

**ANALYSIS OF STIFFNESS AND STRENGTH OF A COMPLEX TOPOLOGY
OPTIMIZED THERMOPLASTIC PART DESIGNED FOR 3D PRINTING**

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**A thesis submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled “Analysis of Stiffness And Strength Of A Complex Topology Optimized Thermoplastic Part Designed For 3d Printing” 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.

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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 the degree of Bachelor of Mechanical Engineering.

Signature :

Supervisor's Name : Dr. Faiz Redza bin Ramli

Date :

DEDICATION

To my beloved mother,
Siti Zaimah binti Mat Salleh,
and
my late father,
Ishak bin Paimin.

ABSTRACT

The analysis of stiffness and strength of a complex topology optimized part designed for 3D printing is a new method to design product beyond a certain level of complexity. The complex part chosen was an engine load bracket which have four load cases applied to it. Topology optimization is a method that used to solve design problems which conventional manufacturing process have constraint during design stage to ensure feasible design. The purpose of this study is to develop an optimized engine load bracket by complying all the requirements assigned. In order to produce a optimized product, many areas need to be studied and analysed such as the material properties, strength, weight, 3d printing fabrication and design improvement. This project carried out all of the necessary background research required to sustain the design requirements. Finite element analysis was used to simulate the conditions of various load applied. This project selects two types of topology optimization method I with design control II without design control to optimized engine load bracket. The result shows two different geometries after topology optimization was applied. The design result shows different geometry, strength, and weight reduced after topology optimized. The results were compared to original model to analyse the strength after topology optimized was applied. The fabrication of the optimized parts is analysed to have the minimum material usage when printing. 3D printing used support for parts with overhanging geometry, the design improvement after topology optimized is to avoid overhanging geometry of the product. The findings suggest that improvement of the bracket will leads to lower material usage of material and time consumption to fabricate the parts with 3D printing technologies. The parameter findings also related to final design of engine load bracket and fabrication with 3D printing. The final design of engine load bracket with using topology optimization method has potential for future developments and manufacturing. During the development and fabrication of the engine load bracket, some areas for improvement were recognized and future recommendations were suggested.

ABSTRAK

Analisis kekukuhan dan kekuatan bagi pengoptimuman topologi kompleks yang direkabentuk untuk percetakan 3D adalah kaedah baru bagi menghasilkan produk di tahap kerumitan yang lebih kompleks. Produk kompleks yang dipilih adalah enjin beban pendakap yang mempunyai empat kes bebanan di dikenakan pada produk tersebut. Pengoptimuman topologi adalah satu kaedah yang digunakan untuk menyelesaikan masalah reka bentuk di mana proses pembuatan konvensional mempunyai kekangan pada peringkat reka bentuk dan penghasilan. Tujuan kajian ini adalah untuk menghasilkan produk yang optimum dengan mematuhi semua penanda aras yang diberikan. Untuk menghasilkan produk yang paling optimum, banyak perkara yang perlu dikaji dan analisis seperti sifat bahan, kekuatan, berat, cara percetakan 3D dan juga penambahbaikan reka bentuk. Projek ini dijalankan untuk semua kajian latar belakang yang diperlukan untuk mengekalkan keperluan reka bentuk. Analisis kekuatan reka bentuk digunakan untuk membuat simulasi keadaan beban yang dikenakan. Projek ini memilih dua jenis kaedah pengoptimuman topologi I dengan kawalan reka bentuk II tanpa kawalan reka bentuk untuk produk yang dioptimumkan. Hasil menunjukkan dua geometri berbeza selepas pengoptimuman iaitu selepas konsep topologi digunapakai. Hasil reka bentuk menunjukkan geometri, kekuatan dan berat yang dikurangkan adalah berbeza bagi kedua-dua kaedah tersebut. Hasil pengoptimuman dibandingkan dengan model asal untuk menganalisis kekuatan setelah pengoptimuman dilakukan. Percetakan 3D memerlukan sokongan semasa penghasilan produk. Penambahbaikan reka bentuk selepas topologi yang dioptimumkan adalah untuk mengelakkan geometri yang mengganggu produk semasa penghasilan. Penemuan menunjukkan bahawa penggunaan sokongan akan membawa kepada penggunaan bahan yang berlebihan. Reka bentuk terakhir produk dengan menggunakan kaedah pengoptimuman topologi mempunyai potensi untuk perkembangan masa depan dan pembuatan. Semasa penghasilan dan fabrikasi produk, terdapat ruang untuk penambahbaikan dan saranan untuk dicadangkan pada masa hadapan.

