ADDITIVE MANUFACTURING OF NATURAL FIBRE REINFORCED THERMOPLASTIC COMPOSITES

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

By

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Date : 6 June 2018

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 are as follow.

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(Dr. Zulkeflee bin Abdullah)

ABSTRAK

Percetakan 3D adalah teknologi yang berkembang pesat dan digunakan secara luas dalam pengeluaran industry di seluruh dunia. Fused Deposition Modeling (FDM) yang berkos rendah paling biasa diguna dan popular di kalangan pencetak 3D seperti laser sintering selektif (SLS) dan stereo litografi (SLA). Teknologi percetakan 3D boleh mencetak beberapa struktur geometri kompleks tanpa alat dan acuan. Malangnya, cetakan 3D masih menghadapi cabaran besar dalam pretasi mekanikal bahagian cetak yang hanya boleh ditunjukkan sebagai model paparan. Untuk memastikan kualiti bagus bahagian dicetak, pembanguan bahan percetakan baru untuk percetak FDM adalah penting. Tujuan projek ini adalah untuk menguji pengaruh sifat mekanik menggunakan gentian kenaf yang memperkuatkan PLA termoplastik sebagai filamen untuk pencetak FDM. Pemboleh ubah yang digunakan untuk eksperimen ini adalah filamen PLA, filament PLA diekstrakan dari PLA pelet, PLA + 3wt % kenaf fiber dan PLA + 5wt % kenaf fiber. Sumber bahan dan pencetak 3D akan ditetapkan sebagai pemboleh ubah kawalan untuk mendapatkan hasil konsistenci. Terdapat 4 ujian percubaan untuk setiap tindak balas yang disusun menggunakan Design of experiment (DOE). Projek ini akan belajar percetakan 3D termoplastik dengan fiber semulajadi boleh meningkatkan sifat tegangan bahagian bercetak. Filamen dibuta oleh pelet PLA dan kenaf fiber untuk proses cetakan 3D. Selepas proces cetakan 3D, kesan pada sifat tegangan adalah percubaan eksperimen.

ABSTRACT

Additive manufacturing is a fast growing technology and widely used in industry production in worldwide. Low cost of fused deposition modelling (FDM) is the most common used and popular among the 3D printing printers such as selective laser sintering (SLS) and stereo lithography (SLA). 3D printing technology can print some complex geometrical structure without tool and mould. Unfortunately, it still face big challenge which is mechanical performance of printed part only can show as display model. In order to ensure the quality of printed part, it is essential to develop new printing material for FDM 3D printer. The aim of this project is to study the influence of mechanical properties using Kenaf fibre reinforced PLA thermoplastic as feed filament for FDM 3D printer. Variables used for this experiment was PLA filament, PLA filament extruded from PLA pellet, PLA + 3wt % of Kenaf fibre and PLA + 5wt % of Kenaf fibre. Source of material and 3D printer will set as control variable to obtain the consistency result. There are 4 experiment for each responses that were arranged using design of experiment (DOE) method. This project is going to study if 3D printing of thermoplastic reinforced with natural fibre can increase tensile properties of printed part. The feedstock filament were fabricated from PLA pellet and Kenaf fibre for 3D print process. After 3D print process, effect on the tensile properties (tensile strength, Young's Modulus, ductility and toughness) of specimens were experimentally investigated.

DEDICATION

Dedicated to

My beloved father, Poo Choon Hin

My appreciated mother, Tan Poh Chin

My sibling, Poo Wei Liang

For giving me moral support, money, encouragement and also understandings

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LIST OF ABBREVIATIONS

3D	-	3 Dimensional
ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
ASTM	-	American Standard for Testing and Materials
CAD	-	Computer Aided Design
DOE	-	Design of Experiment
DSC	-	Differential Scanning Calotimetry
FDM	-	Fused Deposition Modelling
IM	-	Injection Moulding
OM	-	Optical Microscope
PBS	-	Polybutylene Succinate
PLA	-	Polylactic Acid
PP	-	Polypropylene
SLA	-	Stereo Lithography
SLS	-	Selective laser sintering
STL	-	Stereolithographic

LIST OF SYMBOLS

%	-	Percentage
°	-	Degree
℃	-	Degree Celsius
g	-	Gram
GPa	-	Giga Pascal
kN	-	Kilo Newton
mm	-	Millimetre
mm/min	-	Millimetre per minute
mm/s	-	Millimetre per second
MPa	-	Mega Pascal
rpm	-	Revolution per minute
Tg	-	Transition temperature
wt. %	-	Weight percentage

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Additive Manufacturing (AM) technology customarily known as 3D printing or rapid prototyping, it is one of the method in manufacture where a solid object is created from a three dimensional model data by joining material layer upon layer (ASTM International, 2013). The first rapid prototyping technologies was born and layer upon layer method for manufacturing in 1980 described by Dr Kodama from Japan. In 80's, three main 3D printing technologies are born which is Stereo lithography (SLA) from photopolymer liquid, Fused deposition modelling (FDM) from plastic filament and Selective laser sintering (SLS) from powder grain (Hannah Bensoussan, n.d.).

