UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

CHARACTERISTICS OF A NEW ENHANCED RECYCLED POLYLACTIDE FOR SUSTAINABLE 3D PRINTING THROUGH PROCESS OPTIMIZATION

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A report submitted
in fulfilment of the requirements for the Master of Mechanical Engineering

Faculty of Engineering Mechanical

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2020

DECLARATION

I declare that this report entitled “Characteristics of a New Enhanced Recycled Polylactide for Sustainable 3D Printing through Process Optimization” 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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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award as a partial fulfillment of Master of Mechanical Engineering (MMCM).

Signature	: …………………………………………
Supervisor Name	: Dr. Shafizal Bin Mat
Date	: …………………………………………

DEDICATION

Specially dedicated to my beloved family

ABSTRACT

3D printing has been known as additive manufacturing which fabricate a three dimensional of the desired object, part, or assembly model very quickly in layers by using a 3D computer-aided design (CAD). The fast growth of inexpensive 3D printing machines has provided opportunities to users for making useful stuff even at their homes. Polylactide acid (PLA) filament is widely used as a material for 3D printing machines due to inexpensive cost yet has lower toxicity and higher in mechanical performance. However, the rapid growth of 3D printing desktop resulting in the polymer consumer to rise up. Furthermore, the finished products are always refused because of human error and technical error. The higher number of rejections 3D printed products causing the 3D printing waste to increase drastically. Therefore, this project is conducted to minimize the issue by developing a recycled PLA filament using a hand-build extruder machine. The objectives of this project are to optimize the parameters of extruding filament process through the Design of Experiment including analysing the mechanical and surface properties of recycled PLA filament. The optimization of critical process parameters for extruding recycled PLA filament was done using Minitab software. The extruding parameters evaluated are temperature, extruding speed, and extruder machine power. According to the analysis, the Taguchi method suggests an optimal value for every extruding process parameter. The PLA waste went through several processes which are washing process, cutting process and shredding process before proceeding to the extruding process. After recycled PLA filament has been made, analysis on diameter size for every 200 mm was done for the purpose of calculating percentage error. The percentage of error for the diameter of filament specifies 1.73mm diameter with 1.14% as the lowest error while the diameter of 1.60mm with 8.57% as the highest error. A five-set of dog-boned shape objects of recycled PLA filament and original PLA filament were fabricated using Fused Deposition Modelling (FDM). Mechanical properties for both specimens were evaluated through tensile testing using INSTRON 8872. The data showed that the recycled PLA filament and original PLA filament can absorb the same amount of maximum load and tensile stress which the percentage error of those properties obtained a similar value of 5.361 %. However, the value of Young’s Modulus for original PLA and recycled PLA specimens are 1863.55 MPa and 1781.80 MPa, respectively, which indicates that the original PLA filament is more flexible compared to recycled PLA filament. The experiment used Scanning Electron Microscope (SEM) for surface analysis of both filaments, the results illustrated that the surface of recycled PLA filament contained several air gaps while there are no defects on the surface of the original PLA filament. Overall, the utilization of recycling PLA filament in 3D printing machines can surely reduce waste pollution and also able to save a lot of money.