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TABLE OF CONTENTS

PAGE	
DECLARATION	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF APPENDICES	xii
LIST OF ABBREVIATIONS	xiii
LIST OF PUBLICATIONS	xiv
CHAPTER	
1. INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement	2
1.3 Objective	2
1.4 Scope	3
2. LITERATURE STUDY	4
2.1 Rapid Prototyping	4
2.1.1 Introduction of Rapid Prototyping	4
2.1.2 Principle of 3D Printing	5
2.1.3 Type of Rapid Prototyping	6
2.2 Fused Deposition Modelling (FDM)	6
2.2.1 Introduction of Fused Deposition Modelling (FDM)	6
2.2.2 Process of FDM	7
2.2.3 Material of FDM	8
2.2.4 Properties of ABS and PLA	9
2.3 Jet Engine Loading Bracket (ELB)	10
2.3.1 Introduction of GE Jet Engine Bracket Challenge	10
2.3.2 Jet Engine Loading Bracket (ELB) Specification	10
2.4 Topology Optimization	11
2.4.1 Introduction of Optimization	12
2.4.2 Types of Structural Optimization	13
2.4.3 Topology Optimization Method	14
2.5 Topology Optimization on Rapid Prototyping	16
2.5.1 3D Printing Splice Software	17
2.5.2 3D Printing Machine	18
2.6 Topology Optimization Tools (Software)	19
2.6.1 Introduction and Comparison of Optimization Tools	19
2.6.2 SolidThinking Inspire	21
2.7 Computer Aided Design (CAD)	21
2.7.1 Introduction of CAD	21

3.	METHODOLOGY	23
3.1	Introduction	23
3.2	Flow process for PSM	23
3.2.1	Flow process for PSM I	24
3.2.2	Flow process for PSM II	25
3.3	Description of Methodology	26
3.3.1	Project Proposal	26
3.3.2	Project Planning	26
3.3.3	Literature Study	26
3.3.4	Analysis	27
3.3.5	Topology Optimization Setup	28
3.3.6	Fabrication model with 3D printing	29
3.3.7	Compare Analysis Data	30
3.3.8	Report Writing	30
3.4	Finite Element Analysis Setup	30
3.4.1	Applying the material	31
3.4.2	Adding load case and support	32
3.4.3	Analysis setup	33
3.5	Topology Optimization Setup	34
3.5.1	Design space and non-design space	34
3.5.2	Optimization Features	34
3.6	Fabrication of Engine Load Bracket	35
3.6.1	Parameter of 3D printing	35
3.6.1.1	Quality Parameter	37
3.6.1.2	Fill	37
3.6.1.3	Speed and Temperature	38
3.6.1.4	Support	38
3.6.2	Fabrication at CreateBot	39
3.7	Summary	40
4.	RESULT AND DISCUSSION	41
4.1	Introduction	41
4.2	Engine Load Bracket Original Data	42
4.2.1	Initial Data Obtained for Original ELB	42
4.3	Initial Setup for Topology Optimization	43
4.3.1	Applying Type of Partition And Type Of Body Contact	43
4.3.2	Applying Load Cases for Load Condition	44
4.3.3	Shape Control of Topology Optimization	45
4.4	Topology Optimization Result by Mass Reduction Without Shape Control	46
4.4.1	Data of topology optimization mass reduction without shape control	46
4.4.2	Comparison of Topology Optimization Data Without Shape Control	48
4.5	Topology Optimization Result by Mass Reduction with Shape Control	50
4.5.1	Data of Topology Optimization Mass Reduction with Shape Control	50
4.5.2	Comparison of Topology Optimization Mass Reduction with Shape Control	51

