Faculty of Manufacturing Engineering

THE EFFECT OF TEMPERATURE AND FILAMENT COLOUR IN 3D PRINTER TO THE MECHANICAL STRENGTH AND IMPACT BEHAVIOUR OF THE PRODUCT

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Master of Manufacturing Engineering
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I declare that this thesis entitled "The Effect Of Temperature And Filament Colour In 3D Printer To The Mechanical Strength And Impact Behaviour Of The Product" 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.

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I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Manufacturing System Engineering).

Signature	:	……………………………
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DEDICATION

To my beloved mother Hajjah Mek @ Siti Eshah binti Che Soh for her endlessness loves and support and to my late father Haji Muhamad bin Awang even could not see the completion of this thesis as well as my lovely wife Nor Hidayah binti Othman.

ABSTRACT

3D printing or additive manufacturing (AM) based on fused deposition modelling (FDM) is currently the most widely available 3D printing platform. This method is a procedure of creating three dimensional solid objects from a digital file (CAD software). Additive process is the main conception in 3D printed. In this process, the object/product is created by laying down layers by layer of material until the object is created. Each of these layers of the process can be seen as a thinly sliced horizontal cross-section of the eventual piece. Even-though 3D printer offer various things of output product and can handle any level of complexity but there are many quality-related problems with 3D printing such as fragile product, delaminated FDM parts, low-resolution output materials and etc. To overcome this problem, this study is dedicated to investigate the effect of temperature and filament colour in 3D printing. Experimental method was select during this study. Four types of ABS filament colour which is yellow colour, brown colour, green colour and black colour was used. The level of temperature varies from 215°C and 245°C. In addition, two types of experiment was conducted in order to test mechanical properties for each specimen which is tensile test and charpy impact test in order to get the mechanical properties of the specimens. The 3D specimen was print by following ASTM standard D638-10 and ASTM D6110-04 for testing process. From the result finding, the maximum force is 902.8 N for black colour by using 225°C and its stress is 23.15 N/mm^3. However the lowest force result comes from yellow colour at 215°C, this colour only archives at 399.29 N which is 55% lower than the maximum force value and the stress value is 10.24 N/mm^3.

ABSTRAK

Percetakan Percetakan 3D atau pebuatan tambahan berasaskan permodelan deposit bercantum (FDM) semakin mendapat perhatian di dalam bidang percetakan 3D. Kaedah ini merupakan proses membuat objek padat 3 dimensi secara lapisan berperingkat dengan menggunakan bantuan model digital (perisian CAD) untuk membentuk objek. Di dalam proses ini, objek dibuat dengan membuat lapisan-lapisan dari bawah ke atas seringa terbentuk objek. Setiap lapisan ini boleh dilihat dengan potongan yang nipis bagi setiap lapisan samaada didalam keadaan melintang atau potongan menegak. Walaupun percetakan 3D mama menjanjikan rekabentuk objek yang terhasil dari rekabentuk yang mudah sehingga kepada rekabentuk yang sukar kepada pengguna, namun terdapat beberapa masalah yang berkaitan kualiti objek yang terhasil. Antaranya ialah masalah ojek rapuh, lapisan objek terangkat, kualiti bahan objek yang rendah serta pelbagai lagi. Oleh yang demikian, kajian ini didedikasikan untuk mengkaji kesan suhu dan warna filamen di dalam percetakan 3D. Kaedah kajian dipilih bagi mengkaji hubungkait pemboleh ubah ini. Sebanyak empat jenis warna dari jenis filamen ABS dipilih, antaranya ialah warna kuning, warna perang tua (cokelat), warna hijau dan warna hitam. Skala suhu yang dipilih pula adalah diantara 215°C sehingga 245°C. Dua jenis kaedah kajian dipilih bagi menguji ciri-ciri mekanikal setiap specimen yang dicetak iaitu kajian regangan dan kajian hentakan charpy. Segala penyedian spesimen dan kaedah kajian yang dibuat ini berdasarkan ASTM D638-10 dan ASTM D6110-04. Berdasarkan keputusan hail Cajan yang diperolehi, daya yang paling tinggi ialah 902.8 N dari spesimen yang berwarna hitam pada keadaan suhu 225°C dan daya regangannya ialah 23.1523.15 N/mm^3. Keputusan yang paling rendah ialah bagi spesimen yang berwarna kuning pada suhu 215°C hanya mencapai daya sebanyak 399.29 N iaitu 55% lagi rendah dari daya yang paling maksimum dan regangan sebanyak 10.24 N/mm^3.