KARAKTERISTIK POLILAKTIDA YANG DITINGKATKAN BARU UNTUK PENCETAKAN 3D YANG BERKESAN MELALUI OPTIMASI PROSES

ABSTRAK

Percetakan 3D telah dikenali sebagai pembuatan aditif yang dapat membuat tiga dimensi objek, bahagian, atau model pemasangan yang diinginkan dengan cepat dalam lapisan dengan menggunakan reka bentuk berbantukan komputer 3D (CAD). Pertumbuhan pesat mesin percetakan 3D yang murah telah memberi peluang kepada pengguna untuk membuat barang yang berguna walaupun di rumah mereka. Filamen Asid Polilaktida (PLA) digunakan secara meluas sebagai bahan untuk mesin cetak 3D kerana kos yang murah namun mempunyai ketoksikan yang lebih rendah dan prestasi mekanikal yang lebih tinggi. Namun, pertumbuhan desktop percetakan 3D yang pesat menyebabkan pengguna polimer meningkat. Selanjutnya, produk siap selalu ditolak kerana kesalahan manusia dan kesalahan teknikal. Jumlah penolakan produk cetak 3D yang lebih tinggi menyebabkan sisa percetakan 3D meningkat secara drastik. Oleh itu, projek ini dijalankan untuk mengurangkan masalah dengan penghasilan filamen PLA kitar semula menggunakan mesin penyemperit buatan tangan. Objektif projek ini adalah untuk mengoptimumkan parameter proses penyemperitan filamen melalui Reka Bentuk Eksperimen termasuk menganalisis sifat mekanik dan permukaan filamen PLA kitar semula. Pengoptimuman parameter proses kritikal penyemperitan filamen PLA kitar semula dilakukan dengan menggunakan perisian Minitab. Parameter penyemperitan yang dinilai adalah suhu, kelajuan penyemperitan, dan kuasa mesin. Menurut analisis, kaedah Taguchi mencadangkan nilai optimum untuk setiap parameter proses penyemperitan. Sisa PLA melalui beberapa proses iaitu proses mencuci, proses memotong dan mencincang sebelum meneruskan proses penyemperitan. Setelah filamen PLA dikitar semula dibuat, analisis mengenai ukuran diameter setiap 200 mm dilakukan untuk tujuan mengira peratusan kesalahan. Peratusan ralat untuk diameter filamen menentukan diameter 1.73mm dengan 1.14% sebagai ralat terendah sementara diameter 1.60mm dengan 8.57% sebagai ralat tertinggi. Lima set objek berbentuk tulang anjing dari filamen PLA yang dikitar semula dan filamen PLA yang asli dibuat menggunakan Pemodelan Pemendapan Bersatu (PPB). Sifat mekanikal untuk kedua-dua spesimen dinilai melalui ujian tegangan menggunakan INSTRON 8872. Data menunjukkan bahawa filamen PLA yang dikitar semula dan filamen PLA yang asli dapat menyerap jumlah beban maksimum dan tegangan tegangan yang sama dengan kesalahan peratusan sifat-sifat tersebut memperoleh nilai yang serupa iaitu 5.361 %. Walau bagaimanapun, nilai Young's Modulus untuk PLA asli dan spesimen PLA kitar semula masing-masing adalah 1863.55 MPa dan 1781.80 MPa, yang menunjukkan bahawa filamen PLA asli lebih fleksibel berbanding dengan filamen PLA yang dikitar semula. Eksperimen menggunakan Scanning Electron Microscope (SEM) untuk analisis permukaan kedua filamen, hasilnya menggambarkan bahawa permukaan filamen PLA yang dikitar semula mengandungi beberapa jurang udara sementara tidak ada cacat pada permukaan filamen PLA yang asli. Secara keseluruhan, penggunaan filamen kitar semula PLA dalam mesin cetak 3D pasti dapat mengurangkan pencemaran sampah dan juga mampu menjimatkan banyak wang.

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LIST OF ABBREVIATIONS

3D	3 Dimensional
PLA	Polyactic acid or Polyactide
ABS	Acrylonitrile butadiene styrene
PET	Polyethylene terephthalate
PS	Polystyrene
FDM	Fuse Deposition Modelling
SLA	Stereolithography
DLP	Digital Light Processing
AM	Addictive Manufacturing
CAD	Computer-aided Design
BC	Years
RSM	Response Surface Methodology
DOE	Design of Experiment
ANOVA	Analysis of Variance
L_9	Level 9
PIC	Plastic Identification Code
ASTM	Standard test methof for tensile test
HDPE	High Density Polyethylene
FFF	Fused Filament Fabrication
MREs	Millions of ready to eat meals
US	United State

LDPE	Low-density polyethylene
UTeM	Univesiti Teknikal Malaysia Melaka
UTM	Universal tensile machine
S/N ratio	Signal-to-noise ratio
SEM	Scanning Electron Microscope
DOF	Degree of freedom
L_{27}	Level 27
P-value	Probability value
R-squared	Regression model
PWM	Pulse with Modulation
PID	Proportional integral derivative
DC	Direct current
RP	Rapid Prototyping
Z offset	Nozzle Z-axis
INSTRON 8872	Instron Universal Testing Machine
UTM	Universal Testing Machine

LIST OF SYMBOLS

%	Percentage
°C	Degree celcius
mm	Millimeter
RPM	Revolutions per minute
s	second
E	Young's modulus
σ	Stress
ε	Strain
$\bar{y}$	Average data
s^2_y	Variance
n	Number of trial
W	Watt
Δ	Change in some unit measure
Y	Regression model
MPa	Megapascal
N	Newton
µ	Micro
µm	Micrometer

CHAPTER 1

INTRODUCTION

1.1 Project Background

In this new era of globalization, there are many kinds of advanced technologies in manufacturing had been developed. One of the technologies that have been increasing significantly and known as an excellent example of a machine is 3D printing. 3D printing is recognized to cost-efficiently lesser the production process in markets which provided less volume, custom-made, and great-value production group as aerospace and medical unit manufacturing (Gebler et al., 2014). 3D printing is a method in which products are made, such as plastic or metal, are placed onto each other in layers to construct a desired 3D object, an example a match of eyeglasses or more 3D shapes (Schubert et al., 2013). The fast growth of inexpensive desktop 3D printers has provided opportunities to user for making useful stuff even at their home (Wojtyła et al., 2017). The low cost of 3D printers are Fuse Deposition Modelling (FDM), Stereolithography (SLA), Digital Light Processing (DLP), etc. Fused deposition modeling (FDM) is the most familiar method for 3D printing, principally due to the simplicity of conducting and cost-effectiveness (Wojtyła et al., 2017). Rapid growth in 3D printing technology resulted in a substantial increase in plastic usage. The attraction to create a workable, reliable, and cheap product for concept visualization requires not merely the demands of an inexpensive machine but also the demands of low-priced material utilization (Ramli and Abdullah, 2018). Instead of Manufacturing, 3D printing is being affective technology in medicine. Numerous reviews demonstrated the benefits and disadvantages of 3D printing in the field of medicine. Among the drawbacks listed, the most critical weaknesses are the needed time and price of the procedure (Nicolas et al., 2015).