4.5.3	Analysis of Critical Point That Exceed the Yield Strength	53
4.6	Design Result of Topology Optimization	54
4.6.1	Design Result of Engine Load Engine Bracket Without Shape Control	55
4.6.2	Design Result of Engine Load Engine Bracket with Shape Control	56
4.6.3	Comparison of Original Design and After Design Topology Optimization	57
4.7	Result of ELB From Creatware Splicer Software	59
4.7.1	Result of Creatware Splicer Software with Design Shape Control	59
4.7.2	Result of Creatware Splicer Software without Design Shape Control	60
4.8	Design Improvement of Topology Optimization Model	60
4.8.1	Data Result of Improvement Engine Load Bracket	62
4.8.2	Comparison Data of Improvement Engine Load Bracket	62
4.8.3	Result Improvement of ELB with CreatWare Splicer Software	65
4.9	Data of Elb From Creatware Splicer Software	65
4.10	3D Printing Result of Topology Optimization ELB	67
4.10.1	3D printing of Topology Optimization ELB with Shape Control	67
4.10.2	3D Printing of Improvement Topology Optimization ELB Without Shape Control	68
4.11	ELB Topology Optimization Comparison with Other Studies	69
4.11.1	3D Printing Comparison of the Engine Load Bracket	70
4.11.2	Von Misses Stress and Safety of Factor Comparison to Engine Load bracket	71
5.	CONCLUSION AND RECOMMENDATION	
5.1	Conclusion	73
5.2	Recommendations	75
	REFERENCES	77
	APPENDICES	80

LIST OF TABLES

FIGURE	TITLE	PAGE
2.1	Comparison Properties of PLA and ABS	9
2.2	The Characteristic of Jet Engine Bracket	11
2.3	Parameter in 3D printer splice software (www.CreatBot.com)	18
3.1	Quality parameter for 3d printing	37
3.2	Fill Parameter for 3D Printing	37
3.3	Speed and Temperature Parameter for 3D Printing	38
3.4	Support Parameter for 3D Printing	38
4.1	Properties data gathered from FEA of ELB	42
4.2	Data gathered from FEA of ELB	43
4.3	Data for 40% topology optimization mass reduction without shape control	47
4.4	Data for 50% topology optimization mass reduction without shape control	47
4.5	Data for 60% topology optimization mass reduction without shape control	47
4.6	Data for 40% topology optimization mass reduction with shape control	55
4.7	Data for 50% topology optimization mass reduction with shape control	51
4.8	Data for 60% topology optimization mass reduction with shape control	51
4.9	Data of von misses and safety of factor for design ELB without shape control	55
4.10	Data of von misses and safety of factor for design ELB with shape control	57
4.11	Data of von misses and safety of factor for improvement design	62
4.12	Data of mass reduction after improvement	64

4.13	Data gathered from CreateWare software of ELB	66
4.14	Comparison of von misses' stress and safety of factor for current studies and previous studies	72
5.1	Table of comparison topology optimization software (H.D Morgan et.al, 2014)	76

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Aircraft engine bracket	2
2.1	Example of product print by 3D printing (www.enablingthefuture.org)	5
2.2	Example of 3D printing machine (www.tested.com)	6
2.3	Type of Rapid Prototyping processes (Wong and Hernandez 2012)	6
2.4	The principle of FDM (Mohamed, Masood, and Bhowmik 2015)	7
2.5	Example of ABS and PLA material in spool (3dprintingforbeginners.com)	8
2.6	The Load Condition to The Engine Bracket	10
2.7	Example of Structural Optimization with manufacturing constraint (Doubrovski, 2011)	12
2.8	Figure shows sizing, shape and topology optimization (artistinunta.com)	13
2.9	SIMP approach to volume constraint (Bruns 2005)	15
2.10	Flow chart of BESO algorithm (Cazacu and Grama 2014)	16
2.11	Logo of CreatWare software for splicer (www.creatbot.com)	17
2.12	CreatBot DX 3D printer (www.3dprintmegastore.com)	19
2.13	The comparison between commercial topology optimization tools (Ferguson 2015)	20
2.14	The comparison between commercial educational tools (Ferguson 2015)	20
2.15	SolidThinking Inspire logo	21
2.16	Autodesk Fusion 360	22
3.1	Methodology flow chart for PSM 1	24
3.2	Methodology flow chart for PSM 2	25
3.3	Example of model undergoing finite element analysis FEA (http://www.rjlewisdesign.co.uk)	28
3.4	Flow Chart to get Topology Optimization of ELB	29

