Faculty of Mechanical Engineering

EFFECT OF POST PROCESSING PARAMETERS AND COMPRESSION BEHAVIOR ON FDM 3D-PRINTED ABS LATTICE-STRUCTURES

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EFFECT OF POST PROCESSING PARAMETERS AND COMPRESSION BEHAVIOR ON FDM 3D-PRINTED ABS LATTICE-STRUCTURES

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DECLARATION

I declare that this thesis entitled "Effect of Post Processing Parameters and Compression Behavior of FDM 3D-printed ABS Lattice-structures" 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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Date	:	....

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	:	…………………………
Supervisor Name	:	Dr. Rafidah binti Hasan
Date	:	…………………………

DEDICATION

To my beloved mother and father

ABSTRACT

There is a growing development in lattice structure due to fundamental interest of the industries in producing parts with higher performance albeit with a low energy and cost consumption. Lattice structure is a periodic cellular structure which can serve the purpose of achieving lightweight parts with good mechanical properties. The complexity of manufacturing numerous types of lattice structures can be overcome by additive manufacturing (AM) process which offers better reliability and relatively simple procedure as compared to normal manufacturing. For the past decade, there are many studies on the lattice structure fabrication by AM. However, from literature, it is found that not many studies reported about the investigation on lattice structure by non-metallic, especially the ABS polymer. The use of ABS polymer to produce lattice structure serves as an added value for lightweight applications due to the lightweight characteristics of the ABS itself. The fused deposition modeling (FDM) 3D printed process of lattice structure is rarely reported in previous studies, hence it is difficult to confidently understand the behaviour of produced lattice structure by using combinations of FDM parameters. On top of that, there is limited information regarding the relationships between the pre-set parameters of CubePro's mid-range FDM printed lattice structure with its mechanical properties. Therefore, this study characterized and examined the manufacturability of lattice structure geometry that was produced by FDM. The effect of process parameters of mid-range FDM 3D printer on the geometry of ABS lattice-structure were then evaluated. Later, the relationships between mechanical properties of ABS FDM 3D printed lattice structure with its geometry were derived by using experimental approach to justify the material as lightweight material. The CubePro 3D printer machine was utilized to fabricate the BCC lattice structure cube specimens with dimension of 20 x 20 x 20 mm3 with strut's diameter sizes of 1.2 mm, 1.4 mm and 1.6 mm. Optical microscopy was used to characterize the printed lattice structures cube specimens. Theoretical approach was performed to compare the results with previous studies. The lattice structures specimens were tested with quasi-static compression loading to examine its mechanical properties and then the relations between process-properties of FDM 3D printed lattice-structure were derived. The significant process parameters that influenced the mechanical performance as well as the geometrical properties for this particular FDM printer machine was found to be the layer thickness. The best mechanical performance of lattice structure was observed for that produced with 200 µm layer thickness as it gave a good agreement between the theoretical approach and experimental data analysis. With respect to the deformation behavior of the lattice structure in this study, the material is found to be more suitable in energy absorption applications such as in car engine hood or arm parts of the drone due to the bending dominated behavior when subjected to loading.

