigation On Mechanical Properties Of Additive Manufactured Bone Scaffold" is the results of my own research except as cites in the references.

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Date : 29 MAY 2017

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons). The member of the supervisory is as follow:

……………………………………………

(DR. SHAJAHAN BIN MAIDIN)

ABSTRAK

Perancah tulang (Bone scaffold) diperbuat daripada proses Additive Manufacturing (AM) teknologi kerana AM memiliki ciri-ciri kelebihan iaitu, berupaya mereka bentuk komponen yang rumit dan penyatuan bahagian sesuatu komponen atau produk. Perancah tulang digunakan untuk menggantikan bahagian rosak dalam tulang kerana ia menyediakan satu rangka struktur yang sementara untuk pembangunan tisu. Perancah tulang dapat menyelesaikan masalah gangguan tulang yang dijanka akan berganda dalam tahun 2020. Perkembangan perancah tulang juga dapat membantu mungurangkan isu penolakan yang biasanya ditolak oleh sistem imun penerima sendiri selepas proses pemindahan. Sejak perancah tulang mepunyai permintaan yang tinggi dalam bidang perubatan, oleh itu projek ini mencadangkan empat reka bentuk yang berbeza dan simulasi bersama dengan ujian mekanikal dibuat untuk memilih struktur dan bahan yang mempunyai sifat mekanikal yang terbaik semasa perancah tulang pembuatan. Dengan menggunakan empat reka bentuk tersebut, perancah tulang yang mempunyai sifat mekanikal yang terbaik akan dipilih selepas menjalankan simulasi dan ujian mekanikal. Selepas ujian tersebut, struktur perancah tulang dengan reka bentuk 3 yang berbentuk empat segi, saiz liang 0.4mm dan dihasil dengan PLA dipilih disebabkan nilai tekanan yang tinggi. Nilai tekanan yang tinggi menunjukkan perancah tulang mempunyai kekuatan mekanikal yang tinggi kerana ia boleh tahan jumlah tenaga tekanan yang tinggi. Hal ini kerana perancah tulang dengan tekanan yang tinggi membolehkan lebih mudah pengendalian pembedahan dan pembinaan semula tisu tulang yang keras selepas proses implantasi. Oleh itu, reka betuk 3 adalah struktur yang paling sesuai dan PLA adalah bahan yang paling sesuai untuk pembuatan perancah tulang.

ABSTRACT

Bone scaffold is made through the process of Additive Manufacturing (AM) Technologies due to its advantages of design complexity and parts consolidation. Additive manufactured bone scaffold used to replace damage part on the bone as it provides a temporary structural framework for development of tissue. Additive manufactured bone scaffold able to solve bone disorder problem since the cases of bone disorder expected to double up in year 2020. The development of bone scaffold also helps to decrease the rejection issue which normally rejected by recipient's own immune system after transplantation process. Since bone scaffold has a high demand in biomedical field, so this project was proposed with four designs of bone scaffold and simulation together with mechanical testing have been done to choose the best structure and material of bone scaffold which performed the best mechanical properties. After undergone those testing, Design 3 scaffold with square shape, 0.4mm pore size and fabricated with PLA is selected among others designs due to its high value of stress. High value of stress implies that the scaffold has high mechanical strength due to the high amount of force it can withstand. This is because scaffold with high strength allows easier surgical handling and reconstruction of hard bone tissues after implantation process. Therefore, design 3 is the most suitable structure while PLA is the best suitable material to fabricate scaffold.

DEDICATION

Dedicated to

My beloved parents

Dearest siblings

Honorable supervisor, panels and lectures

Loyal friends

My prayers upon you will be embedded in my heart whenever I go and where I think of you

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First and foremost, I am grateful to Gautama Buddha for giving me the strength and health during the process of doing this project.

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Thank You

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LIST OF ABBREVIATION

ASTM	-	American Society for Testing and Materials
AM	-	Additive Manufacturing
TE	-	Tissue Engineering
SLA	-	Stereolithography
SGC	-	Solid Ground Curing
3DP	-	Three Dimensional Printing
SLS	-	Selective Laser Sintering
LOM	-	Laminated Object Manufacturing
FDM	-	Fused Deposition Modeling
FYP	-	Final Year Project
ABS	-	Acrylonitrile Butadiene Styrene
PLA	-	Polylactic acid

LIST OF SYMBOLS

%	-	Percentage
MPA	-	Megapascal
kN	-	Kilo Newton
mm	-	Millimeter

CHAPTER 1

INTRODUCTION

According to ISO/ASTM 52900 (2012), additive manufacturing (AM) is a process of joining materials to make parts from 3D model data. It usually carried out layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies. The application of AM can be applied in various fields especially in biomedical fields as it able to produce product with geometrical freedom and design consolidation.

