# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# INVESTIGATION OF OPTIMUM PARAMETERS OF FDM RAPID TOOLING PATTERN FOR SAND CASTING

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

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# ABSTRAK

Tajuk projek ini adalah penyiasatan parameter optimum "FDM Rapid Tooling" corak untuk proses petuangan pasir. Penuangan pasir adalah proses pembuatan utama dalam industri pada masa kini. Kaedah konvensional yang menghasilkan corak penuangan pasir menyebabkan kehilangan kepercayaan pelanggan di dalam pandangan ekonomi. Hal ini demikian kerana kaedah konvensional mempunyai kesukaran untuk menghasilkan bahagian yang kompleks dan rumit sama ada kayu atau corak logam. Selain itu, kaedah ini memerlukan masa pembuatan yang lama dan juga kos pembuatan yang tinggi. Tambahan pula, kualiti acuan penuangan pasir merupakan kebimbangan utama bagi aktiviti penuangan pasir. Reka bentuk acuan yang tidak sesuai untuk penuangan pasir akan menjejaskan kualiti produk. Oleh itu, kaedah konvensional telah digantikan oleh "Fused Deposition Modeling" (FDM). FDM adalah salah satu proses "Additive Manufacturing" yang menghasilkan corak penuangan pasir dengan cepat and secara ekonomi. Di samping itu, sistem gating memainkan peranan penting untuk menghasilkan kualiti produk yang baik. Sistem gating akan dianalisis supaya reka bentuk acuan penuangan pasir yang optimum dapat dihasilkan. Oleh itu, tiga konsep reka bentuk acuan penuangan pasir akan direka bentuk menggunakan perisian SolidWorks dan dianalisis dengan perisian ANSYS berdasarkan tetapan yang telah ditetapkan. Berdasarkan keputusan analisis, reka bentuk acuan yang terbaik akan dipilih and digunakan dalam proses penuangan pasir. Tujuan proses tuangan pasir dijalankan untuk mengesahkan hasil dapatan kajian.

# ABSTRACT

This project investigates optimum parameters of FDM rapid tooling pattern for sand casting. Sand Casting is a major manufacturing process in manufacturing industries today. However, conventional method of producing sand casting pattern may cause customer to lose faith in the economic view. This is due to conventional manufacturing method has difficulty of producing complex and intricate part either in wood or metal pattern. Hence, it causes longer lead time and also higher production cost. Moreover, casting quality is a main concern for sand casting activities. Inappropriate sand casting mould design will lead to casting defects and more rejection numbers of product. Therefore, conventional manufacturing method of producing sand casting pattern is replaced by Fused Deposition Modeling (FDM). FDM is one of additive manufacturing processes that enable fast, flexible and coat-efficient production of sand casting pattern. Moreover, gating system plays an important role to produce high casting quality. Hence, gating system is analysed in order to obtain optimum design of sand casting mould. Three concept designs are developed using SolidWorks software. In order to select the best design concept, ANSYS software has been chosen to stimulate sand casting mould. Lastly, sand casting process is carried out to validate the results of findings.

## DEDICATION

Dedicated to my beloved parents

Dearest siblings

Honourable lecturers

Loyal friends

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# LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

| | | |
|---|---|---|
| ABS | - | Acrylonitrile Butadiene Styrene |
| AM | - | Additive Manufacturing |
| ASTM | - | American Standard of Testing of Material |
| CAD | - | Computer Aided Design |
| CNC | - | Computer Numerical Control |
| EBM | - | Electron Beam Melting |
| FDM | - | Fused Deposition Modeling |
| LENS | - | Laminated Engineered Net Shaping |
| LOM | - | Laminated Object Manufacturing |
| PC | - | Polycarbonate |
| RP | - | Rapid Prototyping |
| RT | - | Rapid Tooling |
| SL | - | Stereolithography |
| SLS | - | Selective Laser Sintering |

