UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DETERMINATION OF TENSILE PROPERTIES OF TOPOLOGICALLY OPTIMIZED FDM FOR END-USED PART

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

by

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DECLARATION

I hereby, declared this report entitled “Determination of Tensile Properties of Topologically Optimized FDM for End-Used Part” is the results of my own research except as cited in references.

Signature : …………………………………………………………..

Author’s Name : …………………………………………………………..

Date : …………………………………………………………..

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) with Honours. The member of the supervisory committee is as follow:

………………………………

(Official Stamp of Supervisor)

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honours. The members of the supervisory committee are as follow:

………………………………

(Official Stamp of Principal Supervisor)

ABSTRAK

Additive Manufacturing proses mampu memfabrikasi komponen berfungsi yang mempunyai geometri yang kompleks serta pelbagai bahan. Additive Manufacturing juga mampu untuk memfabrikasi geometri yang dioptimumkan dengan kekuatan yang baik. Fused Deposition Modeling (FDM) adalah salah satu teknologi AM yang digunakan dalam projek ini untuk memfabrikasi produk akhir. Mesin FDM boleh fabrikasi prototaip atau produk akhir dengan menghasilkan lapisan demi lapisan pada produk tersebut dan komponen tersebut mempunyai kekuatan tegangan yang baik. Walau bagaimanapun, kos fabrikasi adalah mahal oleh demikian bahan-bahan mentah yang digunakan itu perlu dikurangkan supaya kos dapat menurun. Pengoptimuman topologi membolehkan untuk mengoptimumkan massa atau kos dengan mengoptimumkan geometrinya. Oleh itu dalam projek ini, terdapat sepuluh spesimen bagi setiap dogbone dan pendakap akan difabrikasikan menggunakan Printer CubePro Trio 3D. Sifat-sifat mekanikal bagi komponen tidak dioptimumkan dan komponen dioptimumkan akan diperhatikan dan dianalisis dengan menggunakan Finite Element Analysis (FEA) yang mampu mengesahkan data yang telah diperolehi.

ABSTRACT

Additive Manufacturing (AM) process able to fabricate functional parts which have complex geometries as well as multi-materials and able to fabricate optimized geometries with good strength. Fused Deposition Modeling (FDM) is one of the AM technologies that used in this project to fabricate the end-used part. FDM machine fabricate prototypes or end-used parts layer by layer and the strength of the parts have good tensile strength. However, cost of fabrication is costly and thus raw materials used have to reduce in order to reduce the cost. Topology optimization enables to optimize the mass or cost by optimize the geometry of the parts. In this project, there are ten specimens of each dogbone and bracket will be fabricated using CubePro Trio 3D Printer. The mechanical properties of the non-optimized part and optimized part will be observed and analyzed. Furthermore, Finite Element Analysis (FEA) that issued to validate the data collected to compare the behavior of the parts.

DEDICATION

To my beloved family member

My beloved father, Su Eng Lai

and my appreciated mother, Tan Swee Chin

for giving me moral support, encouragement and understanding along this project.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ABS	-	Acrylonitrile butadiene styrene
AM	-	Additive manufacturing
ASTM	-	American Society for Testing and Materials
C_3H_3N	-	Acrylonitrile
C_4H_6	-	Butadiene
C_8H_8	-	Styrene
CAD	-	Computer-aided Design
CAM	-	Computer-aided Manufacturing
CNC	-	Computer Numerical Control
EDM	-	Electrical Discharge Machining
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FDM	-	Fused Deposition Modelling
FTMK	-	Fakulti Teknologi Maklumat dan Komunikasi
MBB	-	Messerschmitt-Bolkow-Blohm
SIMP	-	Solid Isotropic Microstructure with Penalisation
STL	-	Stereolithography
TO		Topological Optimized
UTeM	-	Universiti Teknikal Malaysia Melaka
2D	-	2 Dimension
3D	-	3 Dimension
σ	-	Tensile stress

CHAPTER 1

INTRODUCTION

1.1 Background

AM is a term that uses to describe a process which produces a part or a system rapidly before final release by using computer-aided design (CAD) math data. In simple words, creation of an object quickly and the output is a prototype. There are few terms of AM including rapid prototyping, 3D printers and etc. The term "rapid" refers to quick creation of physical models compared to traditional methods such as milling, turning, drilling and etc. (Villalpando, Characterization of Parametric Internal Structures for Components Builts by Fused Deposition Modeling, 2013). Lately, a formed Technical Committee within ASTM International decided that new terminology should be implemented by the term Additive Manufacturing (Ian Gibson, David Rosen, Brent Stucker, 2015). AM involves addition of material to the component which different from traditional manufacturing where substrate material from the initial component. AM is labeled as disruptive technology (One kind of technology that substantially modifies paths that businesses operate) attributable to the associated capable to manufacture in low batch size and highly complex components (Martin Leary, 2014). This capability offers an opportunity to implement topology optimization geometry which manages to manufacture complex geometry.

