Faculty of Mechanical and Manufacturing Engineering Technology

CHARACTERIZATION AND GRAVIMETRIC ANALYSIS OF EXPOSURE FROM SELECTIVE LASER SINTERING (SLS) PA12 NYLON POWDER HANDLING PROCESS

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

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CHARACTERIZATION AND GRAVIMETRIC ANALYSIS OF EXPOSURE FROM SELECTIVE LASER SINTERING (SLS) PA12 NYLON POWDER HANDLING PROCESS

NG SIEW MAN

A thesis submitted in fulfilment of the requirements for the Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning Systems) in Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled “Characterization and Gravimetric Analysis of Exposure from Selective Laser Sintering (SLS) PA12 Nylon Powder Handling Process” is the result of my own research expect 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 for the award of Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning Systems) in Mechanical Engineering.

Signature : ……..……………………….....

Supervisor Name: Amir Abdullah Muhamad Damanhuri

Date : ………………………………

DEDICATION

To my beloved mother and father

ABSTRACT

One of the rapid advance prototyping that is selective laser sintering (SLS) increases rapidly worldwide. With the increased usage of SLS printers, the issues of the operator and safety become a main course. Ultrafine particles (UFPs) and other chemical contaminants are emitted during the SLS printing process. The powder exposure may cause the eyes, throat pain, heart and respiratory illnesses with long-term exposure. To date, there are limited studies measured exposure using a powder bed fusion type of additive manufacturing. The purpose of this study is to investigate the operator exposure using NISOH 0500 and 0600 method using two different ratios, which are virgin powder and recycle nylon powder. Prior to the experiment, the powder was sent for characterization for scanning electron microscopy (SEM), thermos gravimetric analysis (TGA) and particle size analysis (PSA). In SEM analysis, the morphology of the powder shows the uniform spherical shape with size 50-60µm. Calibration block was select to be print along with the experimental measurement of dust. Gravimetric analysis of the filter was measured during the handling powder process. For NISOH 0500, the concentration of total particulate, C = 0.2 mg/m^3 while NISOH 0600, the concentration of respirable particulate does not show a significant amount of $PM_{2.5}$. It can conclude that the particle size is more than 2.5 µm that proved by the particle size analysis result. Personal protective equipment and suitable ventilation system are suggested for operators that run the SLS machine printing process.

ABSTRAK

Salah satu prototaip yang semakin meningkat di zaman ini adalah Selective Laser Sintering (SLS). Dengan meningkatnya penggunan pencetak SLS, keselamatan pengendali telah menjadi perkara yang harus diberi perhatian. Zarah ultrafin (UFPs) dan bahan kimia lain yang tercemar dipancarkan semasa proces percetakan SLS. Pendedahan serbuk boleh menyebabkan sakit mata, sakit tekak, sakit jantung dan masalah pernafasan dengan pendedahan jangka masa yang panjang. Sehingga kini, kekurangan kajian untuk mengukur pendedahan serbuk yang menggunakan jenis serbuk dalam pembuatan tambahan. Tujuan kajian ini adalah untuk mengkaji pengendalian menggunakan cara NIIOSH 0500 dan NIOSH 0600 dengan menggunakan dua nisbah yang berbeza iaitu nilon serbuk dara dan serbuk lama. Sebelum eksperimen ini, serbuk itu dihantar untuk pencirian pengimbasan mikroskop electron (SEM), analisis thermos gravimetrik (TGA) dan analisis saiz zarah (PSA). Dalam analisis SEM, morfologi serbuk telah menunjukkan bentuk sfera yang seragam denagn saiz 50-60µm. Blok penentu ukuran telah dipilih untuk dicetak bersama dengan eksperimen pengukuran serbuk. Analisis gravimetric untuk penapis telah diukur semasa mengendalikan proces serbuk. Bagi NIOSH 0500, kepekatan zarah keseluruhan, C = 0.2mg/m^3manakala NIOSH 0600, kepakatan zarah pernafasan tidak menunjukan jumlah sebesar $PM_{2.5}$. Ini menunjukkan saiz yang lebih daripada hasil analisis saiz zarah (PSA). Peralatan perlindungan peribadi serta sistem pengudaraan telah dicadangkan untuk pengendali yang menjalankan proses pencetakan mesin SLS.