Additive manufacturing technology are growth rapidly and widely used in varies industries such as aerospace, automotive, medical, retail industries in recent decade as it's bring lot of advantages compare to traditional manufacturing. After 2009 when the last real patent for combined affidavit displaying (FDM) expired, printers could be delivered without encroaching on licensed innovation, AM starts risen its popularity and acceptable in public although it has existed for over 30 years. AM is the new technology which can help companies increase their manufacturing efficiency and reduce complexity in the supply chain with 5 key of benefits which is cost, quality, impact, speed and innovation (Attaran, 2017).

There are few tropical natural fibres which available in Malaysia such as banana fibre, coconut fibre, Kenaf fibre, oil palm fibre, sugar palm fibre, pineapple leaf fibre and sugarcane fibre. These fibres are easily can get from any place and it commonly transform to useful material or to be used as composite. Natural fibre now are growing interest as alternative material to replace commonly used fibre to reinforce such as glass and carbon fibre due to its environment friendly and fully biodegradable. Compare to glass fibre, low density and high specific density of natural fibre is highly possible to replace glass fibre as reinforcement fibre in thermoplastic polymer composite such as PLA (Salit, 2014).

Fused deposition modelling (FDM), one example of the Additive Manufacturing system, initially developed by Stratasys, which enable construct 3D products from thermoplastic filament by heating and extruded semi-liquefied thermoplastic on the build platform in a layer by layer order from base to top. The common used of thermoplastic pellet are Polylactic acid or Acrylonitrile butadiene styrene A plastic filament is mollify at temperature above its melting point in liquefier, then extruded it through small diameter hole tip, nozzle to form layer as the material harden immediately when exposed to cooler environment (Szykiedans &Credo, 2016). FDM starts with the .stl format then slicing software will create the path for the nozzle infill to accomplish 3D printing.

1.2 Problem Statement

As additive manufacturing has growth rapidly and widely used in various industrial field such as aerospace and automotive, limited mechanical properties of the pure thermoplastic filament used by FDM become significant issue and enhancement of mechanical properties of the 3D printed product should be researched and developed. Strength of 3D printed part able this manufactured product functional rather than display model. It is possible to reinforced natural fibre into thermoplastics by increase adhesion between matrixes of materials. But, it is limited number of studies on developing new material especially the fibre thermoplastic composites using FDM process. Key of the challenge is selecting suitable reinforced fibre and content ratio of the natural fibre to thermoplastics (Hofstätter et al., 2017).

1.3 Objectives

There are few objectives that will be carried out through this project:

1. To experiment with new rapid prototyping material.
2. To investigate the effect of Kenaf fibre content reinforced with PLA thermoplastic pellets in additive manufacturing.
3. To study the outcome on the tensile properties of the specimen produced by additive manufacturing of the new materials.

1.4 Scope

This study is to focus on the natural fibre reinforced with thermoplastic pellets to enhance its mechanical properties for sustainability purpose. The objective of this research is to study the optimum ratio content of Kenaf fibre reinforced in PLA thermoplastic pellets. This research will use Fused Deposition Modelling (FDM) machine to fabricate specimen as this machine allow to use in Rapid Prototype lab at FTMK. For further mechanical properties measurement, testing machine of tensile test is carried out to collect data, such as point of break, ultimate tensile test is available in laboratory FKP. Specimen were printed using ASTM D638 Type IV.

CHAPTER 2

LITERATURE REVIEW

2.1 Common Material Used In 3D Printing

2.1.1 PLA

Polylactic acid (PLA) is a standout amongst the most capable biopolymer which is proficient being decayed by microorganisms or other living being. PLA can got from the controlled depolymerisation of the lactic corrosive monomer acquired from the aging of sugar feedstock or corns, which are sustainable asset promptly biodegradable. The extraction of this material contrast by area in the US and Canada the PLA is separated from sustainable asset, for example, corn starch. PLA is a standout amongst the most generally utilized consumables, and as indicated by Market Study: Bio plastics in 2010, PLA has the second most noteworthy utilization rate all inclusive.

