UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF ACETONE VAPOR ON MECHANICAL PROPERTIES OF FUSED DEPOSITION MODELING PRINTED PART

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

by

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APPROVAL

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

……………………………….

MADAM NURUL AIN BINTI MAIDIN

(Project Supervisor)

ABSTRAK

Projek ini bertajuk Kesan Wap Aseton kepada Sifat-sifat Mekanikal terhadap model cetakan "*Fused Deposition Modeling*" yang difokuskan kepada teknologi "*Rapid Prototyping (RP)*" dengan teknik "*Fused Depostion Model (FDM)*". Teknologi "*RP"* mampu menghasilkan model dengan geometri yang sangat kompleks yang mustahil dihasilkan dengan kaedah tradisional atau dihasilkan dengan kos yang tinggi. Bagi kos bahan, kos alat teknologi "*RP"* adalah kebanyakannya berkaitan dengan saiz produk. Projek ini akan menggunakan polimer bahan khusus iaitu "*Acrylonitrile Butadiene Styrene (ABS)*". Walau bagaimanapun, teknik "*FDM"* menghasilkan kekasaran permukaan yang buruk, menghalang penggunaan dalam beberapa bidang yang memerlukan integriti permukaan yang tinggi. Oleh itu, peringkat pasca pemprosesan diperlukan untuk meningkatkan kekasaran permukaan bahagian "*FDM"* dicetak. Dalam kajian ini, aseton wap akan digunakan dalam pasca pemprosesan untuk meningkatkan kekasaran permukaan bahagian yang dicetak, tetapi skop kajian ini akan memberi tumpuan kepada kesan sifat mekanik bahagian dicetak. Sifat-sifat mekanikal spesimen akan disiasat melalui ujian tegangan, ujian lenturan dan susunan mikrostruktur. Kesimpulannya, sifat-sifat mekanikal pada bahagian asal yang dicetak tanpa memalui pemprosesan wap aseton akan dibandingkan dengan bahigan yang dicetak dan melalui pelaksanaan pemprosesan wap aseton.

ABSTRACT

This project entitled Effect of Acetone Vapor on Mechanical Properties of Fused Deposition Modeling Printed Part is focus on the Rapid Prototyping (RP) technologies with Fused Depostion Modeling (FDM) technique. RP has the benefit being capable to create very complex geometries, which could be impossible with traditional methods or fabricated at high cost. For material cost properties, the cost of RP parts is mostly related to the size of the product. The project will be used polymer-based material specifically Acrylonitrile Butadiene Styrene (ABS). However, the FDM technique suffers from poor surface roughness, restricting it application on some areas requiring high surface integrity. Therefore, a post processing stage is required to improve the surface roughness of the FDM printed part. In this study, an acetone vapor post process will be employed to improve the surface roughness of the part but the scope of the study will focus on the effect of mechanical properties of the printed part. Mechanical anisotropy behaviour of the specimen will be investigated via tensile test, flexure test and microstructural arrangement. As conclusion, the results of implementation of acetone vapor as post processing of FDM printed part will be compared to the original printed part regarding the mechanical properties.

DEDICATION

Specially dedicated to my beloved parents and siblings.

ACKNOWLEDGEMENT

It has been an adventure journey for me while completing this final year project report. However, with the helps from beneficent people, I am successfully completed this report. I am so grateful that now I can express my gratitude to all of them.

I am thankful and would like to express my sincere gratitude to my supervisor Madam Nurul Ain binti Maidin for her precious guidance, continuous encouragement and constant support in making this research possible. I really appreciate her guidance from the beginning to the end that enabled me to develop an understanding of this report project thoroughly. Without her advice and assistance it would be harder for me to complete this report. Sincerely thanks too for the time spent proofreading and correcting my mistakes.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
ASCII	-	American Standard Code for Information Interchange
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Drawing
CAM	-	Computer Aided Manufacturing
CNC	-	Computer Numerical Control
CT	-	Computerized Tomography
FDM	-	Fused Deposition Modeling
MIG	-	Metal Inert Gas
NEMA	-	National Electrical Manufacturer Association
PLA	-	Polylactic Acid
RP	-	Rapid Prototyping
SFF	-	Solid Freeform Fabrication
STL	-	STereoLithography
3D	-	Three-dimensional
σ_t	-	Tensile strength
σ_f	-	Flexural strength

