Faculty of Mechanical and Manufacturing Engineering Technology

INVESTIGATION OF AEROSOL AND NANOPARTICLES EMISSION FROM SELECTIVE LASER SINTERING (SLS) 3D PRINTER PROCESS USING (2:2:1) RATIO AND VIRGIN POWDER

Ooi Qi Xiang

Bachelor's Degree in Mechanical Engineering Technology (Refrigeration and Air Conditioning System) with Honours

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THE INVESTIGATION OF AEROSOL AND NANOPARTICLES EMISSION FROM SELECTIVE LASER SINTERING (SLS) 3D PRINTER PROCESS USING RECYCLE AND VIRGIN POWDER

OOI QI XIANG

This report submitted of the fulfilment of the requirements for the Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning System) with Honors

Faculty of Mechanical and Manufacturing Engineering Technology

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2019

DECLARATION

I declare that this thesis entitled "The Investigation Of Aerosol And Nanoparticles Emission From Selective Laser Sintering (SLS) 3D Printer Process Using (2:2:1) Ratio And Virgin Powder" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and on in candidature of any other degree.

Signature :..

Name : OOI QI XIANG

Date : ……………………...

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning System) with Honors

Signature :………………………………………...

Supervisor Name : Amir Abdullah Muhamad Damanhuri

Date :…………………………………………

DEDICATION

To my beloved parents, I acknowledge my sincerity and gratitude to them for their love, support, dream and sacrifices throughout my life. Initially, I am thankful for their sacrifice, patience and understanding that were inevitable to make this work completely. Their sacrifice had inspired me to learn how to study and write since the day I was born. I couldn’t find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams. Lastly, I would like to send my gratitude to any person that contributes to my final year project whether it is directly or indirectly. I would like to acknowledge their comments and suggestions, which are crucial for the completion of this investigation successfully.

ABSTRACT

Indoor Air Quality (IAQ) was significant and serious to our health and human. The qualities of the air related to the air contaminants at the indoor area. Poor IAQ leads several consequences to the occupants such as dizziness, vomit, irritation, headache and others. Additive manufacturing classified as one of the emerging technology, but there are limited investigation and studies on the emission of SLS 3D printing technology. Additive manufacturing would draw a lot of attentions and concerns due to its health impacts to our human body and the indoor environment. The studies on the emission of 3D printing carried out in this study was to create the safety limits and health concerns for the users and consumers. An investigation stated that PM and UFP have most negative effects on human and environmental health while on long term exposures and needed to be noticed often for occupants' safeties. From this printing process, the calibration block is selected to be printed to measure and investigate the emission when carrying out the SLS printing process. The powdered material applied from this research is 100% virgin nylon (PA12) and mixed ratio powder (virgin: reheat: recycle) as the powder material which classified as (2:2:1) of ratio. Four phase mentioned in this printing process that strated from before printing, preparation printing, during printing and after printing. The highest concentration of particulate matter $PM_{2.5}$ measured as 3.81 mg/m^3 at pre-printing phase which has exceed the ICOP acceptable limit of 0.15 mg/m3 at preparation process. Besides, the ultrafine particles (UFP) classified in comparison in graph form. The value of virgin powder in one of the graph at ultrafine particle level was 20010 pt/cc. The data collected from the emissions of selective laser sintering (SLS) 3D printing by either 100% virgin nylon powder or mixed ratio powder suggested that ventilation system of the location should be improve to remove excess pollutant air and fresh air is suggest to supply constantly to the occupants.