Fused Deposition Modeling (FDM) is an additive manufacturing technology used to fabricate the prototype where it works by laying down material in layers. FDM products can be used as a prototype, even as an end-used part. Some FDM modeled part have a good in tensile strength and it is suitable for medical or aerospace application. However, not every topology optimized FDM products have the same strength compared FDM products without topology optimization. Hence, the tensile properties of the FDM end-used product is important to be investigate to confirm the value of topology optimization and to confirm it have a good quality end-used product with good mechanical properties.

Topology optimization is a quite new and fast growing field of structural mechanics which able to reduce the consumption on raw material, manufacturing cost and time (Rozvany G. , 2011). Generally, topology optimization used to approach practical design problems with traditional manufacturing process in mind, such as casting and machining. The process that the part is fabricated by material removal can be known as subtractive processes while process that the part is fabricated by a mold can be known as formative processes. There are some significant manufacturing constraints have to consider during the design stage to ensure a feasible design. Therefore, an experimental analysis of the tensile properties of topology optimization FDM end-used product has to be conducted.

1.2 Problem Statement

Topology optimization is a strong approach for determine the best material distribution. By applying topology optimization, the cost may reduce with increased the complexity of the component (D.Brackett, 2011). However, not every topology optimized FDM products have the same strength compared FDM products without topology optimization. Hence, an experimental study has to perform to determine the tensile properties of topological optimized FDM for end used parts.

1.3 Objective

The main objectives of doing this project are:

1. To design and fabricate end-used parts using Fused Deposition Modeling.
2. To determine the influence of topology optimization to the tensile strength of FDM used part
3. To validate the results via Finite Element Analysis (FEA).

1.4 Scope of Project

In this study, it will focus on additive manufacturing technology of Fused deposition Modeling (FDM) of the end used parts. The results of tensile properties test on the end used parts will be concluded in this project. The relationship of the design of the topology optimization on the component and the tensile properties of the end used parts will be discussed in the project.

The purpose of this project is to determine the tensile properties of topologically optimised FDM for end used part. The scopes of the project are:

i. Fabricate end-used functional parts using FDM technology
ii. Measure the tensile strength of the parts
iii. Topologically optimised the parts – reduce the density of the parts.
iv. Measure the tensile strength of topologically optimised parts.
v. Observe and compare the behaviour of the two parts.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Additive Manufacturing

Additive manufacturing (AM) is defined by ASTM: F2792-10 as a way of a process of joining materials to make components from 3D model data, typically layer upon layer, as opposed to subtractive manufacturing methodologies (ASTM International, 2011). Precisely, it defines as a professional production technique which is totally different from conventional manufacturing methods of material removal. By additive manufacturing technology that able to build up components layer upon layer with materials which are in fine powder is rather than milling a workpiece from a solid block. There are varieties of different plastics, metals and composite types of materials may be used in this application.

2.1.1 History

First AM equipment and materials were developed in the 1980s. In year 1981, two AM fabrication methods of 3D plastic model together with photo-hardening polymer, in which UV exposure area is controlled by scanning fiber transmitter was invented by Hideo Kodama of Nagoya Municipal industrial Research Institute. Later in year 1984, Chuck Hull from 3D Systems Corporation had developed a prototype system depend on stereolithography where is a process that layers are added through curing photopolymers together with ultraviolet light lasers. He contributed in designing the STL file format that generally accepted by 3D printing software which included digital slicing and infill strategy which common to many process nowadays. This 3D printing previously refers to a process that using standard and custom inkjet print heads.

AM processes for metal sintering, for example selective laser sintering, direct metal laser sintering and selective laser melting had their own individual names in 1980s and 1990s. Casting, fabrication stamping and machining even plenty of automation was applied to those technologies were able to manufacture all metal working during that time.

In the decade of 2000s, term of 3D printing still remarked only to polymer technologies. The AM term was prospective used in metalworking contexts than those inkjet or polymer or stereolithography enthusiasts. These terms, AM and 3D printing were compounded in the same AM technologies in early 2010s. There are some other terms that have appeared instead of additive manufacturing, such as desktop manufacturing, rapid manufacturing, on-demand manufacturing, and etc. (Wikipedia, n.d).

2.1.2 Process Flow of Additive Manufacturing

AM implicates a few steps from virtual CAD description to physical resultant part. Different AM methods and degree are applied on various types of products. For those small and simple products may possibly use AM for visualization models however large and complex products with higher engineering content may involve AM during some stages in development process. Due to speed of AM been used to fabricate, the initial stage of the product may only need a rough parts. Later, the parts may need cleaning and post-processing which including surface finishing and painting as well before the parts are used.