CHAPTER 1
INTRODUCTION

This chapter mostly presents the background of the project. Besides that, this chapter would be included with problem statement, objectives, and scopes of the project. The background describes about the overview of the project. Meanwhile the problem statement states the reason of conducting this project. The aim of the project describes by the objectives and the scopes would be the limitations of the project implementation.

1.1 Research Background

Mechanical properties of materials are important to be considered in order to make the parts that produced has a good quality. Thus, mechanical properties are also used to help classify and identify material. The properties can be defined as the ability of the material to undergo any stress of deflection which will affect the parts physically or mechanically. Mechanical properties can be classified to many types such as tensile strength, flexural strength, shear strength, toughness, hardness and elasticity. The mechanical properties that will be studied for this projects are tensile strength, flexural strength and microstructural arrangement of the material.

Rapid prototyping (RP) consists a set of techniques that used to manufacture a measure model of a physical part or assembly by using three dimensional computer aided design (CAD) data in a short time. The creation of the part or assembly is commonly completed the use of three-dimensional printing or 'additive manufacturing' technology. One of the commonly used techniques of rapid prototyping is Fused Deposition Modeling (FDM) which works by a heated nozzle laying down molten material in layers to produce a desired part. The nozzle is heated to melt down the material and can be relocated in both parallel and perpendicular directions by a numerically controlled mechanism which will directly structure by a computer-aided manufacturing (CAM) software package. Therefore, the type of machine that will be used to produce the specimens for this project is FDM RP machine. There are a few materials that can be used for this FDM technique. For examples, Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polyamide (PA), Polystyrene (PS), Polylactic acid (PLA), lignin and rubber. The materials can be used with different trade-offs between strength and temperature properties. Thus, the selected material that will be used for this project is ABS which is a thermoplastic that is malleable when heated. Besides that, ABS allow the post-processing process to be easier which suitable for this project that will undergo a post-processing for the printed part. The material exists in plastic filament or metal wire form that is compatible with FDM machine.

Acetone is a colorless, volatile and flammable liquid used as a solvent and antiseptic. It is can be dissolved with water and serves as an important solvent which is typically for cleaning purposes in the laboratory. Acetone is the best solvent for many plastics and some synthetic fibres. Therefore, an acetone will be used in the phase of post-processing for this project printed part. An acetone vapor will be applied to the complete printed part. The acetone vapor will be produced by a simple and safe method. The vaporing process of printed part will be applied with in a set duration of time. The results will show the effect of acetone vapor on the mechanical properties of the FDM printed part.

1.2 Problem Statement

Fused Deposition Modelling (FDM) is the most diffused rapid prototyping techniques which is low maintenance cost and quick production of complexity parts. There are many choice of materials can be used for FDM machining process. One of the material is Acrylonitrile Butadiene Styrene (ABS) which the composition of the material was provided by the company that produced the material. However the fluctuations of temperature during production lead to delamination and high surface roughness of the printed part. The printed part that suffers from poor roughness restricting its application in some areas requiring high surface integrity. Therefore it is required a post-processing stage for the printed part in order to improve the surface finish, thus will affect the mechanical properties of the part. The mechanical properties for finished printed part are important in order ensure the part produced with a good quality and can undergo any stress or deflection at a certain range of conditions. There are many post-processing solutions can be applied for improving the mechanical properties of the printed part. Therefore, it can be differentiate the mechanical properties of the original part with the part that undergo post-processing process.