ABSTRAK

Kualiti Udara Dalaman (IAQ) adalah penting dan serius kepada kesihatan dan manusia. Kualiti udara yang berkaitan dengan pencemaran udara di kawasan tertutup. IAQ yang lemah membawa beberapa akibat kepada penghuni seperti pening, muntah, kerengsaan, sakit kepala dan lain-lain. Pengilangan tambahan dikelaskan sebagai salah satu teknologi yang baru muncul, tetapi terdapat penyelidikan dan kajian terhad mengenai pelepasan teknologi percetakan SLS 3D. Pengeluaran aditif akan menarik banyak perhatian dan kebimbangan kerana kesan kesihatannya kepada tubuh manusia dan persekitaran dalaman. Kajian tentang pelepasan pencetakan 3D yang dilakukan dalam kajian ini adalah untuk mewujudkan had keselamatan dan kebimbangan kesihatan pengguna dan pengguna. Siasatan menyatakan bahawa PM dan UFP mempunyai kesan yang paling negatif terhadap kesihatan manusia dan alam sekitar semasa pendedahan jangka panjang dan perlu diperhatikan serentak bagi keselamatan penghuni. Dari proses percetakan ini, blok penentukuran dipilih untuk dicetak untuk mengukur dan menyiasat pelepasan ketika menjalankan proses pencetakan SLS. Bahan serbuk yang digunakan dalam penyelidikan ini adalah 100% nilon dara (PA12) dan serbuk nisbah campuran (dara: pemanasan semula: kitar semula) sebagai bahan serbuk yang dikelaskan sebagai nisbah (2: 2: 1). Empat fasa yang disebutkan dalam proses percetakan ini yang ditanggalkan sebelum percetakan, pencetakan persiapan, semasa percetakan dan pencetakan. Kepekatan tertinggi partikulat $PM_{2.5}$ *diukur sebagai 3.81 mg / m3 pada fasa pra-percetakan yang melebihi had ICOP yang boleh diterima sebanyak 0.15* mg/m^3*semasa proses penyediaan. Selain itu, zarah ultrafine (UFP) dikelaskan sebagai perbandingan dalam bentuk graf. Nilai serbuk dara dalam satu graf pada peringkat zarah ultrafine ialah 20010 pt / cc. Data yang dikumpulkan dari pelepasan sintering laser selektif (SLS) pencetakan 3D dengan baik serbuk nilon 100% atau serbuk nisbah bercampur mencadangkan sistem pengudaraan lokasi itu perlu diperbaiki untuk menghilangkan udara pencemar yang berlebihan dan udara segar mencadangkan untuk membekalkan sentiasa penghuni.*

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LIST OF SYMBOLS AND ABBEVIATION

et al	-	et alia
IAQ	-	Indoor Air Quality
3D	-	Three Dimensional
AM	-	Additive Manufacturing
PA	-	Polyamide
SBS	-	Sick Building Syndrome (SBS)
ICOP	-	Industrial Code of Practice
RH	-	Relative Humidity
PM	-	Particulate Matter
UFP	-	Ultrafine Particles
IEQ	-	Indoor Environmental Quality
HVAC	-	Heating, Ventilation, and Air Conditioning
OSHA	-	Occupational Safety Health Administration
ASHRAE	-	American Society of Heating, Refrigerating, and Air- Conditioning Engineers
WHO	-	World Health Organization
NIOSH	-	National Institute for Occupational Safety and Health
SLA	-	Stereo-lithography
SLM	-	Selective laser melting
SLS	-	Selective Laser Sintering
DLP	-	Digital Light Processing
EBM	-	Electronic Beam Melting
LOM	-	Laminated object manufacturing
FDM	-	Fused Deposition Melting
FFF	-	Fused Filament Fabrication

DOSH	-	Department of Occupational Safety and Health Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background Studies

Additive manufacturing (AM) classified as an advanced and well-known technology in the manufacturing field. AM enables in production of complex shapes with the addition of materials layer upon layer, as the distinct from the conventional subtractive, with creating and other manufacturing approaches. AM has a lot of evolution with flourished few processes and techniques since the middle of the 1980s. According to 2018 Wohlers report, it reported that the metal of AM systems in marketing sales highly rose to 80% in the year of 2017, almost 1,768 metal of AM systems been sold in the whole year which better than the year of 2016. These metals AM system installations accompanies rose dramatically due to its upgraded process on controlling and quality assurance of measurements. Also, the report stated that manufacturers in worldwide beware of the benefits brought by AM (Agudo, 2018). Basically, AM is all about the material joining process from layer by layer into a new 3D objects which are 3D printing (Huang, Leu, Mazumder, & Donmez, 2014). It started by creating a design with the software of computer aided design (CAD) or 3D scanning of the object. 3D printing is getting famous and common worldwide due to its specialty in Rapid Prototyping (Huang et al., 2014). The application for this 3D printing was the reconstruction of fossils, construction of large parts in a short period and rebuilding the bones or body parts to assist the investigation of crime (Prakash, Nancharaih, & Rao, 2018a) (Environmental, 2013). Indeed, AM has recognized to be formed in various beneficial impacts for our environment such as material waste is reduced significantly and the transportation impacts reduction by the manufacturer and save a lot of human energy (Rejeski, Zhao, & Huang, 2018). However, the application of 3D printers will make the operators exposed to various emissions, such as dangerous dust particles and other air contaminants (Wojtyła, Klama, & Baran, 2017). The 3D printer applies various types of materials such as thermoplastics, photopolymers, phenyl phosphates, powder metals, the ceramics or papers. Aerosol or nanoparticles will release out during the 3D printing process and coming up with the health impacts (To, 2018). Other hazards are overall safety that related to 3D printing equipment, high power voltage, multiple moving parts, hot surfaces, indoor air quality, and static electricity (Yi et al., 2016).