The cases of bone disorders in worldwide are increases every year and expected to double up by year 2020 (Amini *et al.* 2012). Therefore, bone tissue engineering aims to induce functional bone regeneration by using AM technique since AM able to produce different kinds of product with complex structure.

According to Da Silva *et al.* (2009), the field of tissue engineering has emerged to regenerate damaged tissue by combining cells from the body with scaffold biomaterial which is highly porous. The scaffold such as bone plays an important role in tissue engineering as it provides a temporary structural framework for development of tissue. Bone scaffolds are made from porous degradable materials which will consequently provide mechanical support during regeneration of bone (Bose *et al*., 2012). Figure 1.1 shows the before and after implantation of bone scaffold into the damaged bone. Bone scaffold is complex in shape and function to act as a framework for bone cells to regenerate. The bone is healed after the scaffold is incorporated into the defected bone.

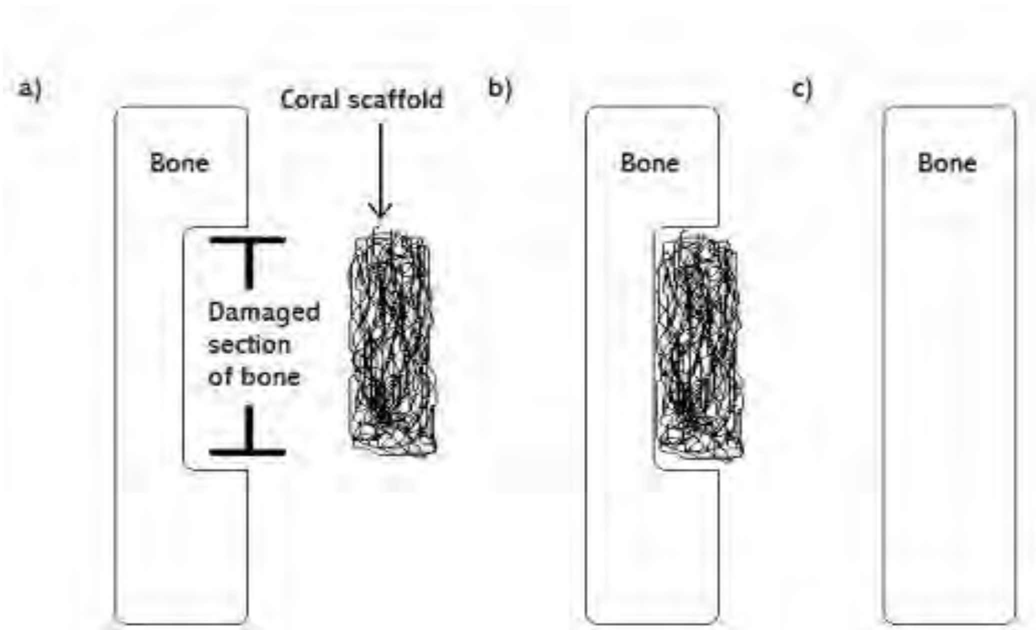

Figure 1.1: a) Before implantation of scaffold into damaged bone; b) Scaffold inserted into damaged section of bone; c) Completely healed bone
(Source: http://web.stanford.edu/group/mota/education/Physics%2087N%20Final%20Projects/Group%20Gamma/bone.htm/30/11/2016)

There are several methods to fabricate bone scaffolds but due to material and time constraint, the mechanical properties of scaffold are focused so that the optimum bone scaffolds can be chosen. Bone scaffolds should have appropriate mechanical properties to help in bone healing. To be able to produce the model of scaffold, few test specimens of bone scaffold are fabricated by using fused deposition modeling. Testing included compression, flexural and tensile test are carried out to determine and predict the mechanical properties of fabricated bone scaffold accurately and specifically.

This project looks at the ways to produce three dimensional scaffolds by using AM. Several designs of scaffolds with an integrated 3D network are develop and the fabricated scaffolds are test on its mechanical properties and the suitable scaffold is selected.