1.3 Objectives

To improve the mechanical properties of a printed FDM part, it is necessary to perform the work study needed precisely and accurately so that an improvement of mechanical properties for a FDM printed part can be obtained. The purposes of this research writing is:

a) To study the effect of acetone vapor on mechanical properties of Fused Deposition Modelling (FDM) printed part.
b) To conduct a test in order to differentiate the mechanical properties of the original printed part with the acetone vapor part.
c) To optimise the mechanical properties of ABS fused deposition modeling printed part for tensile test and flexure test.

1.4 Scopes

The scope of the project will be studying the area of rapid prototyping by fused deposition modeling technique. Thus, the selection of material used will be focusing to acrylonitrile butadiene styrene (ABS) thermoplastic filament as it is more stable and resistance to chemicals compared to PLA filament. This material is a tough material that can be used to create robust plastic objects for everyday use. Besides that, ABS filament is better malleable with easier post-processing. Therefore it is suitable for the project as the part will undergo post-processing process. Besides that, the printed part can be cut, filed, sanded, painted and bonded. Even though the material is not biodegradable but it can be easily recycled.

The project will also cover the mechanical properties of the FDM printed part. Mechanical properties are important to ensure the part produced in a good quality. Therefore the mechanical properties will focus on the tensile strength, flexural strength (bending) and microstructural arrangement of the material. In order to improve the surface roughness, the printed part will undergo post-processing process which is acetone vaporing process. The acetone vapor will be produced by a simple and safe method from an acetone solution. Then, the printed specimen part will be vapored with the acetone vapor in a range of time.

Therefore, the design of the specimen for tensile strength test will be a dog bone shape. The specimen is a regular sample cross-section. It consist of two shoulders and a gage section in between. The shoulders are big so they can be freely gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in that area. Meanwhile, the design of specimen for flexure test will be a simple rectangular block. The specimens can be divided to five types of part which were the original without undergo the vaporing process and the part that undergo vaporing process of four different set duration of time. The set duration of time were 15 minutes, 30 minutes, 45 minutes and 1 hour. Each type of part will be prepared by two samples. The designs will be done by using Solidwork software as the computer-aided design. Then, the design was converted to STL file before proceed with fabricating the specimens by 3D printing process of FDM technique for rapid prototyping machine modeled Up Plus.

Thus, the mechanical properties will be tested after the implementation of acetone vapor. The vaporing process will be in a range of time in order to study the effect of the acetone vapor varies with the time of vaporing process. The testing for both tensile and flexural will be using a Universal Testing Machine but with different grips and fixtures. A wedge action grips will be used for tensile test while a static 3 point 5 kN flexure fixture for flexure test. Besides that, the microstructural arrangement of the material will be checked with a microscope in order to determine how the material performed under a given application of acetone vapor that varies with a different duration set of time. The testing for the specimens will be conducted until the best results achieved with minimum attempt. In specified, there will be two specimens for each set duration of vapor time including the original part that without vaporing process. Thus, based on the results of the tests that will be conducted, a comparison of the mechanical properties will be done in order to differentiate the effect of the original printed part with the printed part that will undergo acetone vaporing process. Therefore, this project will discover the improvement of mechanical properties of the printed part after undergo the acetone vapor process. The project is limits to open source printer as a reference for the using of rapid prototyping process.

CHAPTER 2
LITERATURE REVIEW

While the first chapter of the project describes background, problem statement, objectives as well as the scopes of the project, this chapter proceeds with referenced review from the relevant literature. Generally, this chapter contains a literature review on rapid prototyping of fused deposition modelling technique which includes the materials used. Sources of information were obtained from secondary sources which are books, journals, reports and electronic-media publications. The primary objective of this review is aiming at searching the current status and history of mechanical properties for a FDM printed part. Hence, this chapter will narrow the topic into the element that commonly used for improving the mechanical properties of the FDM printed part. It also explains elements related to the testing for the mechanical properties. After explaining the studies, this chapter enlightened the tools that will be used for this project.

