PRINTING LARGE 3D OBJECTS WITH INTERLOCKING PART DESIGN

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Manufacturing Design) (Hons.)

by

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I hereby, declared this report entitled "Printing Large 3D Objects with Interlocking Part Design" is the result of my own research except as cited in references.

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Date : 17^{th} June 2017

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Engineering Design) (Hons). The members of the supervisory committee are as follow:

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(Dr Zulkeflee Bin Abdullah)

ABSTRAK

Projek ini memberi tumpuan kepada tiga reka bentuk yang saling berbeza iaitu “hinges”, “planar” dan “snap fit” untuk menentukan reka bentuk yang optimum untuk mencetak objek besar. Setiap reka bentuk dibuat untuk berhimpun bersama-sama untuk membentuk kiub saiz berbentuk berongga lebih kurang 200mm x 200mm x 200mm. Ini kerana pencetak 3D tidak dapat mencetak objek yang lebih besar daripada pencetak “working volume”, maka objek yang besar perlu dibahagikan dahulu dan kemudian “assembled” untuk membentuk objek besar. Dalam usaha untuk menentukan reka bentuk saling optimum, “finite element analysis” dilakukan untuk menentukan sama ada reka bentuk akan gagal di bawah tekanan yang tertentu. Tekanan 1MPa, 2MPa, 3MPa, 4MPa, 5MPa, 6MPa dan 7MPa digunakan dibahagian badan reka bentuk. Keputusan diperoleh dengan menggunakan “Structural Analysis” dari perisian ANSYS. Diantara keputusan yang dianalisis dari “Structural Analysis” ANSYS ialah “total deformation”, “equivalent stress”, dan “safety factor”. Keputusan di antara tiga reka bentuk “interlock” iaitu “hinges”, “planar” dan “snap fit” akan dibandingkan untuk menentukan reka bentuk yang optimum untuk mencetak objek besar. Bahan yang digunakan dalam projek ini adalah bahan Acrylonitrile Butadiene Styrene (ABS). Setiap reka bentuk akan dicetak menggunakan UP-PLUS 2 mesin. Kesimpulannya dari keputusan FEA, “snap fit” merupakan reka bentuk yang optimum untuk mencetak objek besar. Ini kerana, reka bentuk “snap fit” boleh menahan tekanan maksimum tertinggi iaitu 6MPa jika dibandingkan dengan reka bentuk “hinges” yang hanya boleh menahan 1MPa tekanan dan reka bentuk “planar” yang hanya boleh menahan 3MPa tekanan.

ABSTRACT

This project is focused on three different interlocking designs of hinges, planar and snap fit in order to determine the optimum interlocking design to print large 3D object. Each design is made to be assembled together to form a hollow cube shaped size of approximately 200mm x 200mm x 200mm. Since the 3D printer are unable to print large object than its working volume, the large objects needs to be partitioned first and then assembled in order to form the large objects. In order to determine the optimum interlocking design, finite element analysis is done to determine whether the design will fail under certain applied pressure. In this project pressure of 1MPa, 2MPa, 3MPa, 4MPa, 5MPa, 6MPa, and 7MPa are applied to the body part of interlocking design. Hence by using Structural Analysis from ANSYS software, the result of the Finite Element Analysis of each interlocking design can be obtained. The results analysed from the Structural Analysis are total deformation, equivalent stress and safety factor. Thus, the result between the three interlocking design of hinges, planar and snap fit are compared to determine the optimum interlocking design to print large object. The material used for this project is the Acrylonitrile Butadiene Styrene (ABS) material. Each of the interlocking design is fabricated by UP-PLUS 2 machine. From the result, it is concluded that the snap fit interlocking design is the optimum design to print large objects. This is because, the snap fit interlocking design can withstand the highest maximum pressure applied of 6MPa to be compared with hinges interlocking design that could only withstand 1MPa of pressure applied and planar interlocking design that could only withstand 3MPa of pressure applied.

DEDICATION

Dedicated to those who care for others

This report is dedicated

To my beloved parents

Zulkfili Bin Mohamad

and

Zaleha Binti Sulaiman

Who educated me and enabled me to reach at this level

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In the name of Allah S.W.T, the most gracious and the most merciful, thanks a lot for giving me this strength and opportunity to complete this report. In completing this final year project, I would like to thank Dr Zulkeflee Bin Abdullah as my official supervisor, Dr. Shajahan and Dr Rosidah as my FYP panels and other lecturers and technicians who have significantly helped directly and indirectly in completing this project. I would also like to extend my appreciation to my peer friends who have helped me by giving me moral support and exchanging ideas and knowledge in completing this project.