1.1 Problem Statement

According to O'brien and F. J. (2011), transplantation of tissues or organ from donor to recipient can cause rejection issue, therefore scaffold need to be produce in order to regenerate tissue instead of replace.

Since the fabrication of scaffolds are expensive and time consuming, thus the mechanical properties of scaffold are focus in order to find the optimum design as the mechanical properties of scaffold are important during bone healing process. Besides that, the material to fabricate scaffold also important since implantation is needed for cell regenerate. Therefore, the purpose of this project is to fabricate different structures of scaffold and determine which structure and material is the best for tissue regenerating.

1.2 Aims

The aim of this project is to study and select the best additive manufactured scaffold design structure and material which have the best mechanical properties.

1.3 Objectives

The objectives of this project are:

1) To design different structures of bone scaffold.
2) To choose the optimum design structure of the bone scaffold via simulation and mechanical testing.

3) To 3D print the optimum design structure using fuse deposition modeling machine.
4) To conduct mechanical testing to test the effect of material on mechanical properties of scaffold.

1.4 Scope

The scopes of this project are design the structures of scaffold using Solidwork 2016 software and carried out finite element analysis with Solidwork Simulation. The optimum structure is fabricated with two different materials which are ABS and PLA through fused deposition modeling (FDM) process. Besides that, universal testing machine are used to test the mechanical properties of the scaffolds.

CHAPTER 2

LITERATURE REVIEW

2.1 Subtractive vs Additive Manufacturing

According to Guo and Leu (2013), additive manufacturing (AM) technology has been developed for more than 20 years. AM process make the three dimensional part directly from 3D models, layer upon layer, to build parts with geometric and material complexities that could not be produced by a subtractive manufacturing process. Subtractive manufacturing is a process in which 3D objects are constructed by cutting those unwanted material away from a solid block of material. Examples of subtractive manufacturing are milling, drilling, turning and so on. Figure 2.1 shows the brief concept about the difference between subtractive and additive manufacturing.

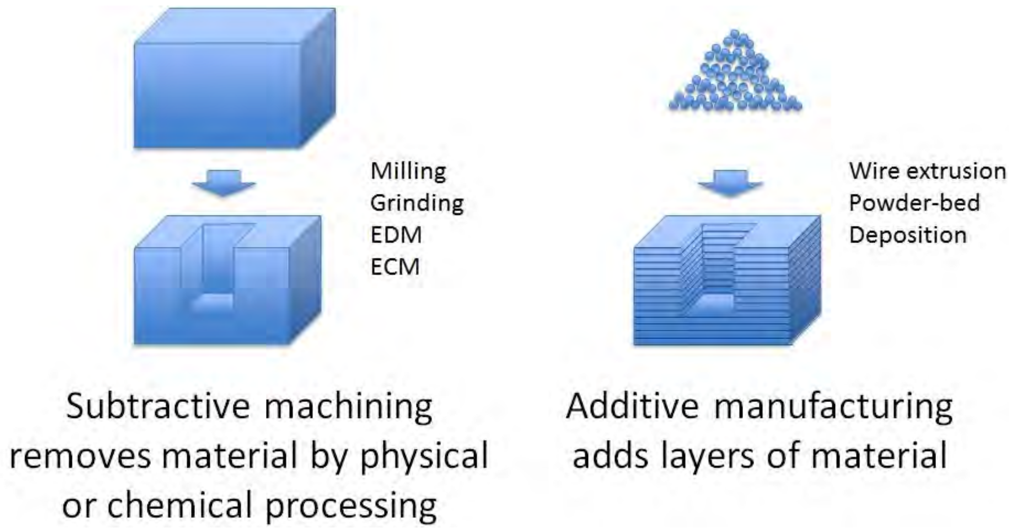

Figure 2.1: Concept of subtractive and additive manufacturing
(Source: http://research.engineering.ucdavis.edu/stemaerospace/sustainable-manufacturing,10/10/2016)

According to Sunny (2015), there are four considerations for method selection between subtractive and additive manufacturing. The four considerations are material selection, part quantity, part geometry and project schedule and part revisions. Table 2.1 shows the comparison of considerations between subtractive and additive manufacturing before production.

