UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

STUDY ON THE MECHANICAL PROPERTIES OF NATURAL PLA AND PLA COMPOSITES FABRICATED BY 3D PRINTING

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HIYAM ADIL HABEEB

A dissertation submitted
In fulfillment of the requirements for the degree of Master of Mechanical Engineering (Applied Mechanics)

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DECLARATION

I declare that this dissertation entitled "Study on the mechanical properties of natural PLA and PLA composites fabricated by 3D printing" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : Hiyam Adil Habeeb

Date : 1-8-2016

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Applied Mechanics).

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DEDICATION

In the name of Allah, The most Gracious, The most Merciful

All of praise for Allah, glorified and exalted be He. Praise the God for Abundant blessings which given to me, and the determination that he gave me to complete this search.

To the great teachers and educator, My Prophet Mohammad (Allah blessings and peace be upon him and his family), which is the light and guidance for world.

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كل الشكر و الثناء لله سبحانه وتعالى، والحمد له على جزيل نعمه وعلى القوة التي منحني اياها لاتمام هذه الر سالة

.

الى معلمي ورسولي العظيم محمد (صل الله عليه وعلى آله اجمعين)، الذي هو نور وضياء للعالمين

لوالدي الحبيبين، العظيمين والمضحيين.....والدي الغالي الذي لم يدخر ابدا اي جهد في سبيلنا, اطمح لان اجعله فخورا بي بقدر فخري به وبكرم نفسه اسال الله ان يحفظه لنا ...امي الحبيبة والغالية (رحمها الله) التي توفيت منذ اشهر قليلة والتي كانت تنتظر بفارغ الصبر اليوم الذي اكمل بة دراستي...رحمك الله ياامي.. امي بوابتي الى الجنة والتي كانت تضيء بدعواتها وحبها دربي وتطرد بابتسامتها كل همومي وحزني. تعجز الكلمات عن وصف حبي واشتياقي لكي

.ياامي الغالية اسأل الله عز وجل ان يرحمها ويجزيها الجنة

الى زوجي الحبيب والغالي ورفيق حياتي احمد, مساندته ودعمه وعطائه الدائم لي ومساعدته لي على التغلب على كل المحن والصعوبات التى مرت بحياتي اسال الله عز وجل ان يحفظه لي. والى ابني الحبيب والغالي قرة عيني حسين.

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.اصدقائي الاعزاء الذين شجعوني ودعموني اثناء فترة دراستي. شكرا لصداقتكم ولذكرياتكم الجميلة

شكرا لجميع الناس من قريب وبعيد على تشجيعهم ودعواتهم . شكرا لهم جميع

ABSTRACT

Fused deposition modeling (FDM) as one of the additive manufacturing process is generally considered as a technique for the creation of a 3D model. Recently, the availability and affordability were improved to a great extent, resulting from the continuous progress and technique enhancement. Although the prototyping processes have enlarge within wide range in productivities, but it is still restricted by the affecting variables which is the optimum design and characteristics. Traditionally, a part was fabricated in limited types only, like the thermoplastics materials which include PLA (poly lactic acid) and ABS (acrylonitrile-butadiene-styrene). In order to achieve a wide range of FDM process, pure materials were merged with metal powder to exhibit new improved properties. Therefore, the current study investigates the properties of metal powder / PLA composite fabricated by FDM. The study weighs upon the properties of a new polymer/metal powder composite tested with various modeling parameters including the layer height and printing speed. The metal in the current study was a result of the use of a mixing between metal powder with polymer. Furthermore, PLA composites were consist of metallic powder for aluminum, copper and bronze in addition to natural PLA. The mechanical properties for the PLA composites were investigated related to the specific properties of porosity and surface roughness, the resulted properties were compared with the natural PLA results. The found results shows that the highest tensile strength values were in the natural PLA of range from 49.86 MPa to 30.79 MPa while the lowest value of the tensile strength were in PLA composites of 36.98 MPa to 29.74 MPa. Apart from that, the results also indicated that the PLA composites produced porosity less than it does in natural PLA. Also, the surface roughness for both natural PLA and PLA composites produced through the implementation of the FDM technique shows that the natural PLA produced better surface roughness in comparison to the PLA composites. Finally, the results shows that printed specimen using low-cost open source Rep Rap 3D printers were recognized with satisfactory tensile strength and porosity properties.

