# INVESTIGATION ON FLEXURAL AND COMPRESSION STRENGTH OF VACUUM ASSISTED FUSE DEPOSITION MODELING SYSTEM SPECIMENS

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

by

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# DECLARATION

I declare that this thesis entitled "Investigation on Flexural and Compression Strength of Vacuum Assisted Fuse Deposition Modeling System Specimens" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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| Date | : | 24 May 2018 |

# APPROVAL

I hereby declare that I have read this report and in my opinion this thesis is sufficient in terms of scope and quality as a partial fulfillment of Bachelor Degree of Manufacturing Engineering.

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| Date | : | 24 May 2018 |

# ABSTRAK

Tujuan projek ini adalah untuk menentukan parameter optimum untuk kekuatan lentur dan mampatan. Parameter optimum yang digunakan dibahagikan kepada 2 pembolehubah bergantung, ketumpatan infill spesimen dan tekanan vakum. Setiap parameter ini ditetapkan kepada 4 tahap iaitu 25%, 50%, 75% dan 100% untuk kerapatan infill dan juga 21 inHg, 24 inHg, 27 inHg dan 30 inHg untuk tekanan vakum. Spesimen dibuat dengan menggunakan mesin Pemendapan pemodenan terlakur (FDM), mesin Up Plus 2. Reka bentuk spesimen ini dicipta dengan perisian CAD yang merupakan SolidWork dan diperlukan untuk menukar terlebih dahulu ke format fail STL. Hanya selepas itu ia boleh dihantar ke mesin FDM untuk langkah seterusnya untuk menghasilkan bahagian yang dicetak. Dalam projek ini, ia hanya memerlukan satu jenis bahan yang akan ditumpukan untuk menghasilkan spesimen, dan ABS dipilih. Sebaik sahaja spesimen dilakukan dicetak, dua jenis ujian akan dijalankan untuk menentukan parameter optimum yang diperlukan untuk kedua-dua kekuatan lentur dan mampatan. Sebanyak 16 eksperimen dijalankan dengan 3 spesimen purata akan diambil untuk satu larian. Memandangkan terdapat dua ujian yang berbeza diadakan, 48 spesimen yang dicetak secara total dihasilkan untuk setiap ujian yang telah dijalankan. Akhir sekali, kaedah ANOVA telah mengesahkan kepentingan set parameter dan parameter yang dioptimumkan ialah pada 30 inHg / 100% iaitu 39.7594 N/mm2 untuk tekanan lenturan dan 5.2678% pada 27 inHg / 75% untuk ketegangan lentur manakala keputusan tertinggi untuk kekuatan mampatan dinyatakan pada 27 inHg / 100% sebanyak 38.6875 N/mm2 untuk tekanan dan 34.8444% pada 24 inHg / 100% untuk ketegangan. Selain itu, permukaan spesimen juga telah dianalisis oleh mikroskop optik. Hasil daripada analisis menunjukkan terdapat beberapa buih dan jarak yang jelas kelihatan antara lapisan-lapisan spesimen.

# ABSTRACT

The aim of this project is to determine the optimum parameters for flexural and compression strength. Optimum parameters used are divided into 2 dependent variables, the infill density of specimen and vacuum pressure. Each of these parameters is set into 4 level of number which are 25%, 50%, 75% and 100% for infill density and also 21 inHg, 24 inHg, 27 inHg and 30 inHg for vacuum pressure. The specimens are fabricated by using one of FDM machine, the Up Plus 2 machine. Designs of these specimens are created with CAD software which is SolidWork and are needed to convert first into STL file format. Only after that it can be send to FDM machine for next step to produce the printed parts. In this project, it requires only one types of material to be focused into to produce the specimens, and ABS is selected. As soon as the specimens are done printed out, two different types of test were be carried out to determine the optimum parameters needed for both flexural and compression strength. A total 16 experiment runs with 3 average specimens will be taken for one number of run. Since there are two different tests were held, 48 printed specimens in total were produced for each testing conducted. Lastly, the final optimum result is 39.7594 N/mm2 at 30 inHg/100% for flexural stress and 5.2678% at 27 inHg/75% for flexural strain while the highest result for compression strength is stated as 38.6875 N/mm2 at 27 inHg/100% for stress and 34.8444% at 24 inHg/100% for strain. Besides that, the surface of the samples also been analysed by Optical Microscope (OM). The result of the analysis showed that the specimens had some bubbles and there were obviously seen gaps between layers of the specimens.