2.1 Rapid Prototyping

The term Rapid Prototyping or Additive Manufacturing (AM) is used in a variety of industries to describe a process which rapidly creates the representation of a system or part prior to final release or commercialization. Additive manufacturing is a layer-based automated fabrication process for making scaled three-dimensional physical objects directly from 3D-CAD data, without using part-dependent tools. It was originally called 3D printing, and this term is still frequently used, however other terms used in this technology include additive layer manufacturing, rapid prototyping, and direct manufacturing (Gibson *et al.*, 2010). Nowadays, rapid prototyping are being used for a wide range of applications and also used to manufacture production quality parts in rather small numbers if needed. The technology being used by some modern sculptors in the process to produce complex shapes for fine art exhibitions.

Briefly, rapid prototyping takes virtual design from CAD or animation modeling software that converts them into cross sections but still virtual, and then form each cross section in physical space, one after the next until the model is finished.

In the area of prototyping fabrication, the machine reads in data from a CAD drawing and the lays down successive layers of liquid or powdered material, then builds up the model from a long series of cross sections. These layers which correspond to the digital move segment from the CAD model are glued together or fused commonly the use of a laser automatically to create the final shape. The primary advantage to additive manufacturing is the ability to create almost any kind of geometry excluding trapped negative volumes. The standard interface between CAD software and rapid prototyping machines is the STL file format (Wikipedia, 2017).

As stated in (Wikipedia, 2017) the word 'rapid' is relative to construct a model with contemporary machines typically takes three to seventy two hours, depending on the machine type and model size. The usage in micro rapid technologies is correct, the products made are ready very fast and the machines can build the parts in parallel.

Advances in technology allow the machines to use multiple materials in the manufacturing of the parts. It is important as it can use one material with a high melting point for the completed part while another material with low melting point as filter to separate individually moving parts within the model. As the model is finished, it will be heated to the point where the undesired material melts away. Even though the traditional injection molding is required a low cost in plastic manufacturing, rapid prototyping can be used to produce finished good in a single phase soon.

The usage of robots or other similar mechanisms are required due to the requirement of high degree of flexibility and adaptability by many rapid prototyping techniques. But now some schemes to improve rapid prototyping technology to the phase where a manufacturer can manufacture its own component parts. The idea is that the new machine could be assembled quite cheap from raw materials by the existing machine. The techniques could consider to reduce the cost of prototyping machine in the future.

2.1.1 Solid Freeform Fabrication

Solid freeform fabrication is a collective term for production techniques for the manufacture of a physical object by sequentially delivering energy and material to a specific point in space. SFF is also referred as rapid prototyping, rapid manufacturing, layered manufacturing or additive fabrication. The usage of soli freeform fabrication is less time consuming because SFF techniques require less post-processing for the same complex shapes and do not use product-specific tools, such as a mold , which must first be made before can be produced. Besides that, the machine does not have to be changed over for each product series and does not require fixation of the product, which also gives it time savings.

Techniques of solid freeform fabrication (Wikipedia, 2017):

a) Fused deposition modeling

   Fused deposition modeling extrudes hot plastic through a nozzle, layer by layer builds up a model.

b) Laser engineered ne shaping

   A laser is used to melt metal powder and deposition it on the part directly. The advantage that the part is fully solid and the metal alloy composition can be dynamically changed over the volume of the part.

c) Laminated object manufacturing

   Sheets of paper or plastic film are attached to previous layers by either sprayed glue, heating or embedded adhesive and then the desired outline of the layer is cut by laser or knife. The finished part typically looks and acts like a wood.

d) Selective laser sintering (SLS)

   A laser to fuse powdered metal on the basis of the cross-section of the virtual model. For example, is built up layer by layer to the entire model.

e) Stereo Lithography (SLA or STL)

Stereolithography is using a laser to liquid substances polymerize

f) Shape deposition manufacturing

Alternatingly deposing sacrificial or part material by a printhead and machining it in shape.

g) 3D printing

Layers of a fine powder are attached by printing a water-based adhesive from an inkjet printhead that includes thermal phase change inkjet and photopolymer phase change inkjet.

h) Solid ground curing

Same as stereolithography, uses solid wax for support.