There are few generic stages of AM process. There will be some variations on the design of the parts and the technology being used. There might be some difference steps involved for some particular machines but is minor. However, for the most part that discussed below is respect to production of polymer parts, most of the stages can be applied same to the production of metal parts as well.

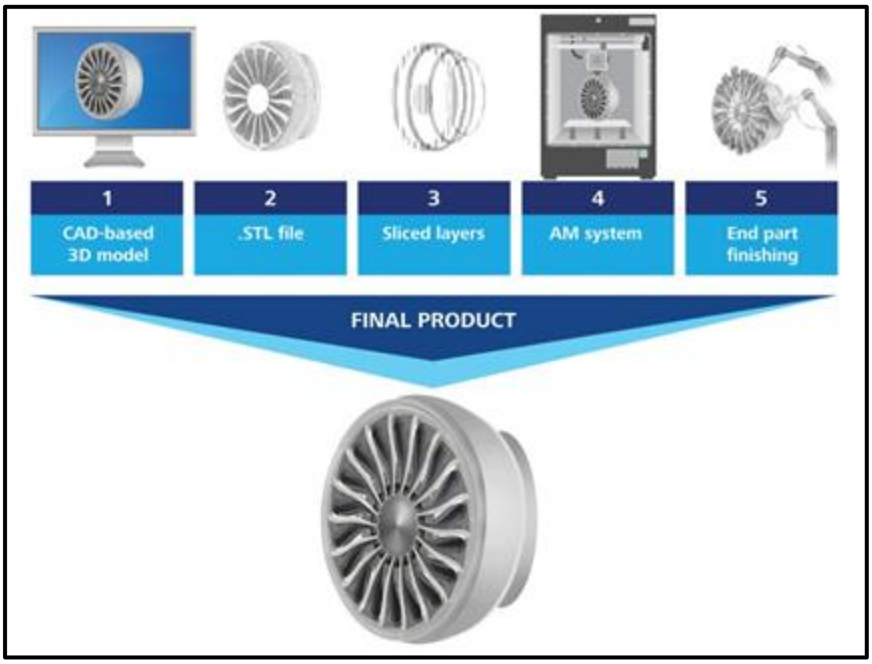

Figure 2.1: Additive Manufacturing process flow (Mark Cotteleer, 2014)

2.1.2.1 Step 1: Create 3D CAD

There may have different kind of method to re-create the 3D source data. Every AM parts have to start from a software model that have the capability to fully defines the external geometry by using any professional CAD software or reverse engineering equipment (such as laser scanning). Most of the 3D CAD systems are solid modeling systems and a few of surface modeling components. From that, joining the surfaces altogether or increasing some thickness onto a surface are able to form a solid model. At present, it is hard for 3D CAD modeling software to create fully enclosed solid models and frequently models would appear to the casual observer to be enclosed but indeed were not.

2.1.2.2 Step 2: Conversion to STL

Most of the AM technologies using STL file format to describe a CAD model in terms of geometry. This STL term was derived from Stereolithography in which it was the first commercial AM technology from 3D Systems in 1990s, considered as de facto standard. STL file performs by eliminating any construction data, modeling history and resembling surfaces of the models with a series of triangular facets. Most of the CAD software able to adjust the minimum size of these triangles and purpose is to ensure the models created do not point out any apparent triangles on the surface. The size of the triangles is controlled by the minimum distance between the plane and the imaginary surface to be represented. 3D CAD data convert to STL file format is automatic in the majority CAD systems. However, there may have risk of errors happen in this stage and thus some advanced software tools are able to detect the problems and fix it if possible.

2.1.2.3 Step 3: Transfer to AM Machine and STL File Manipulation

As soon as the STL file has generated, it can be transfer directly to the AM machine. But, there might have to take some action prior to the parts before the machine start fabricate.

First, make sure that the part is correct. A visualization tool that locates inside AM system software allows the user to observe and manipulate the part. The user would like to relocate the part or else alter the orientation so that it built at a particular location in the machine. It is relatively normal to build one or more part in an AM machine at once. A different STL files or a copy function may need for building a double of the same part. The AM parts may slightly larger or smaller compare to the original model due to certain application that involve for the purpose of shrinkage or coating process.

2.1.2.4 Step 4: Machine Setup

In order to start the part construction, the AM machine has to be set up correctly. All the settings of the AM machine would link to the build parameters such as material constraints, energy source, layer thickness and timings.

Certain machines designed to process a couple of different materials that without any difference in layer thickness or other parameters. Some other machines designed to process only one kind of materials and several parameters that involve optimization to match the type of part that to be built. This type of machines can have various setup routes available. Usually, a wrong setup procedure still able to fabricate the part, however the quality of the part may be unacceptable.