# DEDICATION

This project is dedicated to

My beloved parents

Dearest Siblings

Honorable supervisor, Panels and others lecturers

Supportive friends

Thank you for the moral support, full cooperation and encouragement for this project

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| | | |
|---|---|---|
| ABS | - | Acrylonitrile Butadiene Styrene Additive |
| AM | - | Additive Manufacturing |
| ASTM | - | American Society for Testing and Materials |
| CAD | - | Computer Aided Design |
| 3D | - | 3 Dimension |
| FDM | - | Fused Deposition Modeling |
| FYP | - | Final Year Project |
| PLA | - | Polylactic acid |
| SLA | - | Stereolithography |
| SLS | - | Selective Laser Sintering |
| SOP | - | Standard Operating Procedure |
| UTeM | - | Universiti Teknikal Malaysia Melaka |
| UTM | - | Universal Testing Machine |
| % | - | Percentage |
| inHg | - | Inches mercury |
| OM | - | Optical Microscope |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Additive Manufacturing (AM) technology, also known as rapid manufacturing or 3D printing is a process which includes joining of the materials to create part directly from 3D CAD model data, usually layer upon layer of material, whether it is plastic, metal, concrete, and others (Aliheidari, Tripuraneni, Ameli, & Nadimpalli, 2017). By using AM technology, we are allowed to produce objects with freeform geometries and optimized structures which have no possible to be done by manufacturing practices (Lin, 2014).

Moreover, time to build the prototypes, tooling and models in the product development process also can be reduced. In adapting the rapid changes of product design, AM technology is one of more flexible and faster compared to conventional methods such as lathe, milling, casting, molding and machining. Besides, by using AM technology, parts or products that come with complex geometry can be made easily (German, 2017).

Fused deposition modeling (FDM) is one of the addictive manufacturing (AM) technologies which commonly used in modeling, prototyping, and also for production applications. There are several different methods of 3D printing, but Fused Deposition Modeling (FDM) is the most widely used, which simply means that during printing process, the deposition of material in single layers will fuse together to create a 3D printed part.

FDM process build parts by extruding the material, traverses in X and Y through a nozzle to create each 2-Dimensional layer (Daneshmand & Aghanajafi, 2012). Plastic material such as Acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) is used in FDM to produce the product/model. The durable components with complex geometry can be made in nearly any shape and size by using the FDM technology (Ventola, 2014).

In addition, vacuum technology has become a valuable industrial tool. FDM is the most common technology used in creating 3D printed molds for vacuum forming and offers many unique benefits. It allows us to print in various sparse fills densities, giving the molds inherent porosity that result in uniform vacuum to be drawn throughout the tool. This automatically can greatly simplify the fabrication of the tool. Not only that, FDM machines are capable of printing molds in a variety of durable and also heat resistant plastics (U.S. Department of Energy, 2015).

In this report, a project is carried out about the novelty of using vacuum technology to determine the influences and effects on the mechanical properties of the FDM printed parts. Specimens were built in under a vacuum environment by using an open sourced FDM machine by controlling the different operating parameters set up, which consist of vacuum pressure, layer thickness and infill density. We are aiming the optimum results throughout this project. The results from various parameters were analyzed on the specimen mechanical properties.

## 1.2 Problem Statement

The mechanical property for most FDM material is still poor as it possess anisotropic properties regarding the study of (Motaparti, 2016). The process of FDM has producing objects that are constructed in layers-by-layers has presents the significant of structural anisotropy. It stated that the bonding at vertical is so much weaker compared in the layer bonds (Umetani & Schmidt, 2013).