ABSTRAK

Percetakan 3D menggunakan pemodelan pemendapan terlakur (FDM), yang turut diistilahkan sebagai Pembuatan Tambahan dianggap sebagai satu teknik yang penting bagi penciptaan model 3D. Mutakhir ini, ketersediaan dan kemampuan teknik ini telah meningkat dengan pesat, hasil kemajuan berterusan serta penambahbaikan ke atas teknik. Dalam hal ini, proses pembuatan prototaip telah berkembang pesat, namun ia masih terhad untuk mengendalikan reka bentuk prototaip dan untuk mengesahkan keberfungsian aplikasi yang diuji. Proses tradisional hanya mampu memfabrikasi suatu bahagian dalam jenis yang terhad sahaja, iaitu bahan termoplastik termasuk PLA (asid polilaktik) dan ABS (akrilonitril-butadiena-stirena). Keperluan untuk memperbanyakkan jenis bahan FDM dicapai dengan menggabungkan logam komposit sedia ada dengan serbuk logam bagi mencapai domain aplikasi yang lebih luas. Oleh yang demikian, kajian ini diketengahkan sebagai satu penyelidikan baharu dalam bidang ini, dengan membangunkan komposit logam berasaskan serbuk untuk digunakan dalam teknologi FDM. Objektif utama penyelidikan ini adalah untuk mengkaji sifat-sifat logam baharu tersebut untuk diterapkan dalam pemodelan pemendapan terlakur masa kini atas platform prototaip yang pantas. Kajian ini mengambil kira sifat-sifat polimer/komposit serbuk logam yang baharu, diuji dengan parameter pemodelan berbeza termasuk ketinggian lapisan dan kelajuan penyemperitan. Logam dalam kajian ini merupakan hasil campuran di antara serbuk logam dan polimer. Selain itu, tiga jenis serbuk logam yang telah ditambahkan kepada PLA adalah aluminum, tembaga dan gangsa yang dipanggil komposit PLA. Komposit PLA yang terpilih turut disertakan bagi mengkaji sifat-sifat mekanikal, merangkumi skop kekasaran permukaan dan keliangan, lalu dibandingkan dengan PLA semula jadi. Keputusan menetapkan bahawa purata kekuatan tegangan yang lebih besar adalah untuk PLA semula jadi daripada 49.86 MPa kepada 30.79 MPa dan nilai kurang daripada 36.98 MPa untuk 29.74 MPa pada komposit PLA. Di samping itu, keputusan kajian turut menunjukkan bahawa komposit PLA mempunyai keliangan yang lebih rendah berbanding PLA semula jadi. Demikian juga, kekasaran permukaan PLA semula jadi dan komposit PLA yang dihasilkan melalui teknik FDM turut disiasat; di mana apabila kekasaran permukaan akhir PLA semula jadi dan komposit PLA dibandingkan, didapati PLA semula jadi menghasilkan permukaan yang lebih baik. Akhir sekali, pemerhatian ke atas hasil kajian membuktikan bahawa bahagian yang dicetak menggunakan pencetak 3D Rep Rap murah sumber terbuka mempamerkan kekuatan tegangan yang memuaskan berbanding keliangan.

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LIST OF ABBREVIATIONS

AM	Additive Manufacturing
3D	Three Dimension
CAD	Computer Aided Design
FDM	Fused Deposition Modeling
PLA	Poly Lactic Acid
ABS	Acrylonitrile Butadiene Styrene
Al	Aluminum
Br	Bronze
Cu	Copper
SLS	Selective Laser Sintering
SLM	Selective Laser Melting
DMLS	Direct Metal Selective Laser
FFF	Fusing Filament Fabrication
SLA	Stereo Lithography
LOM	Laminated Object Manufacturing
UV	Ultraviolet laser
USFDA	United States Food and Drug Administration
H_2O	water
PDLA	Poly-D-Lactide
DL-PLA	Copolymer of Poly and Lactide Acid

L-PLA	Light Brown Poly Lactic Acid
MAX	Maximum
STD	Standard
PSI	Population Services International
PLA- Al	Poly Lactic Acid- Aluminum Composite
PLA- Cu	Poly Lactic Acid- Copper Composite
PLA- Br	Poly Lactic Acid- Bronze Composite
ISO	International Organization for Standardization
Sn	Tin
Zn	Zinc
Pb	Lead
Si	Silicon
PLGA	Polylactide-Co-Glycolide
HA	Hydroxyapatite
CS	Compression Strengthen
CPS	Calcium Phosphate Scaffolds
MCC	Mennonite Central Committee
PCL	Polycaprolactone
ABS-Cu	Acrylonitrile Butadiene Styrene-Copper Composite
ABS-Fe	Acrylonitrile Butadiene Styrene-Ferrite Composite
UTeM	Universiti Teknikal Malaysia Melaka

SEM	Scanning Electron Microscope
ASTM	American Society for Testing and Materials
E	Elastic modulus
UL	Underwriters Laboratories