Polylactic Acid (PLA) is an individual from aliphatic polyesters gather typically framed from α-hydroxy which contains polyglyoclic corrosive. It has some huge important points contrast with different polymers; henceforth it might be presented as an extraordinary arrangement. Backpedalling to 1970's, the US Nourishment and Medication Organization (FDA) had acknowledged the items that include PLA to be in coordinate contact with natural liquids. There are four critical component offered in PLA, to be specific sustainability, process capacity, biocompatibility and vitality sparing. As specified before, PLA is delivered from sustainable assets, for example, corn and rice which can offer an extraordinary commitment to diminish the effects produced because of the reliance in fuel assets and offer new assets to explain vitality emergency. Aside from the PLA will corruption and fixing, this fill in as ideal substance for biomedical application. For example, water (H2O) and carbon dioxide are not toxic or cancer-causing to individual utilizing it. Besides, PLA can be prepared by film throwing, expulsion, blow trim, and fibre turning because of its more prominent warm process capacity in contrast with other biomaterial. In conclusion, PLA generated 25-55% less fossil vitality than oil based polymers. Cargill Dow has even focused on a lessening in the fossil vitality utilization by over 90% when contrasted with any of the oil based polymers for the not so distant future, which will likewise without a doubt prompt huge diminishment in air and water poison discharges. It is additionally critical that the aggregate sum of water required for PLA creation is aggressive with the best performing oil based polymers.

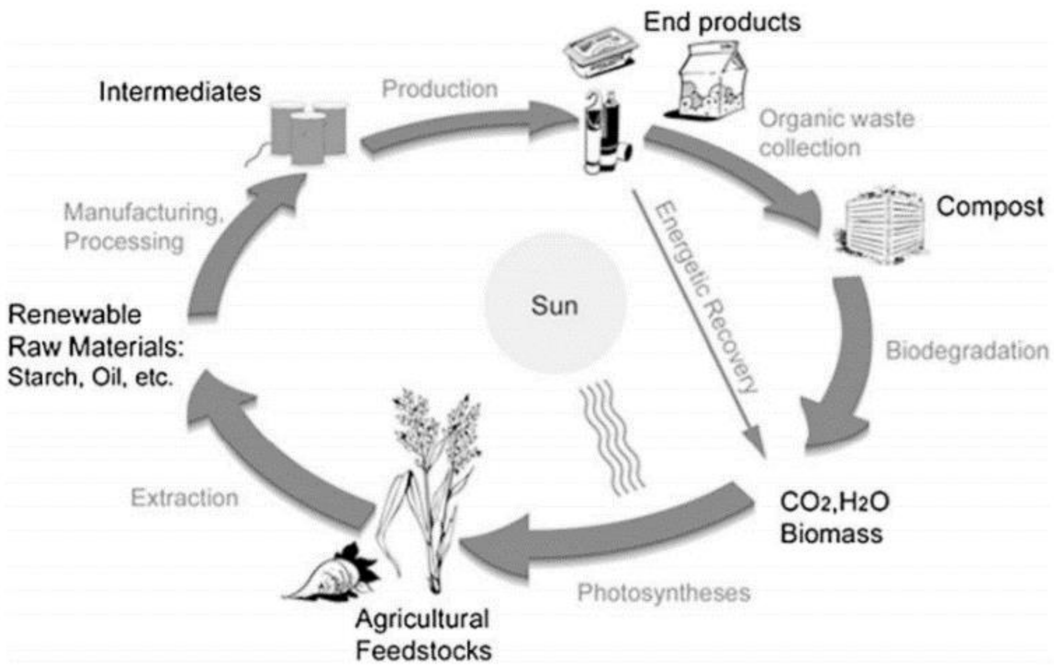

Figure 2.1: Lifecycle of PLA

2.1.2 ABS

ABS is a thermoplastic material. It competes well and has high impact strength with polypropylene, although it is more expensive. The advantages of ABS are included chemical resistance, not harmful to health, low cost, and temperature. Besides that, ABS is an ideal material when strength, stiffness and impact resistance are required for structural applications. It is broadly utilized for machining pre-creation models because of its high dimensional stability and is easy to paste and pain. It can replace die-cast metal components and can be electroplated.

Table 2.1: Comparison of PLA and ABS (Michel, 2016)

	PLA	ABS
Scientific designation	Polylactic Acid	Acrylonitrile Butadiene Styrene
Base material	Plant starch	Petroleum
Properties	Tough Strong	Durable Strong
Pros	Good environment properties High print speed and resolution	Smooth finish Solidifies quickly
Cons	Low heat resistance	Non-biodegradable

Table 2.2: Mechanical properties of PLA and ABS (MakeItFrom.com, n.d.-a)

Material Property	PLA	ABS
Density ρ (Mg/m^3)	1.3	1.0-1.4
Young's Modulus (GPa)	3.5	2.0-2.6
Elongation at break (%)	6.0	3.5-50
Flexural Modulus (GPa)	4.0	2.1-7.6
Flexural Strength (MPa)	80	72-97
Ultimate Tensile Strength UTS (MPa)	50	37-110

2.2 Natural Fibre

Uses of natural fibres in composite applications are developing interest in this recent decade. Contrasted with engineered fibres, normal fibre have part of points of interest, for example, biodegradability, low solidity, low device wear, less expensive cost and accessibility. The most well-known common plant utilized as a part of utilizations are bast strands, for example, hemp, jute, flax, kenaf, and sisal. The primary explanations behind this creating interest is common strands have a higher particular quality than glass fibre and a comparative particular modulus. With these properties and less expensive sources, these regular strands hypothetically offer attractive particular qualities and modulus, at a lower cost. Regular fibre are subdivided in light of their beginning whether they are gotten from plant, creatures, or minerals. Natural fibre are the most famous of the common strands, utilized as support in fibre strengthened composites (Akil et al., 2011).