It is also agreed by Kozior & Kundera (2017), whose states that the direction of the element position on the building platform, layer thickness and temperature of working chamber will affect the result of mechanical properties of parts produced.

In fact, under additive manufacturing processes, the products built by Selective Laser Sintering (SLS) are better in mechanical strength compared to FDM, as it is in the second ranking by having best surface finish after Stereolithography (SLA) because of the nature in powder sintering which is free from anisotropic effects. Despite of that, good strength properties of products can be produced by SLS and it will be suitable used for working prototypes (Ilkgun, 2005).

According to (Maidin, Wong, Mohamed, & Mohamed, 2017), a study has found that lower strength of a product produced is affected by the main problem of imperfect or inadequate bonding occurs between layers at z-axis. The bonding process takes place fast during the printing process. Hence, it leads to improperly fusion of layers. Therefore, the current progress in Fused Deposition Modeling (FDM) system is taking slow as prevention for the product from being fully-utilized as end-use parts. The results obtained is shown the improvement of flexural and compression strength of parts when printed by using vacuum assisted compared to normal atmospherics ones.

## 1.3 Aim

The aim of this project is to improve the flexural and compression strength of printed parts through vacuum assisted FDM machine by identifying the optimum process parameters. In order to fulfill the aim, a few objectives are needed to achieve.

## 1.4 Objectives

The objectives of the project are:

i. To produce 3D CAD model to enable printing of the test specimen via a vacuum fused deposition modeling (FDM) system.
ii. To print the test specimen with different optimum process parameters to study the effect on the flexural and compression strength.
iii. To conduct a flexural and compression test with different types of infill density and vacuum pressure to identify the optimum results.

## 1.5 Scope

This project is covers the use of a desktop FDM system (Up Plus 2) assisted with a vacuum system. An initial study of a finite element analysis of flow simulation will be conducted using CAD/CAE software, and Acrylonitrile Butadiene Styrene (ABS) is used as the material. In addition, few parameters were included, and by using additive manufacturing technology, the fused deposition modeling (FDM), it is consists of the vacuum pressure and the infill density. The combination of parameters is used to achieve an improvement on flexural and compression strength of 3D printed models. A Universal Testing Machine (UTM) will be used and as a result, it will carry out the flexural and compression strength. An Optical Microscopic (OM) machine is use for analyzing and observation process of microstructure of 3D printed parts.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 What is Additive Manufacturing (AM)?

Additive manufacturing (AM) is the process of assembly materials to create objects from Computer Aided Design (CAD) model data, which usually layer upon layer, as contrasting to subtractive manufacturing methods. AM is also well-known with others name as 3D printing, additive fabrication, or freeform fabrication. These new techniques is still evolve in our industry nowadays, and are expected to profound an intense impact on manufacturing. They might contribute into a new designs, the flexibility, reducing the energy used, and shorten time to the market in the industry in future (U.S. Department of Energy, 2015).

More opportunities in losing profits may occur as we had spent so much time focusing on the product development. This one kind philosophy has driven many industries in develop more new products. As we realized that more number of prototypes from the same parts needs to be created and it requires lot of efforts to be contributed to develop those rapid prototyping of replicas of products with cost-effective system. Few aspects such as design, quality and other types of tests can be checked just before the mass of product making and the product's presentation on the market are going to start, which is allowable by cost-effective system (Sljivic, Pavlovic, Stanojevic, & Fragassa, 2016).

AM technologies have been classified into abundant ways. It is commonly approached based on few technologies such as baseline technology (use of lasers), printer technology, extrusion technology and others. Despite of that, another approach is the difference in processes according to types of raw material used (Gibson, Rosen, & Stucker, 2010).

