INVESTIGATION OF MECHANICAL PROPERTIES OF RECYCLED ABS PRINTED WITH OPEN SOURCE FDM PRINTER INTEGRATED WITH ULTRASOUND VIBRATION

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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2019

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **INVESTIGATION OF MECHANICAL PROPERTIES OF RECYCLED ABS PRINTED WITH OPEN SOURCE FDM PRINTER INTEGRATED WITH ULTRASOUND VIBRATION**

Sesi Pengajian: **2018/2019 Semester 2**

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as partial fulfilment of the Bachelor of Manufacturing Engineering (Hons.) requirements. The Supervisory Committee member is as follows:

…………………………………………………………………..

(Associate Prof Dr Shajahan bin Maidin)

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ABSTRAK

Pembuatan tambahan (AM) adalah proses untuk membentuk objek 3D menggunakan lapisan demi lapisan. Salah satu kelemahan AM ialah pembaziran yang dijana dalam proses percetakan. Acrylonitrile Butadiene Styrene (ABS) adalah bahan yang digunakan dalam AM untuk termoplastik. Kajian ini menumpukan pada penggunaan 100% kitar semula ABS untuk proses percetakan 3D *Fuse Deposition Modeling* (FDM). Proses kitar semula bermula dengan menggunakan semula sisa ABS dan mengubahnya menjadi filamen baru. Spesimen ujian dicetak menggunakan filamen kitar semula yang baru. Kajian telah dijalankan terhadap sifat mekanik spesimen ujian dan perbandingan telah dilakukan dengan spesimen ABS yang biasa. Hasilnya menunjukkan bahawa ABS yang dikitar semula boleh diubah menjadi filamen dengan suhu penghantar *extruder* 270°C dan kelajuan *conveyor extruder* pada 18 mm/s. Mengikut keputusan yang diperolehi untuk sifat mekanik ABS yang dikitar semula, ia menunjukkan bahawa pengurangan 32% dalam kekuatan lenturan bahan bercetak, sementara peningkatan kekuatan mampatan sebanyak 82% disebabkan oleh proses kitaran semula. Dengan bantuan getaran *ultrasound*, keputusan menunjukkan kekuatan lenturan meningkat 53% dan kekuatan mampatan meningkat 59% yang dibandingkan antara 0 kHz dan 20 kHz. Secara keseluruhan, ABS yang dikitar semula dengan bantuan getaran *ultrasound* semasa proses pembuatan tambahan dapat membantu meningkatkan sifat mekanikal bahan ABS kitarsemula.

ABSTRACT

Additive Manufacturing (AM) is a process that deposits materials on a platform to form 3D objects layers by layers. One of the downsides of AM is wastage generated during the printing process. Acrylonitrile Butadiene Styrene (ABS) is a popular material used in AM for thermoplastics. This study focused on the feasibility of using 100% recycled ABS for the 3D printing process via Fused Deposition Modeling (FDM). The recycling process began by re-granulating the ABS waste and turning it into a new filament. Test specimens were printed using the new recycled filaments. The experiment was carried out on the mechanical properties of the test specimens, and comparison was made with the standard ABS specimens. The results showed that recycled ABS could be converted into filaments with an extruder conveyor temperature of 270°C and a travel speed of 18 mm/s. The results obtained for the mechanical properties of the recycled ABS, showed that it had decreased, resulting in a 32% reduction in the flexural strength of the printed material, while an 82% increase in the compression strength due to multiple recycling cycles. With the aid of ultrasound vibration, the results showed a 53% increase in flexural strength and a 59% increase in compression strength comparing between 0 kHz and 20 kHz frequency were applied. Overall, the approach to extrude 100% recycled ABS plastic is a viable option for better use of printed materials and, with the aid of ultrasound vibration, it helps to improve the mechanical properties of the recycled ABS.

DEDICATION

Only

my beloved dad, Vincent Sim,

my beloved mother, Angela Liew,

my beloved elder brother, Samson Sim,

admired supervisor, lecturer, and technician,

friends and coursemates,

who supported me, giving me moral support, money, cooperation, encouragement, and understanding.