3.5	Adding material in Solid thinking Inspire	31
3.6	(a) 4 load cases applied to ELB. (b) support for ELB. (c) Properties table for load cases	32
3.7	Analysis setup	33
3.8	Design space and non-design space	34
3.9	Optimization Features	35
3.10	Interface of parameter input for Createware software	36
3.11	CreatBot screen to print the model	39
4.1	Initial analysis of original ELB	42
4.2	(a) Partition for Load Engine Bracket and (b) Type of body contact	44
4.3	Load cases apply to engine load bracket	44
4.4	Engine load bracket (a) without applied shape control (b) applied shape control	45
4.5	(a) 40% mass reduction (b) 50% mass reduction (c) 60% mass reduction without shape control	46
4.6	(a) 40% mass reduction (b) 50% mass reduction (c) 60% mass reduction with shape control	46
4.7	Graph comparison of von misses' stress for mass reduction ELB without shape control	49
4.8	Graph comparison of safety of factor for mass reduction ELB without shape control	49
4.9	Graph comparison of von misses' stress for mass reduction ELB with shape control	52
4.10	Graph comparison of safety of factor for mass reduction ELB with shape control	53
4.11	Critical point of 60% mass reduction at load case 1 with shape control	54
4.12	ELB without shape control (a) Iso (b) Top view (c) Back view (d) Side view	55
4.13	ELB with shape control (a) Iso (b) Top view (c) Back view (d) Side view	56
4.14	Von misses' comparison between before and after topology optimization is applied	58

4.15	Von misses' comparison between before and after topology optimization is applied	58
4.16	Support used to fabricate ELB without shape control in blue colour	59
4.17	Support used to fabricate ELB without shape control in blue colour	60
4.18	Improvement design of engine load bracket	61
4.19	H-beam improvement to engine load bracket	61
4.20	Comparison of von misses' stress after improvement	62
4.21	Comparison of safety of factor after improvement	63
4.22	Improvement design without support in createware splicer software	65
4.23	Data gathered from CreatWare Splice Software (a) Original ELB (b) ELB with design space (c) ELB without design space before improvement (d) ELB without design space after improvement	66
4.24	3D printing of ELB with shape control (a) Iso View (b) Top View (c) Back View (d) Side View	68
4.25	3D printing of improvement ELB without shape control (a) Iso View (b) Top View (c) Front View (d) Side View	69
4.26	Support need to construct the ELB (Hector U Levatti, 2014)	70
4.27	ELB Comparison of (a) Previous Studies (Hector U Levatti, 2014) (b) Current studies	71
4.28	Von misses stress and safety of factor ELB (Hector U Levatti, 2014)	71
4.29	Comparison of von misses' stress between current studies and previous studies	72
5.1	Chemical and Mechanical Specification of Arcam Titanium 6Al-4V (www.mansys.com)	75

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt Chart PSM I	80
B	Gantt Chart PSM II	81
C	2D Drawing Original Engine Load bracket	82
D	2D Drawing Final Topology Optimization Engine Load Bracket	
E	Process 3D Printing with CreatBot DX	83
F	Process 3D Printing without Using Support	84

LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
RP	-	Rapid Prototyping
CAD	-	Computer Aided Design
3D	-	Three Dimension
FDM	-	Fused Deposition Modelling
SLM	-	Selective Laser Sintering
BJ	-	Binder Jetting
SLA	-	Stereolithography
DLP	-	Digital Light Processing
GE	-	General Electric
ELB	-	Engine Load Bracket
TI	-	Titanium
SIMP	-	Solid Isotropic Material with Penalization
ESO	-	Evolutionary Structural Optimization
FEA	-	Finite Element Analysis
BESO	-	Bi -directional Evolutionary Structural Optimization
AESO	-	Additive Evolutionary Structural
NC	-	Numerical Control
STL	-	Standard Tessellation Language
FOS	-	Safety of Factor
STP	-	Standard Exchange for The Product

LIST OF SYMBOLS

In	-	inch
D, d	-	Diameter
F	-	Force
N	-	Newton
%	-	Percent
m	-	Mass
Kg	-	Kilograms
g	-	Grams
mm	-	millimetres
l	-	Length
Gpa	-	Gigapascal
Mpa	-	Megapascal

CHAPTER 1

INTRODUCTION

1.1 Background of Study

We are now currently moving forward in advanced technology for manufacturing process which is called additive manufacturing (AM). 3D printing or additive manufacturing (AM) which also called as rapid prototyping (RP) is a process to make three dimensional objects from a digital file. 3D printing is used to make a product prototype for product development before mass produce the final product.

