INVESTIGATION ON MECHANICAL AND THERMAL PROPERTIES OF 100% RECYCLED 3D PRINTED ABS MATERIAL

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

by

ANIS HAZIRAH BINTI SAMAT

B051510164

960527-06-5352

FACULTY OF MANUFACTURING ENGINEERING

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I hereby, declared this report entitled “Investigation on Mechanical and Thermal Properties of 100% Recycled 3D Printed ABS Material” is the result of my own research except as cited in references.

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Author’s Name : ANIS HAZIRAH BINTI SAMAT

Date : 3 JUNE 2019

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee are as follow:

…….....

(Principal Supervisor)

Associate Prof. Dr. Shajahan Bin Maidin

ABSTRAK

Pembuatan secara tambahan (AM) telah diperkenalkan untuk mewujudkan prototaip atau produk dalam masa yang singkat serta kos yang rendah dalam pengeluaran kecil. Pemodelan Pemendapan Berfungsi (FDM) adalah salah satu kaedah AM yang menggunakan bahan yang mesra pengguna dan murah. Sisa bahan yang dihasilkan dalam proses FDM boleh dikitar semula dan ABS termoplastik dipilih kerana ia boleh dikitar semula 100% dan bahan optimum untuk penampilan percetakan terbaik serta memberikan manfaat untuk teknologi percetakan 3D kelestarian sisa bahan ABS. Projek ini memberi tumpuan kepada sifat mekanik dan sifat terma kepada 100% bahan kitar semula ABS dalam proses percetakan FDM 3D. Filamen ABS yang dikitar semula 100% dicipta dengan menggunakan proses kitar semula secara mekanikal. Filamen ABS kitar semula yang digunakan dalam pencetak 3D untuk membina spesimen ujian ABS 100% yang dikitar semula. Struktur mikro 100% bahan ABS yang dikitar semula dianalisis dengan menggunakan bahagian keratan rentas pecah bahagian spesimen ujian tegangan dalam orientasi X, Y dan Z. Hasil analisis menunjukkan bahawa bahan ABS 100% yang dikitar semula mempunyai beberapa lompang dan liang kecil yang diamati pada permukaan filamen untuk spesimen ujian X, Y dan Z. Struktur mikro spesimen ABS biasa menunjukkan bahawa kawasan patah spesimen ujian mempunyai beberapa buih udara dalam spesimen orientasi X dan Z manakala tiada gelembung udara yang terbentuk dalam spesimen orientasi Y. Kekuatan impak spesimen ABS 100% yang dikitar semula dianalisis dengan menggunakan standard ASTM D256 dan hasil yang diperoleh adalah 154. 67J / m. Kekuatan kesan spesimen ABS biasa ialah 383.31J / m. Untuk menyiasat sifat termal bahan kitar semula, Mesin Pengimbasan Berbeza Calorimetri (DSC) dijalankan dan suhu peralihan kaca (Tg) dianalisis. Keputusan yang diperolehi untuk spesimen ABS 100% dikitar semula adalah 100.14℃. Suhu Tg spesimen ABS biasa adalah 104.97℃. Hasil analisis mikrostruktur, kekuatan kesan dan analisis haba untuk 100% bahan ABS dikitar semula dibandingkan dengan hasil analisis untuk bahan ABS biasa.