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
A&D	-	Aerospace and Defense
AM	-	Additive Manufacturing
ABS	-	Acrylonitrile Butadiene Styrene
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
CGS	-	Computational Geometric Solutions
FDM	-	Fused Deposition Modeling
FEA	-	Finite Element Analysis
LOM	-	Laminated Object Manufacturing
mm	-	Milimetre
MPa	-	Mega Pascal
SGC	-	Solid Ground Curing
SLA	-	Stereolitography
SLS	-	Selective Laser Sintering
UV	-	Ultraviolet

CHAPTER 1

INTRODUCTION

This chapter provides the general ideas of the research study, which provides four main sections, started with the background of research study and continued with the problem statement. The significance of this research study will also be briefly explained through this chapter. Furthermore, the objectives of this research study are also stated in this chapter.

1.1 Background

Fabrication technologies are a prevalent resource for rapid prototyping and industrial production processes. Nowadays, the most commercial 3D printing system is based on the additive process, whereby the shape is made by setting down progressive layers of material to create a 3D object (Alemanno, Cignoni, Pietroni, Ponchio, & Scopigno, 2014). Additive manufacturing (AM) is the process of joining materials usually layer upon layer from 3D model data in contrary to traditional manufacturing techniques, which is a subtractive method such as turning, milling and machining (EPMA, 2013).

Additionally, AM is also known as 3D printing, additive fabrication, and freeform fabrication. The general steps in AM are creating a 3D model by computer aided design (CAD) software such as Solidworks or Catia. Then, the 3D model is converted into STL.

After that, it is built automatically by AM technology after the parameter of the machine is set. AM and traditional manufacturing has distinct differences as each of them has their own advantageous and disadvantageous capabilities in manufacturing. AM are able to give the industry design flexibility, reduce the materials and energy usage, as well speed up the time to market the product (European Powder Metallurgy Association, 2013).

AM technology cooperate easy and fast fabrication of 3D object, including the complex shape. The prevalence interest in additive techniques advanced rapidly with its vast spectrum of applications as it can be used as visualization and end used product. AM provides ample of key benefit, firstly AM offers geometrical freedom, especially in design complexity, parts consolidation, parts customisation, and multiple assemblies. Secondly, is the AM ability for multiple material combinations (Hague *et al.,* 2003).

However, there are still some limitations to this technology, which is due to a limited workspace, the produced objects are usually very small. Generally, the workspace of a common 3D printer is between 20 and 40 cm size cube. This limitation restricts the usage of printing technique to the reproduction of only small objects (Alemanno *et al.,* 2014). Therefore, an interlocking part design is purposed in order to enable the printing of large 3D objects.

1.2 Problem Statement

One peculiar drawback of AM is that the inability to create a single large object that exceeds the build volume of AM machine. Normally, this is constrained by the build volume AM machine, whose measurement of print high is generally around 5 to 10 inches for most AM machine (Song & Deng, 2016). Therefore, rather than using connectors, glue, or screw, it is proposed to partition the large objects into parts and then assembled the parts together to form a large 3D objects. Moreover, although the glue is strong adhesive that can join the printed assembled object together, the connection between the parts is permanent thus it cannot be reassembled and it is not cost effective (Song, Fu, Liu, & Fu, 2015).

There a many advantages of the interlocking design besides that it can be assembled and reassembled. First and foremost, the interlocking design expedites cost-effective maintenance, as rather than reprinting the entire object only the broken part of the object is replaced. Next, since the large 3D object can be disassembled, it is good for storage purpose as it can save space and also for transport as it can avoid breaking during transportation. Moreover, certain interlocking design parts connections can be attained by its own 3D geometry without needing the small connectors to join the part. Furthermore, the interlocking design is known to be strong. Lastly, similar to Lego bricks, the design of the objects can be reconfigure as it facilitates the assembled and reassembled benefits (Song *et al.,* 2015).

1.3 Objective

The objectives are as follows:

a) To design three different interlocking design of a cube that exceeds the working volume of the UP - PLUS machine
b) To compare which interlocking design is the most optimum design through Finite Element Analysis (FEA)
c) To fabricate the interlocking design part by using the UP-PLUS machine

1.4 Scope of project

The scopes of research are as follows:

a) Design the three different interlocking design of a given object without considering computational geometric solutions (CGS). In this project, the goal is to partition a given 3D object into interlocking parts for 3D printing and the 3D object assembly. The design of the interlocking design is based on the free geometrical approach without considering other part partitioned software such as Blender software and without considering the interlocking design that used the CGS approach such as the voxelization method.

b) Design the three different interlocking design of a given object without considering the 3D printing issues such as object appearance, warping and stringing. The object appearance is not considered in this project as only the design of the three different interlocking designs is essential to analyze the optimum interlocking design to print large object via AM through Finite Element Analysis (FEA).

c) The results for the most optimum design via FEA and experimental study is only valid for the Acrylonitrile Butadiene Styrene (ABS) material. All three different interlocking designs will be printed by using the ABS material.