1.2 Problem Statement

Generally, 3D printers applied by a lot of public manufacturer or factories for printing prototypes due to its rapid prototyping skills and techniques (Wong & Hernandez, 2012). 3D printer became the common equipment for plenty of applications such as electronics, medical science investigation, defences for military uses, industrial of automotive and education uses (Anon, 2013). However, the emission of the 3D printer process in additive manufacturing (AM) will affect the air quality of the indoor area (Rejeski et al., 2018). Additive manufacturing would draw a lot of attentions and concerns due to its health impacts to our human body and the indoor environment (Bours, Adzima, Gladwin, Cabral, & Mau, 2017). This is because the AM machines could expel the air pollutants such as VOC and other small particles to pollute the indoor air when operating the printer (Sucaet & Waelput, 2014). The condition might be overwhelming in case inserting a bad ventilation system. An investigation stated that Particulate Matter and Ultrafine Particle have most negative effects on human and environmental health while on long term exposures (van Nunen et al., 2018). The exposure on UFPs is with the formation of atherosclerotic plaque, stress in oxidation, increased inflammatory and pro-coagulant biomarkers, imbalance of autonomic, blood pressure increases and reduced the coronary circulation in our body PM has the higher deposition in alveoli, resulting in the inflammation of tissues, oxidation stress and other systemic health impacts (Bours et al., 2017). Thus, studies on the emission of 3D printing carried out in this condition to create the safety limits and health concerns for the users and consumers (Xing, Sun, & Rana, 2013). From this research, virgin and mixed ratio powder being applied in the printing process because both of the powders indicates a substantial bonding strength (Wang & Laoui, 2003). Thus, investigation needed to carry out to study the effects between the particular matter and ultrafine particles. In order to make saving material, recycle powders will be applied for this printing process to ensure this experiment completed successfully (Yadroitsev, 2017).

1.3 Objectives

a) To investigate the ultrafine particulate matter and aerosol exposures during the SLS 3D printing process using virgin and reheat nylon powder.

b) To characterize the powder exposures of aerosol and nanoparticles of printing preparation in SLS 3D printing process with virgin and reheat (PA-12) nylon powder.

1.4 Work Scope

The researched scope for this study is to investigate and determine the emission rates of selective laser sintering (SLS) printing technology. The printing process carried out in the SLS Laboratory. There were 2 rooms included in this laboratory for the printing process and 2HP split units have set up in each of the rooms. There were 6 m length x 4 m width x 3 m height resulted for surface area in 24 m^2. The temperature and relative humidity (RH) of the rooms is adjusted to 21℃ and 60% respectively. The effective building size of SLS machine is 350×350×430 mm. The selective materials needed in this technology are nylon polymers in powdered form which is PA12. On the other hand, it ought to print out the calibration object for the better accuracy in measurement and dimensions. The dimension of calibration model are length 143 mm x width 143 mm height 23 mm. The product produced by the printer will be selected by the manufacturers according to their desired measurements and requirements. Based on the process, it required different ratios in the mixture of the selective materials to create the objects. However, this technology could affect some implications such as air pollution or bad indoor air quality. Next, the indoor air quality tested with a few equipment in different stages in the 3D printing process. The parameters carried out in this study are particulate matter, ultra-fine particle, temperature and relative humidity (RH). This experiment is conducted in the SLS 3D Printing Laboratory which located in Technology Campus, Factory 4 in UTeM Melaka.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

In the section, there are research workings could be handled for this section. In order to determine the emission rates, literature reviews needed to gather the information or details to support our research. First, there are various types of AM processes and technologies with their definitions included in this chapter. Plus, the details of indoor air quality (IAQ), indoor environmental quality (IEQ), sick building syndrome (SBS) and air contaminants added to understand how to prevent when a reach the hazardous zone. The definition and details of aerosol and nano-particles were explained too in this chapter for more understanding to complete this research project successfully.