ABSTRACT

Additive manufacturing (AM) has been introduced to create prototypes or final product in a short time with low cost in small production. Fused Deposition Modeling (FDM) is one of the methods provided in AM that user-friendly and low-cost materials. The wastes produced in the FDM process can be recycled and thermoplastic ABS was selected as it could be 100% recycled and the optimal material for best printing appearance as well as provide benefits for 3D printing technologies sustainability of waste ABS. This investigation focuses on the mechanical and thermal properties of 100% recycled ABS material in FDM 3D printing process. The 100% recycled ABS filament was created by using mechanical recycling process. The recycled ABS filament used in the 3D printer to build the 100% recycled ABS test specimen. The microstructure of 100% recycled ABS material was analysed by using the fractured cross-sectional area part of the tensile test specimen in X, Y and Z orientation. The result of the analysis shows that the 100% recycled ABS material had some voids and small pores observed on the surface of filament for X, Y and Z orientation test specimen. The microstructure of standard ABS specimen observed that the fracture area of test specimen had some air bubbles in X and Z orientation specimen whereas no air bubbles formed in Y orientation specimen. The impact strength of 100% recycled ABS specimen is analysed by using ASTM D256 and the result obtained is 154.67J/m. The impact strength of standard ABS specimen is 383.31J/m. To investigate the thermal properties of recycled material, Differential Scanning Calorimetry (DSC) machine is run and the glass transition temperature (Tg) analysed. The result obtained for 100% recycled ABS specimen is 100.14℃. The Tg temperature of standard ABS specimen is 104.97℃. The result of the microstructure analysis, impact strength and thermal analysis for 100% recycled ABS material was compared to the result of analysis for standard ABS material.

DEDICATION

This project is dedicated to

My beloved parents

Dearest siblings

Honourable supervisor, panels and other lecturers

Supportive friends

And other people that guide and help me a lot

Thank you for helping me with support, assistance, cooperation and guidance

Thank You Very Much

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
CTE	-	Coefficient of Thermal Expansion
DOE	-	Design of Experiment
FDM	-	Fused Deposition Modeling
SLS	-	Selective Laser Sintering
SLA	-	Stereolithograpgy
3D	-	3 Dimension
2D	-	2 Dimension
FYP	-	Final Year Project
PLA	-	Polyactic Acid
SEM	-	Scanning Electron Microscopy
SOP	-	Standard of Procedure
OM	-	Optical Microscopy
LOM	-	Light Optical Microscopy
DSC	-	Differential Scanning Calorimetry
Tg	-	Glass transition temperature

Tm	-	Melting temperature
PPSF	-	Polyphenylsulfone
UV	-	Ultraviolet
ISO	-	International Organisation for Standardisation
CT	-	Computed Tomography
STL	-	Standard Tessellation Language
AMF	-	Action Message Format
STEP	-	Standard for Exchange of Product model data
3MF	-	3D Manufacturing Format
3DP	-	3 Dimension Printing
MFI	-	Melting Flow Index
TGA	-	Thermogravimetric Analysis

LIST OF SYMBOL

%	-	percent
mm	-	millimetre
J/m	-	Joule per metre
℃	-	degree Celcius
mm/s^2	-	millimetre per second squared
m/s^2	-	metre per second squared
J	-	Joule
δf	-	limiting strain under impact
m	-	mass of the hammer/pendulum
h_S	-	height after the impact
h_E	-	height before the impact
g	-	gravitational acceleration
E_{frac}	-	energy required to break the specimen

CHAPTER 1

INTRODUCTION

1.1 Background

Additive manufacturing (AM) refers to the process of creating an object or prototype by building it layer by layer at a time. The opposite of the AM is subtractive manufacturing which is creating an object by cutting away a solid block until produces the complete final product. Technically, AM typically refers to the 3D printing which is creating the object by using computer-aided design (CAD) or software. The design translated by the software into a layer by layer framework before sending to the 3D printer to create the objects. The AM process can be done in many methods which take different process periods depends on the size of an object such as one of the methods used is laying the materials on top of each other by using a nozzle to form a final product (Linke, 2017).

In the manufacturing industries, some objects or products may not use AM as the right choice to manufacture products due to additive manufacturing has its own pros and cons. It has free variety, provides little-skill manufacturing and little lead time during conducting the process. By using high technology application, the prototype created with a 3D printer immediately, produce less waste of material. Somehow, AM produces high production cost and the high-quality of processes produce high cost. Besides, AM has a discontinuous production process and requires post-processing (Arjun, 2017).

In the AM process, many methods can be used but the most widely used is a Fused Deposition Modeling (FDM) process. It uses thermoplastic filament which is heated and then extruded layer by layer to create the 3D object. It uses two kinds of materials which is a modelling material and a support material. The most common material used in FDM is acrylonitrile butadiene styrene (ABS) and support materials are commonly used polyphenylsulfone (PPSF). In 3D printing methods, FDM is a slow process compared to stereolithography (SLA) and selective laser sintering (SLS) but FDM can be printed in highly-detailed objects, engineers usually used FDM to test parts for fit and form (Palermo, 2013).

