Faculty of Mechanical and Manufacturing Engineering Technology

A STUDY ON SELECTIVE LASER SINTERING BEHAVIOUR AND PROCESSING OF POLYMER POWDER MIXTURES

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Bachelor of Manufacturing Engineering Technology (Product Design) with Honours.

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A report submitted in fulfilment of the requirement for the Bachelor of Manufacturing Engineering Technology (Product Design) with Honours.

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DEDICATION

To my beloved parents who teach me good values and shower me with conditional love and support. To my supervisor Professor Madya Ts. Dr. Umar Al-Amani Bin Haji Azlan who has been guiding me and encouraged me attentively to accomplish my work and my co-supervisor En. Mohamad Rafi bin Omar who always support me and advise me along my final year project journey.

ABSTRAK

Pensinteran Laser Memilih (PLM), salah satu mekanisme pengikat daripada pembuatan bahan tambah yang mampu menghasilkan bahagian-bahagian yang agak rumit dengan geometri sukar mempunyai kelebihan terhadap pendekatan pembuatan konvensional. Walau bagaimanapun, kebanyakan serbuk tanpa pensinteran masih memerlukan suhu tinggi sepanjang proses pembentukan dan dan kitaran penyejukan yang menyebabkan degradasi terhadap sifat bahan. Tiga komposisi yang berbeza daripada serbuk Poliamida (PA) 12, iaitu (i) komersil, (ii) kitar semula, (iii) komposisi campuran komersil, kitar semula dan serbuk panas semula dengan nisbah 2:2:1 dikaji pada reologi melalui reometer dan spesimen bahan-bahan yang dibentuk melalui proses PLM. Mikrostruktur pada bahagian keratan rentas spesimen dan ketepatan dimensi pelbagai profil spesimen termasuk panjang, sudut dan ketebalan dikaji menggunakan SEM dan CMM. Keputusan analisis menunjukkan bahawa spesimen kitar semula PA 12 mempunyai purata sisihan agak ketara bagi semua profil daripada dimensi yang dikehendaki dan mempunyai kelikatan paling tinggi antara tiga sampel. Imej SEM menunjukkan rongga dan keliangan pada keratan rentas spesimen kitar semula PA 12 turut menjelaskan kelikatan tinggi yang menentang aliran leburan adalah faktor sisihan pada beberapa bahagian dimensi. Komposisi campuran PA 12 telah menghasilkan keputusan yang hampir sama tetapi kelikatan lebih tinggi sedikit daripada komersil PA 12 yang menunjukkan sifat bahan yang lebih baik daripada bahan kitar semula. Sisa kitar semula PA 12 daripada proses PLM turut menjimatkan bahan mentah. Namun begitu, ia perlu dicampurkan dengan nisbah bahan baru yang sesuai untuk mencapai prestasi kualiti yang baik.

ABSTRACT

Selective Laser Sintering (SLS), one of the binding mechanisms of additive manufacturing capable in fabricating high complexity parts with complicated geometries had gain its bonus over conventional manufacturing approach. However, most powder is unsintered but undergo high temperature along the building and cooling cycle resulting in degradation of material properties. 3 different composition of Polyamide (PA) 12 powder, (i)commercial, (ii)recycled, (iii)mixed composition of commercial, recycled and reheated powder with ratio 2:2:1 is studied on the rheology through rheometer and specimens of respective materials is fabricated through SLS process. Surface morphology of the cross-sectional area of specimen's part and dimensional accuracy of various profiles of specimens includes length, angle and thickness are studied by using SEM and CMM respectively. Analysis results showed that the specimens of recycled PA12 has the most deviations in average for all profile from the desired dimension and possess highest viscosity among the three samples. Images from SEM showed cavity and porosity in the cross-sectional area of the specimens for recycled PA 12 explained the observation of highest apparent viscosity of the recycled PA 12 among the three samples which resist the melt flow is a factor of the deviations in parts dimension. Mixed composition of PA 12 results in similar but slightly higher viscosity than the commercial PA 12 showed better material properties than the recycled material. Recycling waste PA 12 from SLS process can contribute to economical target but need to be mixed with an appropriate ratio of new material to achieve parts quality performance.

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CO_2	-	Carbon dioxide
T_g	-	Glass Transition Temperature
T_m	-	Melting Temperature
E	-	Elastic Modulus
℃	-	Degree Celsius
wt%	-	Percentage by weightage
T_{pm}	-	Peak Melting Temperature
T_b	-	Build Temperature
T_s	-	Starting Temperature
ω	-	Energy density
η	-	viscosity
τ	-	force
$\dot{\gamma}$	-	Time/area
mm	-	millimetre
s	-	Second
W	-	Watt
V	-	Volt
Hz	-	Hertz
kg	-	kilogramme