LIST OF SYMBOLS

dL/g	deciliters per gram
g/mL	gram per millilitre
psi	Force per square inch
K	Kelvin
°F	Fahrenheit
°C	Celsius
$g.cm^{-3}$	gram per cubic centimeter
mm/min	millimeter per minute
mm/s	millimeter per second
mm	millimeter
MPa	Mega pascal
GPa	Giga pascal
kJ/m2	Kilojoules per square metre
kPa	kilopascal
μ	Microns
cP	centipoise
kN	Kilo Newton
ρ	density

CHAPTER 1

INTRODUCTION

1.1 Background

Additive manufacturing (AM) or three dimension (3D) printing is defined as a technology to manufacture 3D parts by gathering the printable materials by their layers. 3D printing process is an approach from which a digitally stored data is adopted to produce a rigid component with three dimensions. Any product formed through the process is made by layering the successive layers of material until the creation of complete part is accomplished. The 3D printer functioning foundation begins with the visualization for the selected object for printing, with the use of the Computer Aided Design (CAD), such as the 3D modeling software used to create a new object or 3D scanner to produce a digital copy of a present 3D object (Wholer and Caffrey, 2013).There are many techniques available for the development of 3D objects. One of the widely executed techniques is the fused deposition modeling (FDM) following its reliability and simple process. FDM necessitates only a heating process for extruding the materials. Moreover, FDM 3D printers have competitive prices when drawn in comparison with other 3D printing machines. This is the major reason why the FDM 3D printer is the most commercialized in the additive manufacturing industry today. The FDM process uses thermoplastic materials like poly lactic acid (PLA) filaments which are extensively used as the printable materials for FDM processes. PLA filaments are heated to the temperature below their melting temperature at the nozzle, and then the heated filaments are dispensed on the printing plate layer by layer as to yield the 3D products desired. A steady stream of fundamental research pertinent to

FDM processes has been performed since FDM was recognized as the most commercialized 3D printing process (Nikzad, 2011). The study of printing parameters on the characteristics of the final products becomes an important topic to better the quality. Many studies have been done to observe the effects of FDM printing parameters on the mechanical properties of products. Following the literature, air gap and raster orientation and layer thickness are more remarkable parameters because they affect the mechanical properties of the thermoplastics even more (Ahn et al., 2002; Bellini and Güçeri, 2003; Sood, Ohdar and Mahapatra, 2010). The research of new thermoplastic filaments for the FDM process is also one of the most important topics in the 3D printing industry in terms of printable materials. Many researchers have carried out studies to build upon new composite filament materials for the FDM (Masood and Song, 2004; Hwang, et al 2015; Nikzad, 2011).

PLA- Aluminum, PLA- Copper and PLA - Bronze composites were also analyzed for the mechanical properties. In this research, focus on the study of the FDM parameters on the metal powder to avert distortion of the final products concerning large scale 3D printing. Natural PLA functioned as the thermoplastic material, and copper, aluminum and bronze metals powders served as the additive metal particles. The metal polymer composite filaments in this study had fixed metal particle contents 25% wt. and natural PLA contents of 75% wt. for monitoring the effects of added metal content on the mechanical properties, roughness and porosity of the final products made by FDM. Fundamental studies in regard of the process parameters were also performed in this research. The layer height and the speeds fill in a nozzle of thermoplastic material and metal polymer composite were also altered to look into the effects on tensile strength, roughness and porosity. The printing temperatures were fixed from 190 °C to 210°C following the materials produced.

1.2 Objective

i. To examine the mechanical properties of PLA-Aluminum, PLA-Copper and PLA-Bronze composites and to compare them with natural Poly lactic acid (PLA).

ii. To analyze the surface roughness of natural PLA and PLA composites

iii. To study the porosity of natural PLA and PLA composites.

1.3 Problem Statement

3D printing or fused deposition modeling technology is still at its infancy so it is still very much flawed in the industry. There are many potential investigations and research which can be made to enhance the technologies. The fused deposition modeling (FDM) process can currently fabricate parts only in restricted types of thermoplastics materials such as poly lactic acid PLA and acrylonitrile-butadiene-styrene ABS. Very little efforts have been exerted to increase the FDM material range to include metals powder or metal based composites for wider application domains that transcend solely the design and verification. This dissertation presents a new research in this direction by examining the mechanical properties of metal powder based composites for use in the FDM technology. By adding metals powder to the PLA, its overall properties are altered. This study is carried out to monitor the effects of FDM printing parameters on the mechanical properties of natural PLA and PLA composites.

1.4 Scope

This dissertation' primary focus is on additive manufacturing or fused deposition modeling technologies (FDM) using an open source system. The 3D printed parts make