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LIST OF ABBREVIATION, SYMBOL, AND NOMENCLATURE

et al.	-	Et alia
IAQ	-	Indoor Air Quality
SBS	-	Sick Building Syndrome
3D	-	Three Dimensional
AM	-	Additive Manufacturing
CO_2	-	Carbon Dioxide
SLS	-	Selective Laser Sintering
UFPs	-	Ultrafine Particles
NIOSH	-	National Institute for Occupational Safety and Health
PSA	-	Particle Size Analysis
SEM	-	Scanning Electron Microscopy
TGA	-	Thermos Gravimetric Analysis
EDX	-	Energy Dispersive X-Ray
RH	-	Humidity
Kg	-	Kilogram
W	-	Watt
EPA	-	Environmental Protection Agency
CO	-	Carbon Monoxide
O_3	-	Ozone
TVOC	-	Total Volatile Organic Compound
ICOP	-	Industry Code of Practice
ASHRAE	-	America Society of Heating, Refrigerating and Air-Conditioning Engineers
IEQ	-	Indoor Environment Quality

TC	-	Thermal Comfort
VC	-	Visual Comfort
AC	-	Aural comfort
HVAC	-	Heating, Ventilation and Air Conditioning
DOSH	-	Department of Occupational Safety and Health Malaysia
PM	-	Particulate Matter
WHO	-	World Health Organization
μ	-	Micro
AQI	-	Air Quality Index
CAD	-	Computer-Aided Design
STL	-	Standard Tessellation Language
SLA	-	Stereolithography
SLM	-	Selective Laser Melting
FDM	-	Fused Deposition Modelling
LMD	-	Laser Metal Deposition
DMLS	-	Direct Metal Laser Sintering
DMD	-	Direct Metal Deposition
UV	-	Ultraviolet
FFF	-	Fused Filament Fabrication
ABS	-	Acrylonitrile Butadiene Styrene
ASA	-	Acrylonitrile
PBF	-	Powder Bed Fusion
EBM	-	Electron Beam Melting
CLIP	-	Continuous Liquid Interface Production
PC	-	Polycarbonate
PLA	-	Polylactic Acid
NIST	-	National Institute of Standard Technology
PA12	-	Polyamide-Nylon
L	-	Liter

Min	-	Minutes

CHAPTER 1

INTRODUCTION

1.0 Introduction

In the era of globalization, people spend leisure in their office or their own homes (Norhidayah et al., 2013). Indoor air quality for the building will influence the tenants' health, comfort, and performances. Poor indoor air quality could directly affect human wellbeing like respiratory issues, cardiovascular sickness, asthma, skin hypersensitivities, headache, and eye irritation (Agarwal et al., 2016). Normally, human activities are related to the exposure of fine and ultrafine particles, formaldehyde, total volatile organic compound, and carbon monoxide. A few factors may influence the quality of indoor air, namely: the building system, construction techniques, contaminant sources, and respondents themselves, which refer to phenomenon called Sick Building Syndrome (SBS).

Nowadays, advanced technologies are evolving and getting famous around the world. One of the emerging technology is additive manufacturing (AM) or three-dimensional (3D) printers. The growth of this technology increases rapidly worldwide (Kwon et al., 2017). 3D printers used in the field of aerospace, automotive, construction, computers and robots, education and act, medical and others. Also, the AM process is helpful to produce 3D parts directly from computer-assisted design (CAD) by joining materials layer by layer (Prakash, et al., 2018). One of the advanced technologies, which is Selective Laser Sintering (SLS). SLS, which in the process with a powder is sintered or melds by utilizing a CO_2 laser beam (Dizon et al., 2018). At the same time, the machine can produce different kinds of products with the same material. However, people may underestimate the potential impacts of 3D printing on health impacts because of the increasing popularity of 3D printers. These contaminants could impact the Indoor Air Quality (IAQ) in selected areas (Kwon et al., 2017). Hence, this study aims to investigate personal exposures from the SLS 3D printing process. Prior to the investigation, the PA12 powder goes through the characterization process to look deeply on powder properties for virgin and recycle powder.

1.1 Problem Statement

3D printers are the common machine to produces parts and products required by consumers or clients (Olson & Environmental, 2013). Selective laser sintering (SLS) is an advanced laser rapid prototyping which used powder layer by layer to print out the model (Kumar et al., 2017). The complex 3D parts can be built out and do not require any support of an object; unused powder can be recycled for economical purpose. The material used in the SLS process, which is nylon, polyamide-12 (PA12) (Chen et al., 2018). PA 12 is semi-crystalline polymers because of easy and formative. During the SLS printing process, only the powder beginning of melting when heat and start of crystallization via cooling (Dadbakhsh et al., 2017). With the increased usage of SLS printers, the issues of operator exposures and safety become a main course (Mcdonnell et al., 2016). Ultrafine particles (UFPs) and other chemical contaminants are emitted during the SLS printing process (Simon, 2017; Stephens et al., 2013). According to toxicological studies, it confirmed that UFP could enter the bloodstream via the alveoli of lungs and produces inflammatory responses, headache and cardiovascular effect (Kwon et al., 2017; Yi et al., 2016). Currently, fewer studies have been done on the exposure of SLS printing powder handling process and mostly focus on fused deposition modelling (FDM) printing process.