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"Bismillahirrahmanirrahim"

"In the name of Allah, The Most Beneficent, The Most Merciful"

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

3D printing or additive manufacturing (AM) is a procedure of creating three dimensional solid objects from a digital file (CAD software). Additive process is the main conception in 3D printed. In this process, the object/product is created by laying down layers by layer of material until the object is created. Each of these layers of the process can be seen as a thinly sliced horizontal cross-section of the eventual piece. 3D printing is the opposite of subtractive manufacturing which is cutting out / hollowing out a piece of metal or plastic with for instance a milling machine. 3D printing permits user to produce complex (functional) shapes using less material than traditional manufacturing methods. It all starts with the creation of a 3D model in computer. This digital design is for instance a CAD (Computer Aided Design) file. A 3D model is either created from the ground up with 3D modelling software or based on data generated with a 3D scanner.

1.2 Background of study

Even-though 3D printer offer various things of output product and can handle any level of complexity but there are many quality-related problems with 3D printing such as fragile product, delaminated fused deposition modelling (FDM) parts , low-resolution output materials and etc. From the interviewing with experience 3D printer's user states that the different filament colour needs the different setting for extruder temperature for the best quality product. For the current situation, there is no company or individual comes out the general references/table for the best range between extruder temperature and filament colour. To overcome this problem, this research is dedicated to study the effect parameters that focusing to the temperature parameters and filament colour.

1.3 Problem statement

The ability of 3D printer is new technologies. This technology that can produce final output with similar the conventional process is the greatest achievement. 3D printer has numerous advantages over conventional manufacturing; the ability to manufacture parts directly from CAD data, the capability to produce complex geometries, and reduced waste when compared to conventional subtractive manufacturing methods (Gao *et al.*, 2015) . However, in reality the output product have some quality problems with 3D printing such as fragile product, delaminated FDM parts, low-resolution output materials (Gardan, 2016). If this problem not to be overcomes, this situation will make big problem for 3D printing market. In order to create perfect output, many parameter need to identify for example the temperature extruder setting.

1.4 Objectives

The aim of this study is to evaluate the relationship between extruder temperature and colour filament. In order to achieve the aim, the objectives of this study are:

i. To investigate the effect of extruder temperature and colour filament on the mechanical properties of the 3D printer product.
ii. To propose the optimum value of extruder temperature and colour filament for
the best output product.

1.5 Scope of Study

For the current situation, there is no company or individual comes out with general references/table for the best range between extruder temperature and filament colour in 3D printing. To overcome this problem, this research is dedicated to study the effect parameters that focusing to the temperature parameters and filament colour. In order to conduct this research, the ABS filament types with four colours were selected (yellow, brown, green and black). In addition the value of the extruder's temperatures will be set between 215 ° C – 245 ° C. This optimum value for this type of filament is 210°C to 230°C as stated by manufacture.

1.6 Significant of Study

The 3D printing industries will gain huge advantages with this research. It is because the error due to wrong setting of extruder temperature value can be avoided. In other side, the quality of finishing product will be increase.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The research is about evaluation of strengthening and impact behaviour between temperature and filament colour in 3D printer. The suitable value of extruder temperature was review in finding the optimum value for the perfect output product.