Table 2.1: Comparison of solid freeform fabrication method
(Source: <https://en.wikipedia.org/wiki/Solid_freeform_fabrication> 15/03/2017)

Techniques	Accuracy (mm/mm)	Maximum part size (mm)	Process time (hh:mm)
Fused deposition modeling	0.005	254 x 254 x 254 (Stratasys)	12:39
Laminated object manufacturing	0.01	812 x 558 x 508 (Cubic Technologies)	11:02
Selective laser sintering	0.005	381 x 330 x 457 (3D Systems)	4:55
Solid ground curing	0.006	508 x 355 x 508 (Cubital)	11:21
Stereolithography	0.003	990 x 787 x 508 (Sony)	7:03

2.1.2 Fused Deposition Modeling (FDM)

After 20 years of research, additive manufacturing (AM) continues to grow with the addition of new technologies, methods and applications (Lee *et al.*, 2004). Fused deposition modeling which is normally referred by its initials FDM, is a type of additive manufacturing techniques for rapid prototyping technology that commonly used in engineering design. The technology was evolved through S. Scott Crump within the late 1980s and commercialized in 1990. The FDM system has been commercially developed by Stratasys Inc. USA (Garg and Singh, 2013).

According to Lee *et al.* (2007), the operating principle of FDM techniques is possibly most different additive manufacturing techniques including 3D printing and stereolithigraphy which is by using laying down material in layers. In this process, FDM materials like ABS, elastomers, polycarbonates, polyphenol sulphones and investment casting wax feeds into the temperature-controlled FDM extrusion head, where it is heated to a semi-liquid state. A plastic filament or metal cord is unwound from a coil and supplies material to the extrusion nozzle that can turn the flow on and off(Lee *et al.*, 2007). The nozzle is heated to melt the material and can be moved in each horizontal and vertical axes through a numerically managed mechanisms, directly managed with the aid of a computer-aided manufacturing (CAM) software package. The head extrudes and deposits the material in thin layers onto a fixtureless base. The head directs the material into place with precision, as each layer is extruded it bonds to the previous layer and solidifies. The designed object emerges as a solid three-dimensional part without the need for tooling.

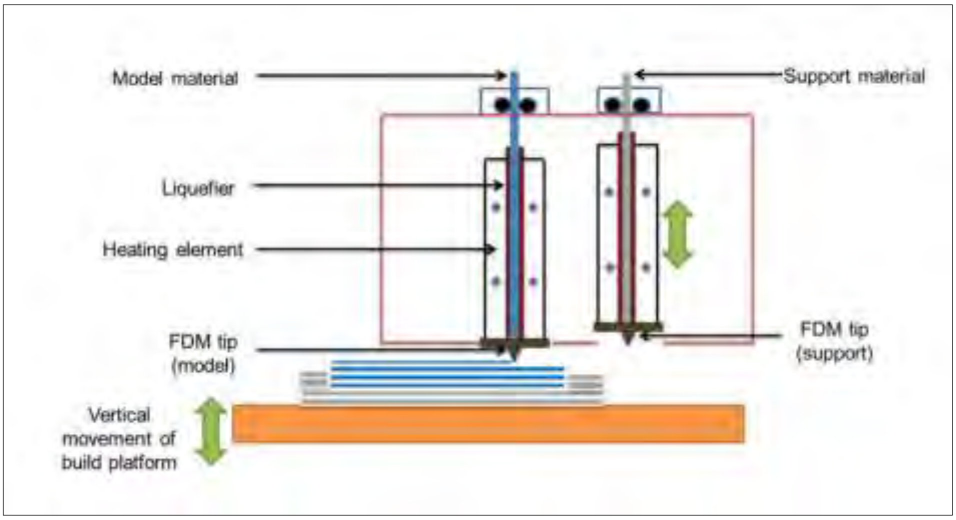

Figure 2.1: Schematic diagram of FDM machine (Shojib Hossain *et al.*, 2014)