1.5 Summary of Chapter 1

In conclusion, this chapter explains the background of AM and its distinctive difficulty in printing single large volume objects due to the limitation of 3D printer printing volume. Hence the proposal of interlocking part design in order to enable the assembly of large volume part through 3D printing. Besides that, the objectives and scopes of the project is also explained in this chapter, whereby the three different design of interlocking part object follows the shape of a cube which exceeds the volume printer of UP-PLUS machine without using any computational geometric solutions (CGS). Moreover, to compare which interlocking design is the most optimum design without considering any 3D printing issues through Finite Element Analysis (FEA). Lastly to print the interlocking parts by using UP-Plus machine with ABS material, hence the results of FEA analysis on the interlocking part is only valid for the ABS material.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Additive Manufacturing

ASTM standard F2792-10 defined AM as a process of joining materials together, usually layer upon layer in order to create 3D model from STL data which is in contrary to traditional manufacturing techniques, that imply subtraction and forming (EPMA, 2013). Plus, there is an increasing number of AM processes available and each process is limited to only one type of material and only a few are able to integrate more than one material together (Klahn, Leutenecker, & Meboldt, 2015)

2.1.1 History

AM was originated and inspired by the Rapid Prototyping era and it has advanced greatly in recent years. The AM technique has been developed for the past 4 decade, though the pioneer of AM application goes back to the 1800s in topography and photosculpture in the 1900s. The very first 3D printing technology is the Stereolithography (SLA) which was developed in 1987 by 3D Systems. SLA is an AM method that uses the laser to solidify thin layers of ultraviolet (UV) light sensitive polymer. SLA was firstly used to visualize the prototype, then it was implemented as end used part in a functioning system due to the advanced performance of AM machine (Campbell *et al.* 2007).

SLA-1 is the first AM commercialized system in the world which was then followed by the SLA 250 machines. Then, the SLA 250 machines were replaced by the Viper SLA product from 3D Systems. After that, in 1991, three AM technologies were marketed. Stratasys marketed the fused deposition modeling (FDM), while the Cubital marketed the solid ground curing (SGC), and Helisys marketed the laminated object manufacturing (LOM). The FDM technologies produces parts by extruding thermoplastic materials in filament layers by layer. While, SGC solidifies a full layers in one pass using UV sensitive liquid polymer. Lastly, LOM used digitally guided laser to bond and cut sheet material. Then, according to Wohlers Report 2014, in 1992 the selective laser sintering (SLS) has been developed. SLS fuse powder materials by using the heat from the laser (Wohlers & Gornet, 2014). Figure 2.1 shows the AM timeline for the past 40 years.

2.2 Classification of Additive Manufacturing

AM processes can be classified into seven areas, according to the ASTM F42 Committee as shown in Table 2.1.

Table 2.1: The Seven AM Process Categories by ASTM F42 (European Powder Metallurgy Association, 2013)

Process Type	Brief Description	Related Technologies	Companies	Materials
Powder Bed Fusion	Thermal energy selectively fuses regions of a powder bed	Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)	EOS (Germany), 3D Systems (US), Arcam (Sweden)	Metals, Polymers
Directed Energy Deposition	Focused thermal energy is used to fuse materials by melting as the material is being deposited	Laser metal deposition (LMD)	Optomec (US), POM (US)	Metals
Material Extrusion	Material is selectively dispensed through a	Fused deposition modeling (FDM)	Stratasys (Israel), Bits from Bytes	Polymers

	nozzle or orifice		(UK)	
Vat Photopolymerization	Liquid photopolymer in a vat is selectively cured by light-activated polymerization	Stereolithography (SLA), digital light processing (DLP)	3D Systems (US), Envisiontec (Germany)	Photopolymers
Binder Jetting	A liquid bonding agent is selectively deposited to join powder materials	Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)	3D Systems (US), ExOne (US)	Polymers, Foundry Sand, Metals
Material Jetting	Droplets of build material are selectively deposited	Multi-jet modeling (MJM)	Objet (Israel), 3D Systems (US)	Polymers, Waxes
Sheet Lamination	Sheets of material are bonded to form an object	Laminated object manufacturing (LOM), ultrasonic consolidation (UC)	Fabrisonic (US), Mcor (Ireland)	Paper, Metals

The powder bed fusion process was developed from the selective laser sintering (SLS) process. While, directed energy deposition is a technique that is usually used in metal material and vat polymerization is used for polymers that can be loaded with ceramic powders. Next, material extrusion with the fused deposition modelling (FDM) technology is a technique where material is deposited from a nozzle and forming an object layer by layer. Furthermore, the binder jetting method was developed in 1990s where it deposits a thin layer of powder onto a build platform. Moreover, material jetting has great challenges, such as getting materials to flow through nozzles without clogging at reasonable speeds. Lastly, sheet lamination method used for plastics and paper that has now been adapted for ceramic tapes (Shulman & Hoag, 2016).