1.2 Objective

a) To characterize virgin and recycle PA 12 nylon powder in terms of particle size, morphology, and thermal degradation.

b) To determine the concentration using gravimetric analysis of virgin and recycle PA12 nylon powder according to NIOSH 0500 and NIOSH 0600 methods.

1.3 Work Scope

The scope in this research is to study operator expose to the powder when handling the Selective Laser Sintering (SLS) 3D printing machine. In this research, it is used to print the calibration block by using nylon powder as a selected material. Two different materials, which are virgin powder and recycle nylon powder, are selected in this research. The recycle powder is collected from previous sintering printing. The weight of the powder is 30kg in this research. The size of the calibration block is 143mm length x 143mm width x 23mm height. The chamber size of this machine is 400mm length x 400mm width x 450mm height. During the experiment, the power consumption of this machine is up to 2.5 kW, and the temperature is 190 °C. The power for the laser is 30W. The laboratory temperature and humidity were set to be 21°C and 60% RH, respectively. This study was investigated the operator exposure of powder is using NIOSH 0500 and 0600 methods, which are using a personal air sampling pump, an open-faced cassette and nylon cyclone. Before the experiment, the powder was sent for characterization of scanning electron microscopy (SEM), thermos gravimetric analysis (TGA) and particle size analysis (PSA). Scanning electron microscopy (SEM) and energy dispersive x-ray (EDX) is used to analyze the morphology and powder properties. Particle size analysis (PSA) is used to see the tabulation of the virgin and recycle powder. Sample of the powders has been analysed by thermos gravimetric analysis (TGA) in the temperature range of room temperature to 600°C under flowing atmosphere with a heating rate 10°C/min. The operator exposure to the powder is measured in four phases that are before printing, preparation of the powder, during printing, and after the printing process in 8 hours. This research is conduct in an SLS 3D printing laboratory that is located in the Technology Campus with the Faculty of Mechanical and Manufacturing Engineering Technology (FTKMP), UTeM.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction of Indoor Air Quality (IAQ)

Indoor Air Quality refers to the quality content around the building and structures that could affect a person. Poor indoor air quality could affect a person’s comfort, wellbeing, and performance in the room, work environment, or school (Melikov et al., 2012). For instance, burning of fuel from heating, cooking, emission of toxic gas from materials may affect human health when indoor exposure from social activities (Circinelli et al., 2017; Norhidayah et al., 2013). From the previous study from EPA state, indoor air contamination is among the top five environmental health hazards (Norhidayah et al., 2013). Nowadays, people are starting to be a concern the indoor air quality is essential. It may affect the life and health of people who always spend their time in the building. However, the decision of building materials and indoor furnishing may impact on the indoor air quality too (Ahmadul Ameen, 2007). Poor indoor air quality may cause Sick Building Syndrome (SBS). Physical parameters and air contaminants can measure the IAQ level by following that distinguish from the Industry Code of Practice (ICOP) on indoor air quality. There is carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), total volatile organic compounds (TVOC), respirable particulates, formaldehyde, bacterial, fungal, temperature, and humidity are be measured (Mentese et al., 2015). As indicated by the ASHRAE standard, good indoor air quality was characterized as 80% or a more significant amount of the people exposed do not express dissatisfaction (Butler et al., 2001).

2.1 Indoor Environmental Quality (IEQ)

Indoor environmental quality (IEQ) and human comfort are firmly related. The IEQ of a building that includes four conditions is thermal comfort (TC), indoor air quality (IAQ), visual comfort (VC), and aural comfort (AC) (Lai et al., 2009). The IEQ of buildings that may influence occupants or employee comfortability, healthy, and productivity (Ben-David & Waring, 2018). The major donors are temperature, carbon dioxide concentration, equal noise level, and lighting level (Lai et al., 2009). The heating, ventilation and air conditioning (HVAC) system of a building can solve indoor environment quality (IEQ) by two parameters are thermal comfort and indoor air quality (IAQ) (Ben-David & Waring, 2018)

2.2 Acceptable range of IAQ

The acceptable range for air temperature, relative humidity, and air movement is presented in Table 2.1. Meanwhile, acceptable indoor air contaminants are shown in Table 2.2.

Table 2.1: Acceptable range for specific physical parameters (DOSH, 2010)

Parameter	**Acceptable range**
(a) Air temperature	23 – 26 °C
(b) Relative humidity	40 – 70%
(c) Air movement	0.15 – 0.50 m/s