ABSTRAK

Pembangunan bahan berstruktur kekisi mendapat perhatian kerana permintaan tinggi industri untuk penghasilan produk berprestasi tinggi selain penggunaan tenaga dan kos rendah. Bahan berstruktur kekisi merupakan bahan berstruktur selular berkala yang memenuhi keperluan penghasilan bahan ringan serta mempunyai sifat mekanikal yang baik. Ia boleh ditakrifkan sebagai struktur tiga dimensi berjejari dan berpenghubung yang terjalin antara satu sama lain. Kerumitan pembuatan pelbagai bahan berstruktur kekisi boleh diatasi dengan proses pembuatan secara tambahan yang menawarkan kebolehpercayaan lebih baik dan mudah berbanding pembuatan biasa. Sepanjang dekad lalu, banyak kajian mengenai pembuatan bahan berstruktur kekisi oleh pembuatan secara tambahan. Walau bagaimanapun, daripada kajian latar belakang, didapati tidak banyak kajian melaporkan pembuatan bahan berstruktur kekisi menggunakan bahan bukan logam, terutamanya polimer ABS. Struktur kekisi yang dicetak mesin FDM jarang dilaporkan kajian terdahulu, oleh itu sukar untuk memahami perilaku bahan berstruktur kekisi dihasilkan menggunakan kombinasi penetapan parameter FDM. Selain itu, sedikit maklumat menerangkan hubungan penetapan pra-set pencetak 3D CubePro jenis pertengahan terhadap ciri mekanikal bahan berstruktur kekisi. Oleh itu, kajian ini memberi pencirian geometri serta keupayaan pembuatan bahan berstruktur kekisi oleh mesin FDM. Hubungkait antara kesan penetapan parameter pencetak 3D jenis pertengahan terhadap geometri dengan sifat mekanikal bahan berstruktur kekisi ABS dicetak pencetak 3D FDM diperoleh dengan pendekatan eksperimen bagi memenuhi justifikasi struktur kekisi sebagai bahan ringan. Mesin CubePro digunakan bagi menghasilkan spesimen kubus berstruktur kekisi BCC bersaiz 20 x 20 x 20 mm3 dan ukur lilit jejari bersaiz 1.2 mm, 1.4 mm dan 1.6 mm. Mikroskop optik digunakan untuk pencirian spesimen kubus berstruktur kekisi yang dicetak. Pendekatan secara teori dilakukan untuk perbandingan dengan hasil kajian terdahulu. Spesimen bahan berstruktur kekisi diuji dengan ujian mampatan kuasi-statik bagi mengetahui sifat mekanikalnya. Hubungan antara ciri proses FDM dan bahan berstruktur kekisi diperolehi. Parameter proses ketebalan lapisan dikenal pasti mempengaruhi prestasi mekanikal dan sifat geometri untuk mesin FDM. Bahan berstruktur kekisi yang dihasilkan dengan ketebalan lapisan 200 μm memberikan prestasi mekanikal terbaik kerana perbezaan kecil antara dapatan melalui pendekatan teori dan eksperimen. Sifat ubah bentuk bahan berstruktur kekisi kajian ini menunjukkan bahan ini mempunyai ciri sesuai digunakan dalam aplikasi bahan serapan tenaga seperti penutup enjin kereta dan bahagian lengan dron kerana ia mempunyai sifat dominasi lenturan apabila dikenakan daya mampatan.

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LIST OF SYMBOLS

d	-	Diameter
E	-	Young’s modulus
ε	-	Strain
ρ	-	Density
ρ_s	-	Density of base material
σ	-	Yield stress

LIST OF ABBREVIATIONS

3D	-	Three-dimensional
ABS	-	Acrylonitrile butadiene styrene
AM	-	Additive manufacturing
BCC	-	Body-centred-cubic
CAD	-	Computer aided drawing
EBM	-	Electron beam melting
FDM	-	Fused deposition modeling
FEA	-	Finite element analysis
LOM	-	Laminated object manufacturing
PEI	-	Polyetherimide
PLA	-	Polylactic acid
PP	-	Polypropylene
SEM	-	Scanning electron microscope
SLA	-	Stereolithography
SLM	-	Selective laser melting
SLS	-	Selective laser sintering
STL	-	Standard tesellation language
TPU	-	Thermoplastic polyurethane

LIST OF PUBLICATIONS

Journal Articles

Rosli, N. A., Hasan, R., Ng, W. H., Baharudin, M. K. and Alkahari, M. R., 2018. Investigation on process-properties relationship with mechanical properties of lattice-structured cellular material for lightweight application. *International Journal of Engineering and Technology*, 7, pp.1-4.

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Conference papers

Rosli, N. A., Hasan, R. and Alkahari, M. R., 2018. *Proceedings of 5th Mechanical Engineering Research Day, Melaka.* pp. 230-232.

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CHAPTER 1

INTRODUCTION

1.1 Research background

There is a growing body of literature that recognizes the importance of additive manufacturing in fulfilling demanding needs of lightweight materials utilization in the industry (Eichenhofer et al., 2017; Jin et al., 2017; You et al., 2018). This is due to the fact that lightweight materials contribute to the reduction of energy consumption, reduction of manufacturing cost and lower the hazardous emissions to the environment (Helms and Lambrecht, 2007; Soo et al., 2015; Tisza and Czinege, 2018). Besides that, lightweight materials which are produced using additive manufacturing route can be formed from various types of materials such as magnesium alloy, fiber-reinforced plastics and even cellular materials with vast manufacturing potential (Rehme, 2010; Abbott, 2014; Zaiß et al., 2017). The increasing applications of additive layer manufacturing or 3D printing in producing lightweight materials can be seen in recent years (Eichenhofer et al., 2017; Jin et al., 2017; You et al., 2018). The 3D printing machine with default parameters such as the CubePro (3D Systems Inc, 2014) can be one of the future affordable manufacturing machine for substitution of low-cost daily equipment. It is reported that 3D printing has been developed by Charles Hull in the 1980s and it is one of the various techniques of additive manufacturing that can fabricate three-dimensional objects by printing successive layers of materials on top of one another from Computer Aided Design (CAD) file (Ngo et al., 2018). The capability of fabricating complex geometry with high precision, material savings and design flexibility are the main advantages of 3D printing (Ivanova et al., 2013).