Thank you very much, and I always love you.

ACKNOWLEDGEMENT

I want to extend my deepest gratitude to all those who have given me the opportunity to complete this report. Without God's blessing, I could not have gained the knowledge throughout the degree study journey. Thanks to a lot of people's cooperation and advice to finish this project. I want to express to all of them my sincere gratitude and appreciation.

First of all, I would like to take this opportunity to express my sincere appreciation to my beloved supervisor, Associate Prof Dr Shajahan bin Maidin for his crucial guidance, consistent supervision, and encouragement, as well as for providing important information to carry out this project smoothly.

In addition, I would like to acknowledge with great appreciation the important role that my parents played in giving me advice and supporting me during this report, but also in educating and teaching me from young people. They always teach me how to achieve the goal and solve a problem in a different way. They taught me to be persevering, committed and determined to face problems in life as well as solving them.

Not to forget, honourable mention course mates who helped me with valuable comments and sharing with me about their report-writing experiences and gave me suggestions and advice for improving my project. Finally, to those who help me carry out this project, I give my blessing and greetings. Thank you.

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LIST OF ABBREVIATIONS

3D	-	3 Dimensional
ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive manufacturing
ASTM	-	American Society for Testing and Materials
CAD	-	Computer aided design
CT	-	Computed Tomography
DED	-	Direct energy deposition
EDM	-	Electrical discharge machining
FDM	-	Fused deposition modeling
LOM	-	Laminated sheet manufacturing
PBF	-	Powder bed fusion
PLA	-	Polylactic acid
Rec	-	Recycle
SLS	-	Selective laser sintering
STL	-	Stereolithography
UAM	-	Ultrasonic Assisted Machining
UTM	-	Universal testing machine
UV	-	Ultraviolet light
VP	-	Vat Polymerization

LIST OF SYMBOLS

°C	-	Celcius
%	-	Percentage
g	-	Gram
kHz	-	Kilohertz
MPa	-	Megapascal
mm	-	Millimeter
mm/s	-	Millimeter per second
N	-	Newton

CHAPTER 1

INTRODUCTION

This chapter explains and describes the background, problem statement, objective, and scope, and of the project.

1.1 BACKGROUND

Additive Manufacturing (AM) is defined as "the process of joining materials to make objects from 3D model data, usually layer by layer, as opposed to subtractive methods of manufacturing, such as traditional machining" (Technologies, 2013). According to ASTM AM can be classified into seven groups which are vat photopolymerisation, powder bed fusion, material extrusion, material jetting, binder jetting, sheet lamination and directed energy deposition. Widely used AM technologies including stereolithography (SL), fused deposition modelling (FDM), selective sintering laser (SLS) and 3D printing (3DP).

Stratasys, Ltd. founder Scott Crump developed Fused Deposition Modeling (FDM), the most common method of polymer AM, as a "single-step operation" which quickly creates 3D prototypes from CAD designs, reducing the cycle time of product development. The computer model is divided into layers, and the model information is used to construct the built-in coating with layers on the removable support material. As a basic material, the process uses a continuous filament feedstock. Solid size and feed material also allow FDM to be produced remotely (S.S. Crump, 1992).

While FDM is considered to be very material and energy-efficient on a one-piece or small-batch production scale compared to conventional manufacturing processes such as injection moulding, a significant amount of waste material is still generated. On average, printed products reach their end of life more quickly as they are intended to be used as prototypes or for special purposes and therefore have shorter lives. The post-production waste stream is a result of material use or failed prints (Juraschek, Bhakar, & Pilani, 2016). To improve the quality of the environment and create an eco-3D printing process in the manufacture of additives, a way to recycle the waste 3D polymers printed products is needed.

Plastics are an integral part of our daily lives and can be found in everything from packaging, furniture, cars, microdevices and even biomedical components (Luijsterburg & Goossens, 2013). The usefulness of plastic and the optimization of its use in manufacturing have led to an increase in its global production, which has risen by more than 500% in the last three decades and is expected to increase to 850 million tons per year by 2050 (Luijsterburg & Goossens, 2013). Sustainable plastics management has now become one of the greatest challenges facing us in modern times.