2.3 Technology of Additive Manufacturing

There are three main technologies used in AM which are Stereolitography (SLA), Selective Laser Sintering (SLS) and Fused Deposition Modelling (FDM).

2.3.1 Stereolitography (SLA)

Stereolithography (SLA) process was developed by Charles (Chuck) W. Hull by 3D Systems in Valencia, California, USA in 1986. SLA process was the first rapid prototyping process during the 1980's and continues to be the most widely used technology. SLA is one of the AM techniques that create solid objects by printing thin layers of a UV curable material one on top of the other. SLA process can produce highly accurate and detailed polymer part. Figure 2.1 shows the illustration of SLA process.

as

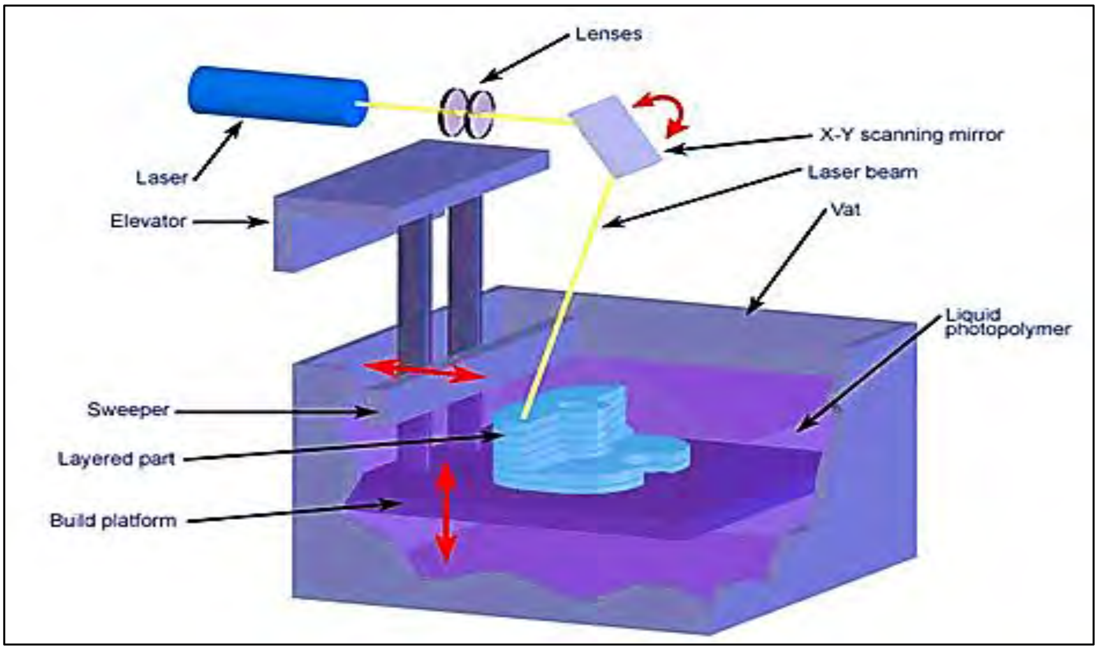

Figure 2.1: Illustration of Stereolitography process (CustomPartnet, 2008)

The SLA method works by curing the cross-sections of 3D parts by a highly UV laser beam in a liquid batch photo reactive resin. Then as the laser traces the layer, the polymer will solidifies and the rest are left as liquid. After that, a resin-filled blade will sweep across the cross section of the part. Then, the SLA's elevator platform will move down bit by bit to recoat it with new material. The distance is equal to the thickness of a single layer of 0.05mm. Until the build is complete, the process of tracing and smoothing is repeated and is kept fully submerged in the tank. Once the part is completed, the platform is then raised above the vat and drained thus exposing the three-dimensional object. Finally, the part is immersed in a chemical bath of liquid solvent in order to be cleaned of excess resin and is subsequently cured (CustomPartnet, 2008). Figure 2.2 a) shows the examples of prototype made with SLA process and b) shows the examples of prototypes made with SLS

 

a) b)

Figure 2.2: a) Examples of prototypes made with SLA (Protorapid, 2016), b) Examples of prototypes made with SLS (Rapidsol, 2016)

2.3.2 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is patented in 1989 at the University of Texas. SLS was originally sold by DTM Corporation, which was then acquired by 3D System in 2001. The SLS method works by feeding powder into a continuous layer with layer thickness typically 0.020mm. Both thermoplastics and metal can be used in SLS process. Figure 2.3 shows the illustration of SLS process. Since SLS parts constructed is surrounded by unsintered powder at all times it does not require support structures such as SLA. Moreover, SLS is able to produce functional parts as shown in Figure 2.2 b)