With the development of 3D printing in the manufacturing industry, the production of lattice structure materials has become feasible. Lattice structure material is a periodic cellular structure material which can serve the purpose of achieving lightweight parts with good mechanical properties (Azman, 2017). It can be defined as a three-dimensional structure with struts and joints interconnected with each other. Lattice structure can be utilized in various applications with its diversity of part designs incorporated in its various cellular approaches within available manufacturing processes (Rehme, 2010). These designs are based on the design parameters that are available in the cellular design classifications which are associated with single unit sizes and shapes of the lattice structures, or also known as topological design. These topological designs can be classified into bending dominated or stretch dominated in which often associated with having greater relative strength. Bending dominated structure is suitable to be utilized in an energy absorbing application (Rehme, 2010). Some of the famous topological designs that have been studied so far are body-centred-cubic (BCC) or octahedral, two-faced body-centred-cubic (F2BCC), tetrahedral, pyramidal, octet-truss, diamond, gyroid and many more (Deshpande et al., 2001b; Ushijima et al., 2010a; Hammetter, 2013; Suard, 2015; Al-Saedi et al., 2018). These topological designs will be further discussed in the next Chapter 2.

There were many researches that have been done to identify the characteristics and mechanical properties of various types of lattice structures which were predominantly associated with additive manufacturing methods and processes such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Stereolitography (SLA) and Fused Deposition Modeling (FDM) (Rehme, 2010). It was reported that the FDM 3D printing technique provides high speed printing with low cost of manufacturing. Materials available by this technique are thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), thermoplastic polyurethane (TPU) and many more. Due to higher strength produced, ABS is one of the frequently used materials in production of parts by using the FDM (Teixera and Santini, 2005; Skelly, 2008; Tang et al., 2008; Sukwisute et al., 2017).

However, the relationship between manufacturing properties with ABS material's load-bearing behavior which is produced by using the 3D printer has not yet been fully understood especially when dealing with pre-set parameter combinations, as available in CubePro machine (3D Systems Inc, 2014). Hence, this study is carried out to focus in details on the effects of FDM pre-set manufacturing parameter toward the properties of the produced ABS lattice structure material. This study aims to come out with concrete relationships of properties-strength for the lattice structure material, based on experimental analysis. The scientifically proven properties-strength relationships can become a strong foundation for the FDM 3D-printed lattice-structure material to be categorized as one of a reliable future lightweight material, with the advantages of easy reproducibility and user friendly.

1.2 Problem statement

Fabrications of lattice structure from numerous types of materials are able to be done by utilizing various additive manufacturing methods such as SLM, SLS, EBM and FDM. From literature, it is found that not many studies have reported about the investigation on lattice structure by non-metallic material, especially the ABS polymer. The use of ABS polymer to produce lattice structure material serves as an added value for lightweight applications due to the lightweight characteristics of the ABS itself. FDM 3D printed process of lattice structure are rarely reported in previous studies, hence it is hard to confidently understand the behaviour of produced lattice structure by using combinations of FDM parameters. On top of that, there are limited information provided regarding the relationships between the pre-set parameters of CubePro's mid-range FDM printed lattice structure with its mechanical properties. This is the loophole in this increasingly used additive layer manufacturing, in which the mechanical properties of its produced material can be greatly affected by relatively small changes in parameters combination. Thus, this study investigates the details of these properties-strength relationships of CubePro FDM 3D-printed ABS lattice-structure material.

1.3 Objectives

The objectives of this study are as follows:

i. To identify lattice structure geometry that can be produced from FDM 3D printer.
ii. To evaluate the effect of layer thickness, print strength and print pattern of mid-range FDM 3D printer on the geometry of ABS polymer lattice-structure material.
iii. To obtain relation formulation between mechanical properties of FDM 3D printed ABS lattice structure material with its geometry by using experimental approach and to justify the material as lightweight material.

1.4 Scopes of work

In this research, a mid-range FDM machine, the CubePro 3D printer machine was utilized to fabricate the BCC lattice structure cube specimens with specific dimension of 20 x 20 x 20 mm3. The pre-set parameter settings which are layer thickness, print strength and print pattern from the CubePro 3D printer machine were used to print all of lattice-structure specimens. The test parameters used in this study are limited to the pre-set parameter settings of the FDM printer machine as mentioned earlier. The lattice-structure specimens were designed with strut's diameter sizes of 1.2 mm, 1.4 mm and 1.6 mm. Characterizations of the printed lattice-structure cube specimens were performed by using optical microscopy as