ABS is a common amorphous thermoplastic with high impact resistance, heat resistance, toughness, and low thermal conductivity with potential use in civil engineering. Two types of ABS are generally classified: one as moulding ABS and one as extrusion/printing ABS (S. Singh, Ramakrishna, & Singh, 2017). ABS is a thermoplastic polymer made in the presence of polybutadiene by polymerizing styrene and acrylonitrile (Hart & Wetzel, 2017). The forces caused by stretching, compressing, twisting and bending can cause deformation in such parts.

In ultrasound-assisted machining (UAM), the cutting tool is vibrated at an ultrasonic frequency with some micrometres of amplitude through an external source – usually a piezoelectric transducer (Tabatabaei, Behbahani, & Mirian, 2013). According to Zheng (2007), ultrasonic vibration can be used to enhance the machining efficiency of traditional processes. Successful applications include the ultrasound-assisted Nitinol microholes electro-discharge machining (EDM), which significantly improved machining efficiency. Inspired by the encouraging results in the ultrasound-assisted EDM, it was hypothesized that the introduction of the ultrasound to an FDM process could be beneficial for the removal of deposited particles, which should produce a better surface finish.

Mechanical properties of recycled ABS 3D printed test specimens will be investigated in this project. An open-source 3D printer integrated with an ultrasound vibration will be used to print the recycled ABS test specimen. The ultrasound frequency will be varied, and it affects the test specimen mechanical properties will be investigated. In addition, the process parameters of the FDM machine will also be anticipated to influence the mechanical properties of the printed test specimen, and some other features include the bed temperature, print speed, layer thickness, raster angle and temperature of the nozzle will be investigated. In this project, the mechanical properties of ordinary ABS filaments test specimens will be compared with the recycled ABS filaments printed with various ultrasound vibration.

1.2 PROBLEM STATEMENT

AM is aimed at reducing waste materials. However, due to printing errors, it still creates a lot of waste material, as most standard FDM 3D printers are used by the inexperienced user (Song & Telenko, 2016). According to Song & Telenko (2016), the amount of failed print is approximately 2.22 times the amount of predicted waste produced. Therefore, the first concern is that too much waste is generated for additive manufacturing, and the waste material needs to be processed or recycled.

Plastics are almost entirely derived from fossil oil and gas-based petrochemicals. Approximately 4% of the annual production of petroleum is converted directly into petrochemical plastics (British Plastics Federation 2008). Since plastics production requires energy, its production is responsible for consuming similar additional fossil fuel quantities. The oil resource cannot, therefore, be wasted as the quantity of oil continues to decrease and the recycled ABS material can be a substitute for the standard ABS filament to decrease the rate of use of oil for the standard ABS filament production.

According to Mohammed et al. (2017), the mechanical properties of the recycled ABS were markedly degraded, resulting in a 13 to 49% decrease in the final strength of the printed material. This is due to poor interlayer bonding, also known as delamination. Delamination can result from the weak matrix, poor lay-up or mechanical loading and often leads to internal damage in composites that could lead to global failure of a component with reduced strength and rigidity. Hence to overcome the delamination in this project, ultrasonic vibration is introduced to improve the mechanical properties of recycled ABS.

1.3 AIM

The project aims at investigating the 100% recycled ABS, improving the mechanical properties of recycled ABS and comparing mechanical properties with standard ABS. The project aims to reduce and enhance the sustainability of ABS waste generated by the AM system. ABS waste was collected, recycled and reproduced in a filament for FDM printers. It then uses the mechanical properties of ultrasound frequencies to improve recycled ABS.

1.4 OBJECTIVE

1. To produce 100% recycled ABS filaments for open-source FDM printing process
2. To print 100% recycled ABS with an open-source FDM printer integrated with an ultrasound vibration.
3. To compare the flexural strength and compressive strength of recycled and the standard ABS printed test specimen.