The thermoplastic filament in the FDM system such as ABS can be recycled and reprinting without the addition of pure materials. The thermoplastic materials give a great advantage in the FDM system because it is durable and suitable for detailed functional prototypes, durable manufacturing tools and manufacturing with low-volume parts. The recycling process is very significant because ABS materials are non-biodegradable and give an impact on the environment. Therefore, the recycled filaments can be generated in FDM 3D printers when the recycled filament processes use the same process with waste recyclable plastics instead of destined for landfill (Mohammed et al., 2017).

This project focuses on investigating the mechanical properties and thermal properties of 100% recycled ABS material in additive manufacturing. The recycled material differs in mechanical and thermal properties compared to virgin ABS material due to the recycling process. Scanning Electron Microscope (SEM), Izod impact tester and Differential Scanning Calorimetry (DSC) would be used for the experiment to aid the investigation. The test specimen used is 100% recycled ABS material printed by using 3D printer set at optimum machine parameters.

1.2 Problem statement

ABS is a thermoplastic polymer which can be recycled and reformed into printer filaments with no addition of virgin materials. Although there are changes in material properties to be reprinted filaments, material integrity with an acceptable loss could provide benefits for 3D printing technologies sustainability of waste ABS (Mohammed et al., 2017). Although polylactic acid (PLA) is a thermoplastic material that used in FDM 3D printing, PLA is more sensitive to UV light and temperature rather than ABS. Thus, recycled PLA has difficulty in determining the mechanical properties since it is more likely to degrade (Kerns, 2017).

ABS is a common thermoplastic polymer known as non-biodegradable material which cannot be decomposed in natural. However, the parameters of the 3D printing may be affected by using 100% recycled ABS compared to standard material. To achieve repeatable prints, the reflected by degradation in mechanical properties and printing parameter influenced because in the notable changes in characteristics of the recycled polymer. In addition, the microstructure of the specimen may change due to the changes of properties at optimum parameters. Plus, the impact strength of 100% recycled ABS may differ from the virgin material due to the effect of recycling on ABS material cause the changes in the mechanical properties test such as tensile strength (Garcia et al., 2015). As the mechanical properties differ, the thermal properties of recycled polymer also affected. The research of microstructure, impact strength and thermal analysis of 100% recycled 3D printed ABS has not been made. Therefore, the effectiveness of 100% recycled plastic material would be observed in AM industries.

1.3 Aim

The aim of this project is to study the microstructure, impact strength and thermal analysis of specimens with the use of 100% recycled ABS filament. A few objectives are presented to achieve the aim.

1.4 Objectives

The objectives of the project are:

i. To investigate the mechanical properties of 100% recycled 3D printed ABS material.

ii. To investigate the thermal properties of 100% recycled 3D printed ABS material.

iii. To compare the mechanical and thermal properties of 100% recycled ABS material with the standard ABS material.

1.5 Scope

This project covers the effect of the microstructure, impact strength and thermal property of the 100% recycled material to be used in FDM system. The 100% recycled ABS material used to study the effectiveness in FDM system to create the objects with the aim of reducing wastages. The CAD system used to design the object was done by using CATIA V5 and transfer to STL file. The wastage of the material is recycled and used it to build the final products. The parameters of the 3D printer such as printer speed, raster angle, layer thickness and print temperature would be fixed to optimum values.

The test specimens created by using recycled ABS material and virgin ABS in the Odyssey X2 3D printer. The microstructure analysis will be studied to analyse the mechanical behaviour of failure structures specimens. The microstructure of tensile test specimen with x, y and z orientation will be investigated and observed under Scanning Electron Microscope (SEM). Impact test of recycled ABS will be investigating the impact strength of 100% recycled material by using Izod Impact Tester. The recycled ABS will undergo thermal analysis for analysing the thermal property of 100% recycled 3D printed ABS. Lastly, data obtained for recycled ABS material will be compared with the mechanical and thermal properties of virgin ABS material.