MPa	-	Mega Pascal
μ	-	Micro
cc	-	Cubic centimetre

LIST OF ABBREVIATIONS

RP	Rapid Prototyping
SSF	Solid Freeform Fabrication
LM	Layered Manufacturing
3D	3 Dimensional
AM	Additive Manufacturing
SLS	Selective Laser Sintering
PA	Polyamide
SLA	Stereolithography Apparatus
CAD	Computer Aided Design
FDM	Fused Deposition Modelling
LOM	Laminated Object Manufacturing
MJF	Multi Jet Fusion
PC	Polycarbonate
STL	Stereolithography
D	Diameter
SEM	Variable Pressure Scanning Electron Microscopy
CMM	Coordinate Measuring Machine

CHAPTER 1

INTRODUCTION

1.1 Background

Rapid Prototyping (RP) also defined as solid freeform fabrication (SSF) or layered manufacturing (LM) which fabricates three dimensional prototypes on a layer-by-layer basis. All the RP processes goes through data pre-processing operations which converts three-dimensional model developed through 3D scanning or computer-aided design into mandatory information in layer for additive manufacturing of 3D objects.

Initially, techniques of additive manufacturing are solely used for constructing prototype of special products. However, RP has shown its growth vastly in several new fields of direct manufacturing. The ability of Additive Manufacturing (AM) in fabricating high complexity parts with complicated geometries, lower consumption of raw material without tooling requirement and consequently lower expenditure had gain its bonus over conventional manufacturing approach like machining. By introducing an approach which can verify quickly and fine-tune designs in the field of design and manufacturing, RP has successfully shortened the market time for a product, reduced test expenditure and enhanced product specification. These high value customized parts typically low in volume with high relative part complexity from metallic alloys, ceramic and polymers are widely applied in industries like bio-medical applications, automobile and not to mention, in aerospace.

Good mechanical properties as well as good part quality especially in appearance is what people look for in functional prototyping by using Selective Laser Sintering (SLS). Part of the major issues in SLS process relative to the quality of appearance in prototype mainly define by dimensional accuracy and geometry quality (Kozak & Zakrzewski, 2018). As mentioned in Han et al. (2018) study, poor surface quality often leads to low mechanical properties and early fracture.

According to Yusoff (2017) , the determining parameter for the final part quality is the quality of material used during the sintering process. Polyamide (PA) 12 is known for its chemically resistant and its application covers wide range. There is over half of the powder which is not sintered collected after the fabrication of prototype using the technique of Powder Bed Fusion. Recycling the waste material can contribute to economical target. However, PA12 shows degradation behavior after processing hence a study on the behavior of the recycled material powder on different reusing state is conducted.

In this research, relationship between viscosity of different composition of PA12 material which is pure recycled material, fresh virgin material and mixture of 2:2:1 recycled, raw and reheated PA12 material and part dimensional accuracy will be studied.

1.2 Objectives

Few objectives are listed as below:

i. To conduct Selective Laser Sintering process using virgin Polyamide (PA) 12, recycled PA 12, and mixture of PA 12 with ratio of 2:2:1 of recycled, virgin and reheated PA 12.

ii. To analyze the respective materials behavior in terms of rheology and microstructure of PA 12 with different compositions.

1.3 Problem Statement

In previous studies, it was stated that there is more than half in average of the material in the building chamber which is in powder form is not sintered during the laser sintering process and could be reused. However, under exposure of high temperature close to melting temperature of the material for a long period throughout the building and cooling cycles, PA12 powder shows deteriorate properties. The recycled powder which repeatedly undergo building and cooling cycles need to be mixed with appropriate amount of fresh new material to achieve good quality parts. However, adding excessive new material or recycled material in either way would results in high manufacturing cost and poor part quality and waste respectively (Yusoff, 2017).

Hence, it would be special interest to study the material behavior of different composition of polyamide 12 related to part dimensional accuracy.

1.4 Scope of Research

In general, this research is conducted to focus on material behavior of PA12 corresponds to different state of powder grade as aged, virgin, and aged-virgin mixture. The material adopted in this study is FS 3200PA from FARSOON. Virgin material is the virgin PA 12, aged material is recycled PA 12 and aged-virgin material is a mixture 2:2:1 PA12 (40% virgin, 40% recycled and 20% reheated material).

Apart from this, the parameters of the SLS machine used in this study model FARSOON 402P are assumed well-tuned for manufacturing functional prototypes. The designer-specified parameters such as orientation on part fabrication and resolution is assumed constant.

1.5 Significance of Research

Despite the previous studies and researches, there is still poor understanding about the relationship between remaining porosity, coalescence behavior and microstructure that can vary due to powder ageing which further affects the parts quality in terms of dimensional accuracy. This works attempts to further discover the relationships of these aspects in PA12 powder available in three different forms as virgin, aged and aged-virgin mixture.

Selective Laser Sintering process produces functional prototypes with high complexity in small batches. Thus, high accuracy in part dimension of SLS prototypes are necessary. This research will contribute to the advancement of knowledge regarding on the reusing of aged PA 12 powder with different composition in SLS process for fabricating prototype with good part quality.