3D printing widely been used to make product prototype due to the efficient of the additive manufacturing process rather than conventional process such as casting, injection moulding or machining which requires longer time and higher cost to make product prototypes. However, as speed, material properties, and affordability improve, we observe a trend towards production of end products using additive manufacturing. (Wohler T, 2010).

3D printing requires to design and converted it into 3D Computer aided design (CAD) software and the data is then converted into 3D printing technologies. 3D printing machine will slice the data into thousands of cross sections. These cross-section perimeters are traced either by a laser, electron beam, extrusion nozzle or jetting nozzle and the area contained by the perimeters filled with a hatching pattern (D. Brackett, 2011). Additive manufacturing is a process by layering, each layer is based from virtual cross -section from the CAD data. Layer by layer are automatically are build it up to make the final product. Generally, there are several types of 3D printer technologies that have been used widely such as fused deposition modelling (FDM), selective laser sintering (SLM), binder jetting (BJ), selective laser melting (SLM), stereolithography (SLA), digital light processing (DLP) and so on.

Topology optimization is a method that used to solve design problems which conventional manufacturing process such as casting and have significant constraint during design stage to ensure feasible design. The former manufacturing process used optimal topology to ease manufacturing but not all constraints can be included easily in the optimization process.

The purpose of topology optimization is to have minimum material usage within a specified region. This is achieved by minimizing (or maximizing) a property of the structure, subject to constraints and boundary conditions. The design domain is discretized into finite elements, and one of a number of optimization techniques are used to determine which elements should contain material and which should be voids (Ian Ferguson, 2015).

1.2 Problem Statement

In this project, optimizing the stiffness and strength of an existing aircraft engine bracket from “GE jet engine bracket challenge” as shown in Figure 1.1. This bracket contains 5 interfaces and has 4 loads applied to it, which are 3 static loads and 1 torsional load as shown in Figure 1.2. Aircraft engine brackets play a critical role by supporting the weight of the engine and staying on the engine at all times even during flight. However, this bracket was designed by conventional manufacturing technologies and not fully optimized for its stiffness, strength, and weight.

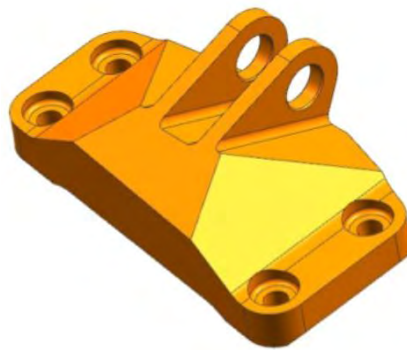


Figure 1.1: Aircraft Engine Bracket

1.3 Objective

Objectives of the project are as follows:

1. To improve the design and structure of the aircraft engine bracket by using Solid Thinking Inspire software.
2. To reduce the weight of the aircraft engine bracket by using topology optimization method.
3. To obtain the prototype of the aircraft engine bracket after topology optimization by using a 3D printer.

1.4 Scope

Scope of the project are as follows:

1. Solid Thinking Inspire will be used to create topology optimization on aircraft engine bracket.
2. Analysis of the new aircraft engine bracket stiffness and strength will be used Solid Thinking Inspire
3. The weight reduces of aircraft engine bracket at least by 40% of original mass
4. The optimization for the whole project is by using Fused Deposition Modelling (FDM) 3D printing.
5. The minimum material usage when printing the prototype of aircraft engine bracket.

CHAPTER 2

LITERATURE STUDY

2.1 Rapid Prototyping

2.1.1 Introduction of Rapid Prototyping

3D printing or also known as rapid prototyping is future of the manufacturing process. Rapid prototyping (RP) is a technology that have been developed in the 1980's in the United States. During the 1990's RP was mainly used to create prototypes, today its applications have gone beyond simple visualization (Rodrigo 2012). Rapid prototyping is usually used for produced model or a prototype parts due to it can produce or print a complex shape part. Today, rapid prototyping can be used for a lot of application rather than produce a prototype.

Reasons 3D printing will become the future of manufacturing technology is due to the ability of RP to produce solid object with high-complexity functional products, rapid prototyping can create almost any shape or geometric features. Manufacturing industries have predicted that 3D printing is going to be industrial revolution of manufacturing process.

