Faculty of Mechanical Engineering

EXPERIMENTAL INVESTIGATION OF 3D PRINTED COMPONENTWITH INTEGRATED PRESSING TOOL

Siti Najatul Aishah binti Majid

Master of Science in Mechanical Engineering

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled " Experimental Investigation of 3D Printed Component with Integrated Pressing Tool" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature : …………………………………..................................

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Date : …………………………………......................................

DEDICATION

To my parents for continuous prayers and love.

To my husband for endless support.

ABSTRACT

Additive manufacturing or 3D printing is a technology that built up the object layer-by-layer from computer aided design (CAD) where a thinly sliced horizontal can be seen from the eventual object. This thin line segment produces the printed part with less superior of physical properties such as low in tensile strength, high in porosity percentage and poor surface roughness especially for the open source 3D printer compared to the commercial 3D printers. Therefore, this study investigates the physical behavior of the printed part of the acrylonitrile butadiene styrene (ABS) material by using the fused deposition modeling (FDM) process under application of pressure to improve the structure of the printed part. Three types of pressing tool has been developed which are roller pressing, ball-shaped pressing and flat-plate pressing that act as a pressure distributor during the 3D printing process. Every types of pressing tool has different shape, ability and function to achieve the most optimum physical behavior of the printed parts. Hence, the results of the samples printed using normal open source 3D printer, commercial 3D printer and improved open source 3D printer of roller pressing tool, ball-shaped pressing tool and flat-plate pressing tool were compared. The parameters that were controlled were layer thickness, fill density, pattern spacing and print speed. The physical behavior of the samples including tensile strength, porosity percentage, surface roughness and dimensional accuracy were observed using Instron machine, scanning electron microscope (SEM), surface roughness tester and 3D laser scanner. The open source 3D printer with roller pressing tool has the highest tensile strength of 38.34 MPa at 0.1 mm layer thickness with lowest porosity percentage of 13.67 % at 1 mm pattern spacing and lowest surface roughness of 1.28 μm at 0.1 mm layer thickness. The application of the roller pressing tool has successfully improved the physical behavior of the printed sample as the roller rolls on the surface layers to distribute the pressure evenly all over the surface causing the contact surface between the layers become larger while reducing the porous areas. The reading of the surface roughness also reduce as the roller removes the uneven surface and smooth the layers.

KAJIAN EKSPERIMEN KOMPONEN BERCETAK 3D DENGAN ALAT PENEKAN BERSEPADU

ABSTRAK

Pembuatan aditif atau percetakan 3D ialah suatu teknologi yang membina objek secara berlapis-lapis dari rekabentuk berbantuk komputer (RBK) di mana garis halus mendatar pada objek 3D yang terhasil dapat dilihat. Segmen garisan ini menghasilkan bahagian yang dicetak dengan sifat-sifat fizikal yang kurang baik seperti kekuatan tegangan yang rendah, peratusan keliangan yang tinggi dan kekasaran permukaan yang teruk terutama pencetak 3D yang menggunakan sistem terbuka berbanding dengan pencetak 3D komersial. Oleh itu, kajian ini mengkaji sifat-sifat fizikal bahagian yang dicetak dengan bahan daripada acrylonitrile butadiene styrene (ABS) dalam proses pemodelan pemendapan terlakur (PPT) dengan mengaplikasikan tekanan untuk menambah baik struktur bahagian yang dicetak. Terdapat tiga jenis alat penekan yang telah dibangunkan iaitu alat penekan beroda, alat penekan berbebola dan alat penekan rata yang bertindak sebagai pengagih tekanan semasa proses percetakan 3D. Setiap jenis alat penekan mempunyai bentuk, kebolehan dan fungsi yang berbeza-beza untuk mencapai kelakuan fizikal yang optimum bagi bahan yang dicetak. Oleh itu, keputusan sampel yang dicetak menggunakan pencetak 3D sumber terbuka normal, pencetak 3D komersial dan pencetak 3D sumber terbuka yang ditambah baik iaitu penekan beroda penekan bebola dan penekan rata telah dibandingkan. Antara parameter yang dikawal ialah ketebalan lapisan, ketumpatan isi, jarak corak dan kelajuan cetak. Sifat-sifat fizikal bagi sampel seperti kekuatan tegangan, peratusan keliangan, kekasaran permukaan dan ketepatan dimensi diuji menggunakan mesin Instron, scanning electron microscope (SEM), penguji kekasaran permukaan dan 3D laser scanner. Pencetak 3D sumber terbuka bersama alat penekan beroda mempunyai kekuatan tegangan paling tinggi iaitu 38.34 MPa pada ketebalan lapisan 0.1 mm dengan peratusan keliangan paling rendah iaitu 13.67 % pada jarak corak 1 mm dan kekasaran permukaan paling rendah iaitu 1.28 µm pada ketebalan lapisan 0.1 mm. Aplikasi penekan beroda telah berjaya menambah baik kelakuan fizikal bagi sampel yang dicetak apabila roda bergolek di atas lapisan permukaan untuk mengagihkan tekanan dengan rata di seluruh permukaan menyebabkan permukaan bersentuh antara lapisan menjadi lebih luas sambil mengurangkan kawasan berliang. Bacaan kekasaran permukaan juga berkurang kerana roda melicinkan permukaan tidak rata.

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
CAD	-	Computer Aided Design
CNC	-	Computer Numerical Control
FDM	-	Fused Deposition Modelling
LOM	-	Laminated Object Manufacturing
SEM	-	Scanning Electron Microscope
SLS	-	Selective Laser Sintering
STL	-	Standard Tessellation Language
3D	-	Three-Dimensional

LIST OF PUBLICATIONS

Journal

S. N. A. Majid, M. R. Alkahari, F. R. Ramli, S. Maidin, T. C. Fai, M. N. Sudin., 2017. Influence of Integrated Pressing During Fused Filament Fabrication on Tensile Strength and Pororsity, *Journal of Mechanical Engineering*, 2, pp. 185-195.