Table 2.1: Comparison between subtractive and additive manufacturing (Sunny, 2015)

	Subtractive Manufacturing	Additive Manufacturing
Material	• Acrylonitirle butadiene styrene (ABS) • Polylactic Acid (PLA) • Polyvinyl Alcohol Plastic (PVA) • Nylon • Resins	• Engineering metals (aluminum and steel) • Wood • Ceramics • Foams, like polystyrene or structural foam
Part quantity	High volume production	Low volume production
Part geometry	For dimensional accuracy and repeatability	Organic surfaces and complex features
Project schedule	Short lead time	Fast lead time

2.2 AM Techniques

According to Wong and Hernandez (2012), the additive manufacturing techniques can be classified into three categories which are liquid based, solid based and powder based. Figure 2.2 shows the flow chart of the process materials cased classification of additive manufacturing.

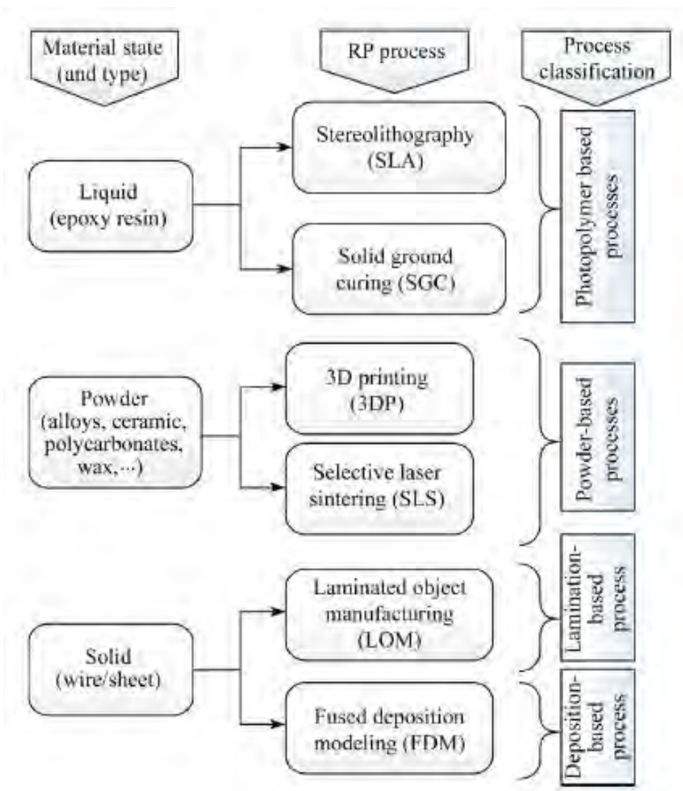

Figure 2.2: Process material based classification of AM
(Source: http://html.rhhz.net/AIM/html/108.htm,10/10/2016)

2.2.1 Liquid based process

The starting material of this technology is liquid. About a dozen of rapid prototyping technologies are in this category (Groover, 2007). The process that uses liquid as a base of rapid prototyping are Stereolithography (SLA) and Solid ground curing (SCS).

2.2.1.1 Stereolithography (SLA)

Stereolithography is a process to fabricate a solid plastic part out of a photosensitive liquid polymer. It solidified the polymer by using a direct laser beam (Groover, 2007). Guo and Leu (2013), had mentioned that during the process of SLA, CAD model is sliced into several layers and cure the resin by using UV light to scan. Then, the platform is lower down a layer thickness after a layer is built. After that, the resin filled blade move across the part cross section and recoat a layer of new resin. The following layer is scanned by adhering the previous layer. Figure 2.3 shows the diagram of the SLA process, whereas Table 2.2 shows the advantages, disadvantages materials used and examples of SLA.

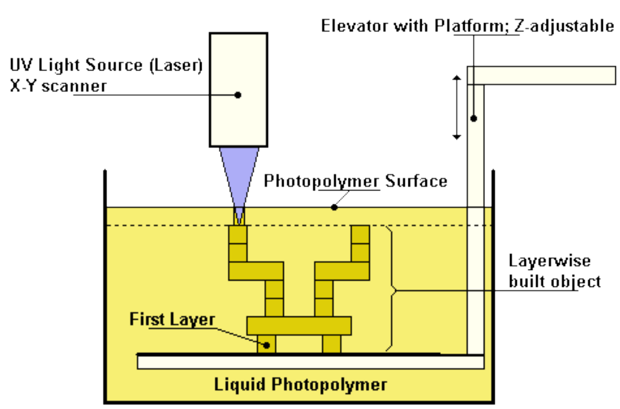

Figure 2.3: Process of SLA
(Source: http://www.proform.ch/en/technologies/stereolithography.html,12/10/2016)