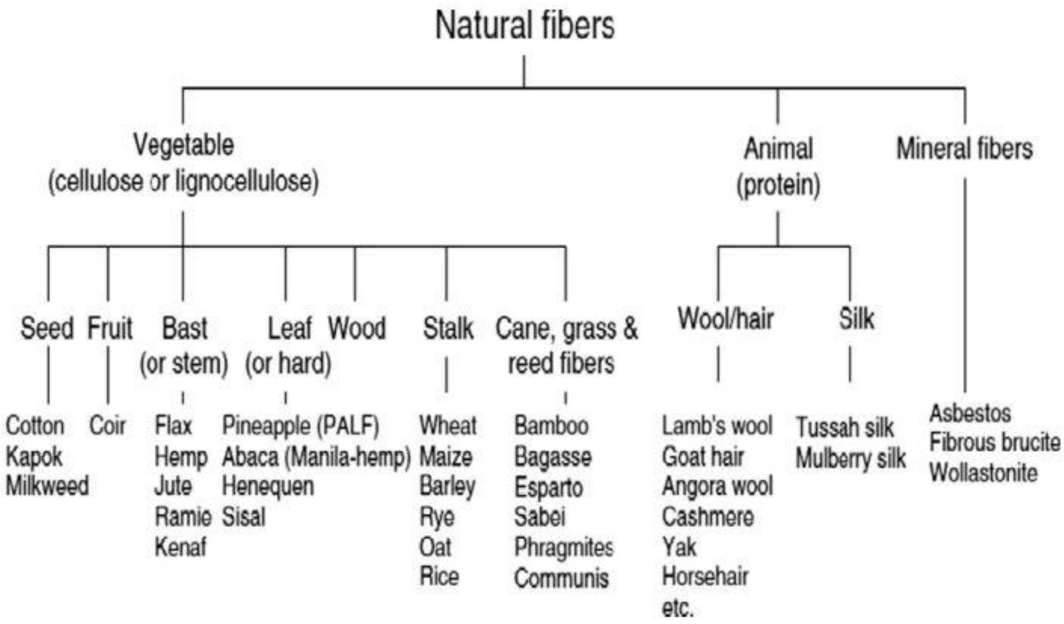

Figure 2.2: Classification of natural fibres(Akil et al., 2011).

2.2.1 Kenaf Fibre

Kenaf fibres (*Hibiscus cannabinus L.*) are harvested worldwide due to its rapid growth and easy cultivation. Taking Malaysia in particular, this plant is harvested twice a year instead of annually. Plant since 4000BC and originated from West Africa, kenaf plant is popular for making ropes, twines and textiles. Furthermore, it is also further processed to make food for animals and used heavily by the automotive industries for various vehicle component fabrication. At the present time, with the tremendous shift of interest using natural fibre as reinforcing agents in polymeric composites, kenaf fibre believed to be a superior substitute to the synthetic fibre such as glass fibre in future. Nevertheless, kenaf fibre is one of the best having its mechanical properties amongst other natural fibres such as cotton, coir, abaca and so forth (Mcrandal et al., 2015).

2.3 Natural Fibre vs Glass Fibre in Fibre Reinforced Plastics.

Glass fibre are the most generally used to strengthen plastics because it is cost less if contrasted with aramid and carbon to obtain great mechanical properties. Unfortunately, glass fibre have more disadvantages compare to natural fibre. The density natural polymers are half lighter than glass fibre but mechanical properties are lower than glass fibre.

Table 2.3: Comparison between Natural Fibre and Glass Fibre.

	Natural Fibre	Glass Fibre
Cost	Low	Higher than NF
Density	Low	Twice then NF
Renewability	Yes	No
Recyclability	Yes	No
Health risk when inhaled	No	Yes
Biodegradable	Yes	No

Table 2.4: Mechanical properties of natural fibres and glass fibre.

	Fibre							
Properties	E-glass	Hemp	Jute	Ramie	Coir	Sisal	Flax	Cotton
Density g/cm³	2.55	1.48	1.46	1.5	1.25	1.33	1.4	1.51
Tensile strength (MPa)	2400	550-900	400-800	500	220	600-700	800-1500	400
E-Modulus (GPa)	73	70	10-30	44	6	38	60-80	12