Proceedings

S. N. A. Majid, M. R. Alkahari, F. R. Ramli, S. Maidin, T. C. Fai, M. N. Sudin., 2016. Effect of Mechanical Pressing on 3D Printed Parts During FDM Processing. APSIM *International Conference on Advanced Processes and Systems in Manufacturing*, pp. 62.

Intelectual Property

M. R. Alkahari, S. N. A. Majid, F. R. Ramli, S. Maidin, S. Subramaniam, M. N. Sudin, "Fused deposition modelling (FDM) with pressure", Patent Application No. PI 2016/04860.

LIST OF AWARDS

- Silver Award, Universiti Teknikal Malaysia Melaka Exhibition (UTeMEX 2016)
- Silver Award, International Research Conference and Innovation Exhibition (IRCIE 2016)
- Silver Award, International Invention, Innovation & Technology Exhibition, Malaysia (ITEX 2017)

CHAPTER 1

INTRODUCTION

1.1 Background

Additive manufacturing (AM) or 3D printing technology was developed in the 1980s and is slowly beginning to adapt into the industry such as manufacturing, engineering, and architecture to create prototype and concept models (Bourell et al., 2009; Wong and Hernandez, 2012; Vyavahare et al, 2020). Basically, AM is a technology that simplifies the process of producing complex 3D objects directly from computer aided design (CAD) data. AM also is a form of advanced technology which give advantages in reducing manufacturing cost and become a tool that allows a designer to customized products at low volumes in an economical way and in a shortened time (Ashley, 1991; Schmitt et al., 2020). This is because it eliminates the need for expensive tooling, molds and dies. This gives more freedom whether to companies or individuals to experiment with the new designs with a minimal manufacture cost (Novakova and Kuric, 2012; Jijotiya and Verma, 2013; Bual, 2014; Patel et al., 2014;). Another supremacy of AM technology is the ability to reduce the carbon footprint of manufacturing by using less raw material, creating less waste material, producing lighter-weight components with optimized designs, and fabricating parts on demand. This also can reduce the transportation cost as the manufacturer of the products can be placed much closer to the customer.

Apart from that, this technology is also utilized in the medical field as its ability to customize nearly anything that can be modelled as a 3D design with almost no limitation to replicate bones, tissue or organ for healing people (Chua et al., 1998; Flowers and Moniz, 2002; Banis et al., 2014; Ozbolat and Hospodiuk, 2016; Sathies and Anoop,2020). AM is not only available to heavy and large industries but it also can be used for personal fabrication in fulfilling the dreams of some enthusiasts. Therefore, many 3D object repositories now provide also accessible 3D models for download-and-print such as Thingiverse where a wide variety of 3D model can be download and print directly such as toys, machine spare parts, musical instrument, smartphones cases, mini statues and much more (Braun, 2012).

Normally, an individual prefers to use an open source 3D printer due to very minimal machine's cost, ease of handling and user-friendly as it has support group community around the world for the development of the machine. However, the mechanical properties of the printed part using such 3D printer is less superior compared to the high-end 3D printer and well-established manufacturing process including tensile strength, porosity percentage and surface roughness (Li et al., 2002; Kim and Oh, 2008; Lee and Huang, 2013; Martínez et al., 2013; Ameta et al., 2015). Therefore, the open source 3D printer is improved by combining the Fused Deposition Modeling (FDM) technique and the application of pressure during the printing process. The application of pressure is crucial in order to reduce the presence of porosity in the printed part by increasing the contact surface between the raster. The transformation of the mechanical behavior of the printed part can be seen by comparing its tensile strength, porosity percentage, surface roughness and dimensional accuracy with the current open source 3D printer and a commercial 3D printer.

1.2 Problem statement

3D printing is seen as one of the future technologies that is able to compete against traditional processing techniques with its distinctive capability of fulfilling the design requirement. It advantages such as minimal product development time, ability to manufacture the high-quality product at reduced cost and customer satisfaction become a key differentiator for the success of products in the competitive world market.

Therefore, 3D printing can satisfy the market's needs as it is able to introduce the new product rapidly to the market, enable customized design and mass customization, increased design complexity and less wastage. Unfortunately, as a new emerging technology, 3D printing still faces stern challenges before it can be adopted in many industries. The areas that still need further study are material characterization, material development, process understanding (such as deformation problem, balling and porosity), simulation, part strength and dimensional accuracy (Bourell et al. 2009). FDM as one of the most commonly used 3D printing also faces issues related to high porosity, low strength and poor surface roughness. Based on Bellehumeur et al. (2004), the neck formation between adjacent deposited layers has resulting porosity in the printed object and (Gordeev et al., 2018; Wang et al., 2016; Wang et al., 2019) state that the porosity is affecting the mechanical properties. This weakness also can be seen clearly as the tensile strength of the ABS printed sample can be achieved only 27.1 MPa while the injection molded ABS parts has greater value which is 37 MPa (Wu et al., 2015). Besides, layer-by-layer technique used by 3D printing has creates a staircase effect which can be seen more clearly on oblique and curved surfaces that resulting poor surface roughness as mentioned ever since by a number of researchers (Armillotta et al., 1999; Bharath et al., 2000; Diane et al., 1997; Kruth et al., 1998, Pandey et al., 2003; Wholers, 1995; Schmitt et al., 2020).

As such, this project proposes an open source 3D printer with mechanical pressing, a combination of FDM and application of pressure to improve the mechanical properties of the printed part in term of tensile strength, porosity and surface roughness.