A 3D filament is a thermoplastic that usually 3D printer use, in order to print 3D objects. In 3D printing, there are 2 types of popular filament that widely used which are, Polylactide acid (PLA) and Acrylonitrile butadiene styrene (ABS). Each of the filaments has its own mechanical properties. There is already a huge number of PLA printing items. The only natural-resource thermoplastic polymer that can be generated with an annual strength of over 140,000 tons is PLA (B. Bax and J., 2008). Compared to other commercial polymers such as poly(ethylene terephthalate) (PET) and polystyrene (PS), PLA has very low toxicity and high mechanical results (Maiza et al., 2015). The PLA however, consists of some of the drawbacks in terms of its mechanical properties when processing at high temperatures. during thermal treatment, PLA will experience unstable and decrease in molecular weight (Wojtyła et al., 2017). Moreover, PLA is generally very expensive (Barletta et al., 2017). The price of the PLA filament is around USD40 per kilogram. In order to improve the usefulness of PLA and lower costs, several researchers have explored the incorporation of natural lignocellulosic fibers as a reinforcement of PLA over the last decade (Chaitanya et al., 2019). As far as surface finishing is concerned, PLA printed 3D objects will not have a smooth surface as great as ABS. ABS is an easy polymer to produce and manufacture cost-effective engineering polymer with good impact resistance, chemical resistance, good machinability, high esthetic performance, adequate strength, and hardness (Wojtyła et al., 2017). For load-bearing applications, ABS is a cheap and obtainable polymer to be used in the production of a 3D printed product (Uddin et al., 2017). However, when a similar tensile strength test is applied to ABS and PLA, ABS will show the result that it is easier to brittle compared to PLA. Rodríguez-Panes et al. (2018) reported that ABS showed a higher degree of ductility than the PLA.

Furthermore, before a zero-defect product 3D printed object can be successfully manufactured, finished products are always refused because of human error and technical error. The higher the number of rejection printed 3D products resulting in the 3D printing waste to drastically increase. Recycle plastic waste has been known as the best option for solid waste disposal in order to reduce plastic pollution (Mwanza and Mbohwa, 2017). The rise of 3D desktop printers creates interest in recycled 3-D printer filaments to reduce distributed production costs (Kreiger et al., 2014). Therefore, the use of waste materials in private-sector additive manufacturing will reduce costs and increase sustainability, providing high-value production for used plastics (Zander et al., 2018). Since the filament of 3D printing is quite costly, it is advised to recycle 3D printing waste in order to prevent environmental pollution and to accomplish cost-efficient the production of 3D printing. To accomplish the goal of an optimized low-cost 3D printing reuse, Ramli et al. (2015) showed out a thought of a low-cost 3D printer attached to a plastic waste disposal system that generates filaments that endure only one phase period. Recycling 3D printed waste and 3D components is, therefore, an important issue to be addressed at the end of their lives (Pakkanen et al., 2017). In consequence, the goal of this project is to design a low cost recycle filament extruder machine which could significantly produce PLA waste filament and to discover the optimized parameter for extruding recycle PLA filament.

1.2 Problem statement

The rapid growth 3D printing machine resulting in the polymer consumer to increase. This situation shows that the popularity of 3D printing to extremely increases. The machine can be classified as an excellent case of manufacturing technology where it can raise the manufacturing rate and save overall cost. 3D printing uses a mixture of petroleum-based and plant-based sources as filament components to print the desire 3D object. The filaments that use surely not biodegradable and very expensive. The rise of the 3D printer generates the demand to reuse 3D printer filament in order to reduce production costs. Therefore, many recycling 3D printer filaments were developed by different companies. The drawback of the recycle filament machines is that mostly none of them is an integrated recycle machine that can be attached to the 3D printer.

The biodegradable PLA is known as a very popular filament compared to other filaments. The PLA properties which are, it has a lower melting point, relatively low shrinkage, and insoluble in the water make it suitable and ideal type to use for 3D printing. The number of PLA printed products is already huge. The PLA however, will not have the best surface finishing 3D printed object compared to ABS. Even the price of the PLA filament is around USD40 per kilogram, the PLA is not cost-effective 3D printing content. The PLA price has not been significantly reducing despite increased market demand. The PLA printed products can be disposed of by some of the sustainable ways that are landfilled, combusted, composted, or recycled. European studies found that recycling PLA has more than 50 times better environmental impacts than composting and 16 times better impacts than PLA combustion. Thus, in order to form and make the recycle PLA filament as the current 3D printing filament, a number of critical problems need to be discussed; these included (i) the thickness of the diameter recycled filament, (ii) the potential loose of the molecular weight that caused irregularities to the filament mechanical properties and (iii) filament processing potential to produce different 3D printing forms.

Thus, this research is to seek whether the recycled PLA filament is qualified to replace the original PLA filament as the new filament for a 3D printer by identifying its processing parameter of the recycled PLA filament throughout the process of extrusion. Moreover, the mechanical properties and the quality inspection of recycled PLA filament