2.2 History first invention of 3D printer

The first 3D printing attempts are granted to Dr Kodama for his expansion of a rapid prototyping technique in 1980. He was the first to describe a layer by layer approach for manufacturing, creating an ancestor for SLA which is a photosensitive resin was polymerised by an UV light. Unluckily, he did not file the patent requirement before the deadline (Ha, 2016).

Four years later, a French team of engineers was interested by the stereolithography but abandoned due to a lack of business perspective. In the same time, Charles Hull was also interested in the technology and deposited a first patent for stereolithography (SLA) in 1986. He founded the 3D Systems Corporation and a year later this company released the SLA-1. In 1988, at the University of Texas, Carl Deckard brought a patent for the SLS technology, another 3D printing technique in which powder grains are fused together locally by a laser. In the meantime, Scott Crump, a co-founder of Stratasys Inc. filed a patent for Fused Deposition Modelling (FDM): the third of the main 3D printing technologies, in which over less than ten years, the three main technologies of 3D printing were patented and 3D printing was born (Dong *et al.*, 2018).

Figure 2.1: The first 3D printer ever created was made in 1983 by Chuck Hull.

2.3 Introduction of 3D printer

Recently, FDM has become one of the most popular 3D printing technologies due to its simplicity, low-cost, and the potential applications for the method (Tanikella *et* al,. 2017). In Harvard Business Review website state that industrial 3D printing is at a tipping point, about to go mainstream in a big way. Most executives and many engineers don't realize it, but this technology has moved well beyond prototyping, rapid tooling, trinkets, and toys. "Additive manufacturing" is creating durable and safe products for sale to real customers in moderate to large quantities(Torrado *et al.*, 2015). The beginnings of the revolution show up in a 2014 PricewaterhouseCoopers (PwC) survey of more than 100 manufacturing companies. At the time of the survey, 11% had already switched to volume production of 3-D-printed parts or products. According to Gartner analysts, a technology is "mainstream" when it reaches an adoption level of 20%. In 2014 sales of industrial-grade 3-D printers in the United States were already one-third the volume of industrial automation and robotic sales. Some projections have that figure rising to 42% by 2020 as stated (D'Aveni, 2015).

However, FDM products still have deficiencies regarding poor mechanical strength due to the inherent nature of thermoplastic resins, which greatly limit industrial applications as stated by (Yao *et al.*, 2017) On the other hand, a reduction in material as a sustainability requirement for industrial applications is also of significant importance for lightweight and inexpensive printed structures even though it would seem to decrease the strength further. Thus, a novel method which can increase the strength of the printed structures while reducing material consumption and even provide early warning of damage to the structure will be valuable to FDM technology.

Currently, there are mainly four strategies to improve the strength of FDM printed components: 1) structural optimization through the addition of ribs and internal printed supports (Gao *et al.*, 2015); 2) optimization of process parameters, such as the print extrusion, temperature, build orientation, raster angle, and contour width ; 3) development of new materials, including the feedstock filaments made of metal/polymer composite material, thermotropic liquid crystalline polymer (TLCP) fibers and, especially, carbon fiber reinforced thermoplastic filament as stated by (Hull *et.* al., 2015); and 4) development of new methods/technologies, such as printing of continuous fiber composites by in-nozzle impregnation, filling voids in the printed parts with high-strength resins and adding short carbon fibers to a matrix of cellulose-modified gypsum powder as stated by (Christ et. al., 2015). However, all these approaches, including the new carbon fiber based materials, only focus on reinforcing the printed structures; few of them aim to studies the temperature parameter for finding the best output product and the same time save the cost of the production.

2.4 3D printing filament

3D printing filament is the thermoplastic feedstock for fused deposition modelling 3D printers. There are many types of filament available with different properties, requiring different temperatures to print. Filament is available in two standard diameters; 1.75mm and 2.85 mm/3 mm (Alaimo *et al.*, 2017). There are various types of 3D printing filament. The most regularly used materials in 3D printing are the thermoplastics PLA and ABS. Other materials that are sold as 3D printer filament include nylon, polycarbonate, carbon fibres, polypropylene, and many more. There are even special blends which can conduct electricity or glow in the dark. All these filament types come with various colour to suit the user application.