2.2 Introduction of Addictive Manufacturing Technology (AM)

The first transformation of creating a three-dimensional object using computer-aided design (CAD) software called as rapid prototyping. It developed in the 1980's for forming models and prototype parts (Wong & Hernandez, 2012). Rapid prototyping considered as the earlier additive manufacturing (AM) processes (Fayazfar et al., 2018). Thus, this process presented the major advances in the development of product. This could be the best way of time and cost reduction, human interaction, and consequently the product development cycle (Agudo, 2018). It also coming up with the possibility to create any shapes that could be a lot difficult to the printing machine (Mcmullen, 2015). In addition, with the rapid prototyping, all the consumers such as scientists and students can build and analyse models rapidly and accurately for theoretical comprehension and studies (Sucaet & Waelput, 2014). For instance, doctors managed to create a model of a damaged body to analyse it and plan the procedures perfectly, market researchers able to understand that people think in a specific new product. In rapid prototyping, it would be easier for artists to explore their thinking and creativity (Rauch, Unterhofer, & Dallasega, 2018). Nowadays, the technologies of rapid prototyping are not just applying in creating models or products. Thus, with the advantages in plastic materials assist in the machine, it is possible to create the finished products, but from the beginning they were developed and shared to expand the situations tested in the prototyping process ("3D Printing Technical Guide," 2019).

AM is the transformation of technology which could totally change our mind into realities in design and manufacturing field, delivering components and goods (Rauch et al., 2018). In 2012, The Economist stated that AM considered as the "Third Industrial Revolution" and grew significantly in manufacturing field. Therefore, it acts as the role to support the industrial base and increase the usage for certain type of parts. This section discusses about the 7 types of process categories in additive manufacturing which are Vat

Photo-polymerization, Material Jetting, Binder Jetting, Material Extrusion, Powder Bed Fusion, Sheet Lamination and Directed Energy Deposition (Sucaet & Waelput, 2014). Indeed, these processes need technologies for completing the whole production flow in manufacturing field (Dewulf & Duflou, 2017). These 3D printing process and technologies to ensure the processes would be more clarified and detailed. Figure 2.1 shows the list of AM printing processes in hierarchy form.

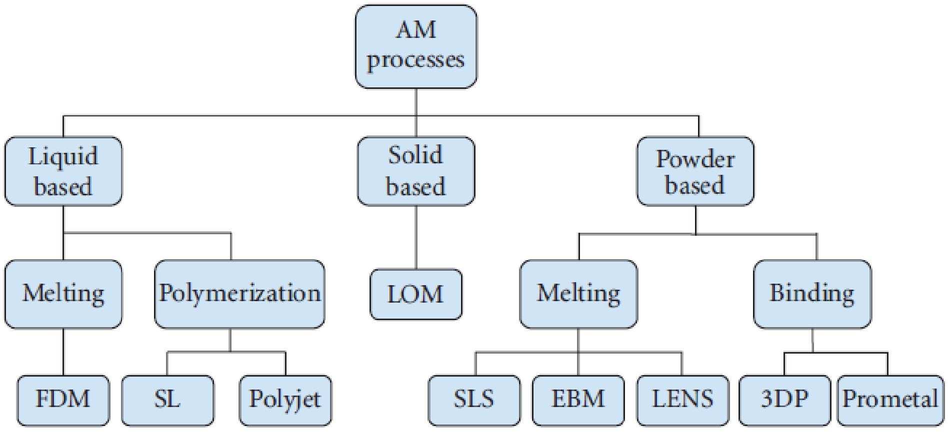

Figure 2.1: AM Processes (Short, Sirinterlikci, Badger, & Artieri, 2015)

2.2.1 Stereo-Lithography (SLA)

It known as the first rapid-prototyping process in 1988s based on 3D systems (A. Ramya & Sai leela Vanapalli, 2016). First, it construct the plastic objects in liquid form into 3D products. With the vat polymerization, the polymers get contact with the UV laser light then the molecules melted and linked together like a bond (A. Ramya & Sai leela Vanapalli, 2016) (Ali, 2015). The applications that applied on this process are Freeform Pico, iPro, CeraFab 7500 and etc (Ali, 2015). Figure 2.2 shows the printing technology of SLA.

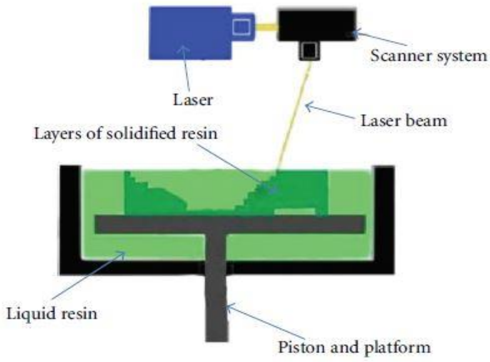

Figure 2.2: Stereo-lithography (Mcmullen, 2015)