Figure 2.1 shows that there are several systems to classify the AM processes:

| Process type | Brief description | Related technologies | Materials |
|---|---|---|---|
| Powder bed fusion | Thermal energy selectively fuses regions of a powder bed | Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS) | Metals, polymers |
| Directed energy deposition | Focused thermal energy is used to fuse materials by melting as the material is being deposited | Laser metal deposition (LMD) | Metals |
| Material extrusion | Material is selectively dispensed through a nozzle or orifice | Fused deposition modeling (FDM) | Various: typically polymer based |
| Vat photopolymerization | Liquid photopolymer in a vat is selectively cured by light-activated or UV polymerization. | Stereolithography (SLA), digital light processing (DLP) | Photopolymers |
| Binder jetting | A liquid bonding agent is selectively deposited to join powder materials, and then product is baked in an oven for final curing. | Powder bed and inkjet head (PBIH), plaster-based 3-D printing (PP) | Various: Polymers, sand, metals, other |
| Material jetting | Droplets of build material are selectively deposited | Multijet modeling (MJM) | Polymers, waxes |
| Sheet lamination | Sheets of material are bonded to form an object | Laminated object manufacturing (LOM), ultrasonic consolidation (UC) | Paper, metals |

Figure 2.1: AM Processes and working principles (U.S. Department of Energy, 2015)

## 2.2 Technology Adoption in AM

In decades, the existence of digital technologies has contributed new and advance possibilities in manufacturing. It even leads to new changes in the way of how engineers and companies has been working and operating nowadays.

One of those technologies is named as Additive Manufacturing (AM). In advanced manufacturing technology, AM is highlighted as a dominant example since new skills are basically needed for the entire “digital engineer" for utilizing the potential that presented by AM (German, 2017). Additive Manufacturing (AM) which also known as 3D printing has seized the imagination of many technology experts and manufacturing professionals. This kind of technology is regarded as a pathway which at the end, we can obtain the production that was digitized, the demand that will be manufacture and also what kind of product design will be considered and they will be rethink about it.

Even the Additive Manufacturing's technological characteristics have been subjected to an investigation from different types of perspective, but there is still important in needing a more detail and realistic grasp of the business case towards AM adoption (Baumers, Beltrametti, Gasparre, & Hague, 2017).

## 2.3 Substractive Manufacturing (SM) vs Additive Manufacturing (AM)

Additive Manufacturing also known as emerging paradigm in manufacturing technology since it act as the middle of deposition material concept to achieve the desired shape of products, as opposed to traditional technology, the subtractive manufacturing. The difference can be seen as the traditional manufacturing techniques are depends on reshaping or removing the parent material (Lin, 2014). Figure 2.2 shows the schematic diagram of material used in 3D printing process.

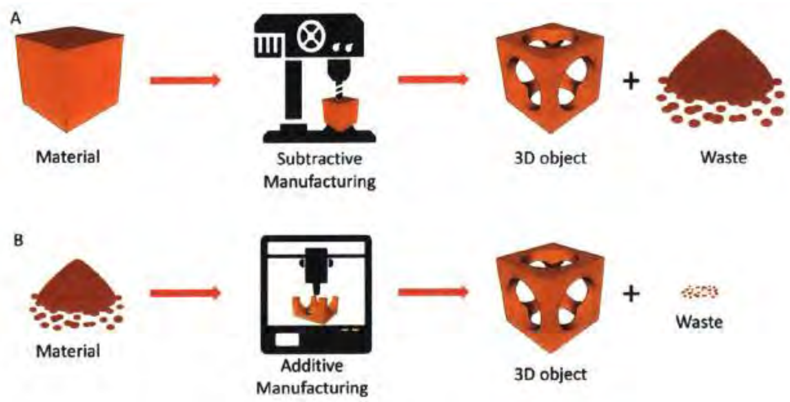


Figure 2.2: Schematic diagram of comparison between Subtractive Manufacturing (SM) & Additive Manufacturing (AM) (Lin, 2014)

Lin (2014) had stated that AM process also described by the ASTM International Subcommittee, Terminology in AM Technologies as a conversion process from 3-dimensional model into a solid physical part by the controlled joining of materials which often occurs in a layer-wise manner. There is difference compared to subtractive manufacturing which required a large billet size of material to start the process. Not only that, a process of successive material removal also needed in order to have the desired shape by reducing that billet of material.