Rapid prototyping (RP) machine has emerged as a key enabling technology, with its ability to shorten product design and development time. RP techniques can also be used to make tooling and even production of quality parts. For run small production runs and complicated objects, rapid prototyping is the best manufacturing process available. Today's additive technologies offer a lot of advantages if compared to traditional manufacturing process which is subtractive fabrication methods such as milling, lathe or turning.

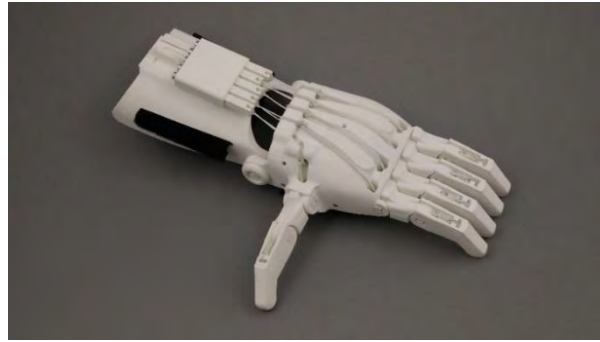


Figure 2.1: Example of Product Print By 3D Printing (www.enablingthefuture.org)

2.1.2 Principle of 3D Printing

Rapid prototyping is an additive manufacturing process that create 3D object from Computer Aided Design data. Computer aided design (CAD) file need to be converted to a stereolithography (STL) file. In this process, the drawing made in the CAD software is approximated by triangles and sliced containing the information of each layer that is going to be printed (Wong and Hernandez 2012).

The information from the STL file are transfer to 3D printing machine and the digital data creates 3D model by adding material from layer by layer. The layers of liquid, powder or sheet material builds up and the model are joined together or fused automatically to create the final shape of the product. The time for completing the final product are depends on the size and complexity of the object. 3D printing allowed to modify the parameter of the printing object You can customize various aspects of the design such as the layer thickness, temperature, and outer finish, etc(Soliman, Feibus, and Baum 2015).

Some additive manufacturing techniques can use multiple materials to construct parts. They can also use multiple colour combinations simultaneously. In case there are projecting parts in the model, supports are used like scaffolding until the overhanging part sufficiently hardens. These supports can be dissolved in water when the model is printed.

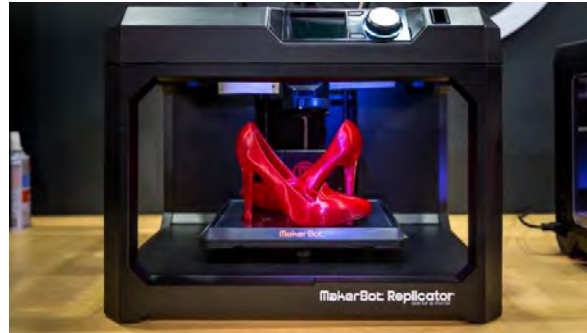


Figure 2.2: Example of 3D Printing Machine (www.tested.com)

2.1.3 Type of Rapid Prototyping

Rapid prototyping can be divided into 3 main section which is Liquid based, Solid based and Powder based. The difference between this 3 is the method of the process. Each method has their unique and advantages, using the correct method for the project of 3D printing could save such as cost, time, and materials. Figure 2.3 below shows the list of additive manufacturing separated by their based and type.

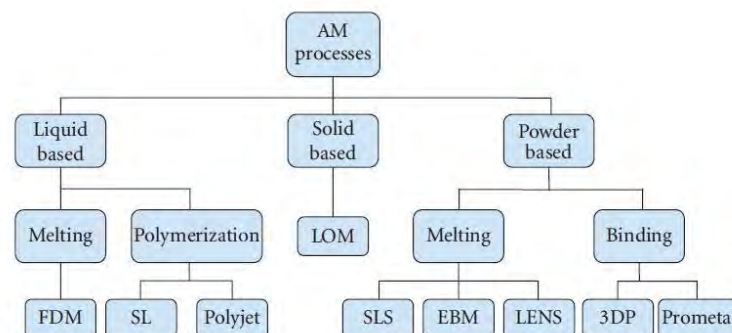


Figure 2.3: Types of Rapid Prototyping Processes (Wong and Hernandez 2012)

2.2 Fused Deposition Modelling (FDM)

2.2.1 Introduction of Fused Deposition Modelling (FDM)

3D printing is affecting daily life in various ways, so do engineer. Engineer will only know the solid physical of CAD design will look until they hold in their hand. It is the only