1.5 SCOPE

This project focuses on 100% recycled ABS production of FDM additive manufacturing. In this project, the quality and mechanical properties of ordinary ABS filaments will be compared with recycled ABS filaments. This covers the analysis of mechanical properties which are flexural test and compression test using SHIMADZU AGS-X 20kN machine. The Haake Rheomax OS filament extruder and the UP Plus 2 3D printer was used for this study. To produce 0, 10, 20 kHz frequencies, the power generator that sends the ultrasound frequency will be used. 3D printing process parameters are set at bed temperature (105°C), print speed (40 mm/s), layer thickness (0.2 mm), raster angle (30°C) and nozzle temperature (270°C). Results and data from flexural and compression tests will determine the ability to replace regular ABS filaments with recycled ABS 100% filaments.

1.6 PROJECT REPORT

This report is divided into five chapters:

Chapter 1: This chapter presents projects that cover project backgrounds, problem statements, objectives, and scope.

Chapter 2: Describes literary and theoretical studies related to this project as well as previous research that may support this research.

Chapter 3: This chapter explains how methods, processes, and steps are used to conduct this investigation.

Chapter 4: Explain the results and discuss the findings in this chapter.

Chapter 5: This chapter provides a summary of the test results and suggestions for future studies.

CHAPTER 2

INTRODUCTION

This chapter focuses on additive manufacturing system theory, additive manufacturing system application, additive manufacturing advantage and disadvantage, plastic waste risk, FDM machine parameter and ultrasonic technology. The purpose of this chapter is to provide a detailed explanation of the materials and processes used in the chronological order. This chapter will also discuss the theory of 100% recycled Acrylonitrile Butadiene Styrene and use it to transform it into a new product. The sources are mostly from textbooks, journals, thesis and other resources.

2.1 THE 7 CATEGORIES OF ADDITIVE MANUFACTURING

AM is defined as: "Manufacturing objects using a print head, nozzle, or other printer technology by depositing thin layers of material." (Technologies, 2013). All current AM technologies can be grouped into seven categories, as set out in Table 2.1.

Table 2.1: Types of Additive Manufacturing (Pinkerton, 2016).

Category	Description	Processes
Binder jetting	A liquid bonding agent is selectively deposited to join powder materials.	Three dimensional printing (3DP)
Directed energy deposition	Focused thermal energy is used to fuse materials by melting as they are being deposited.	Direct metal deposition (DMD), Direct laser deposition, laser engineered net shaping (LENS), Multiple layer laser cladding
Material extrusion	Material is selectively dispensed through a nozzle or orifice.	Fused Deposition Modelling (FDM), Fused Filament Fabrication (FFF), Pressure-based Extrusion (PBE).
Material jetting	Droplets of build material are selectively deposited.	Polyjet Aerosol Jet (AJ) (sometimes also termed three dimensional printing)
Powder bed fusion	Thermal energy selectively fuses region of a powder bed.	Selective laser melting (SLM) and Selective laser sintering (SLS, DMLS).
Sheet lamination	Sheets of material are bonded to form an object.	Ultrasonic additive manufacturing (UAM) and Laminated object manufacturing (LOM)
Vat photopolymerisation	Liquid photopolymer in a vat is selectively cured by light-activated polymerisation	Stereolithography (SLA)

2.1.1 VAT PHOTOPOLYMERIZATION

Vat photopolymerization (VP) processes are defined as "additive production processes in which light-activated polymerization selectively cures liquid photopolymer in a vat" (Technologies, 2013).

According to (Gibson, Rosen, & Stucker, 2015), vat photopolymerization has two primary configurations that have been developed, plus one additional configuration that has seen some interest in research. The configurations discussed include:

- Vector scanning or point-specific approaches typical of commercial SL machines
- Approaches mask projection, or layer-wise, which at one time irradiates whole layers and
- Two-photon approaches which are essentially point-by-point approaches with high resolution

Figure 2.1 shows these three configurations schematically. Note that scanning laser beams are needed in vector scanning and two-photon approaches, while the mask projection approach uses a large radiation beam patterned by another device, a Digital Micromirror DeviceTM (DMD) in this case. In the case of two photons, at the intersection of two scanning