2.5 Effect of filament colour on material properties

(Wittbrodt *et*. al., 2015) proved that the results of their study for PLA material shows each colour presented, when printed at 190˚C, had a distinct tensile strength and percent crystallinity when analysed with tensile testing and XRD. This shows that a conscious decision can be made for the choice of colour that a part is printed in to achieve desired material properties. Also shown is the relative temperature dependence of a material’s tensile strength and, again percent of crystallinity. In addition, the tensile strength increases with temperature, the crystallinity increases from 190˚C to a maximum at 210˚C and back down to a lower value at 215˚C as seen in Table 2.1. Using this data it is possible to hypothesize that there can be a critical temperature of the percent crystallinity present in a given material. This finding also supported by (Rictor *et* al,. 2016) that the consistent of traditional polymer extrusion of PLA is well established that the crystallization of PLA can be initiated by hardening at temperatures higher than the glass transition temperature, but below the melting point to expand their thermal stability.

Table 2.1 : Mechanical properties test. (Wittbrodt et. al., 2015)

Colour	Ultimate tensile strength (MPa)	Yield strength (MPa)	Maximum strain (%)	Crystallinity (%)
Natural	57.16 ± 0.35	52.47 ± 0.35	2.35 ± 0.05	0.93 ± 0.06
Black	52.81 ± 1.18	49.23 ± 1.18	2.02 ± 0.08	2.62 ± 0.09
Grey	50.84 ± 0.23	46.08 ± 0.23	1.98 ± 0.04	4.79 ± 0.10
Blue	54.11 ± 0.30	50.10 ± 0.30	2.13 ± 0.02	4.85 ± 0.15
White	53.97 ± 0.26	50.51 ± 0.26	2.22 ± 0.04	5.05 ± 0.18

When looking at the temperature dependence of the strength of the material, the trend of tensile strength in respect to crystallinity is not followed. Once the material is printed at 215˚C the tensile strength is higher but the percent crystallinity is lower than the critical crystallinity at 210˚C. Due to the layered nature of the 3D printing process a higher printing temperature can give the different layers more time to bond together before cooling to the glass transition temperature.

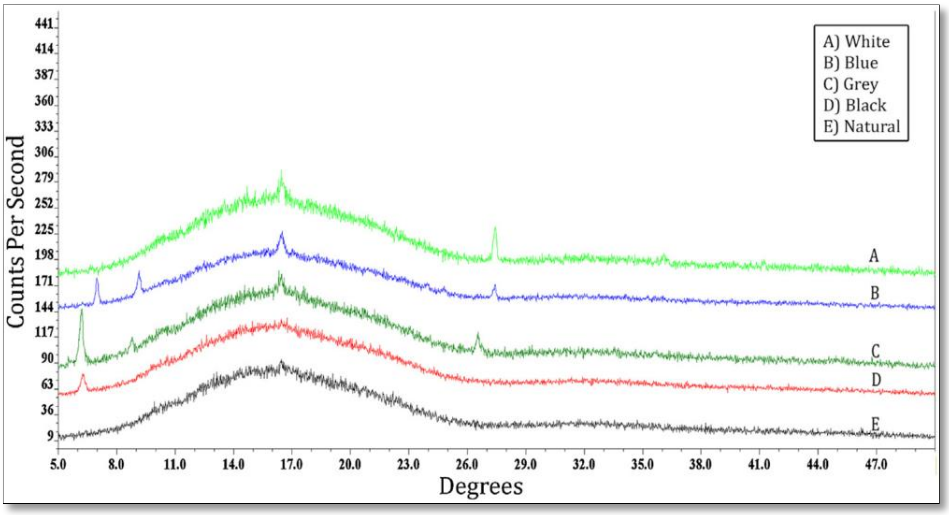

Figure 2.2: Composite XRD scans for different colours. (Wittbrodt et. al., 2015)