# CHAPTER 1
# INTRODUCTION

## 1.1 Introduction of Project

This project investigates the optimum parameters of Fused Deposition Modeling (FDM) rapid tooling pattern for sand casting. Gating system design for sand casting mould is the main criterion to produce good casting quality. Therefore, design parameters of sand casting were analysed in order to reduce casting defect. Next, Desktop FDM 3D printer was used to manufacture sand casting pattern of hand wheel. This is due to conventional method has difficulty of producing complex and intricate part either in wood or metal patterns. Last but not least, sand casting process were carried out to validate the result of findings. The limitation of this project was the pattern size of sand cast product. The design of sand cast pattern was limited by the size of sand casting mould.

There were a total of six chapters in this project. The first chapter covers the introduction, problem statement, aims, objectives and scope of this project. Meanwhile, chapter two consists of literature review. This chapter provides reviews from previous researches that were related to this project such as additive manufacturing, sand casting and simulation software. In chapter three, it was all about the methodology of the project. The methodology describes the methods used to conduct and execute the project. Chapter four and five were result and discussion. The last chapter was conclusion and recommendations. In chapter five, the whole project was summarized and concluded. Recommendation was made on the strategy to improve the casting quality.

## 1.2 Problem Statement

Sand casting is an important manufacturing process in industries today. It is an economic method for mass production of complex metal products. However, conventional method of manufacturing sand casting pattern cannot meet the customer satisfaction. This is due to conventional method has difficulty of producing complex and intricate part either in wood or metal patterns. There are limitations for wood and metal patterns. Wood pattern fails to produce thin part while metal pattern fails to produce weird shape and contours parts (Pranjal et al., 2013).

Moreover, conventional manufacturing time of sand casting pattern is long. In today's market of intense competition, longer lead time may cause customer to lose faith in the economic view. In addition, the tooling cost of conventional manufacturing method for sand casting is high. It is not suitable in manufacturing small quantity production (Baligidad et al., 2014). Hence, rapid tooling is applied to produce sand casting pattern. It is believed that the application of rapid tooling is able minimize the lead time and cost in manufactured of sand casting pattern.

Next, casting quality becomes a famous issue in manufacturing industries. This is because casting quality is one of the main factors that affect production cost. According to Iqbal et al. (2014), design plays an important role to produce a good quality casting product. There are a few researches reported that mainly 90% of the casting defects came from inappropriate design of gating system. Wrong gating system will cause the surface roughness and shrinkage cavity happened in the sand casting. Meanwhile, Taufik et al. (2014) stated that "current practices on designing casting mould is based on trial and error method. It is solely depends on the engineer's experience and knowledge." Undoubtedly, this method consumes more manufacturing time and cost. Hence, CAD design and simulation software are developed to optimize the casting quality.

## 1.3 Aims

The aims of this project is to investigate the optimum parameters of FDM rapid tooling pattern for sand casting.

## 1.4 Objectives

The objectives of the project are:

a) To investigate the optimum design of gating system to minimize casting defect.
b) To produce a FDM rapid tooling pattern of hand wheel for sand casting.
c) To validate results of the findings.

## 1.5 Scope

First of all, the hand wheel was chosen as the sand casting pattern. This is because hand wheel is a common sand casting product and it has encountered casting defects such as surface roughness and shrinkage cavity (Rajkolhe et al., 2014). Next, hand wheel pattern and gating system were designed by 3D Computer-aided design (CAD) design software, which was known as SolidWorks. Meanwhile, ANSYS software was chosen to analyse these design concepts. The optimum design was selected by using ranking process. Next, the pattern and selected gating system were then produced by using UP Plus 2 3D Printer. Then, sand casting process was carried out to validate the result of finding. Two important parameters namely the surface roughness and dimension were used for validation process. On the other hand, hand wheel pattern size was restricted by the mould size (21 cm × 15cm × 10cm). Hence, the size of hand wheel pattern was designed to fit within the sand casting mould.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Chapter Overview

This chapter describes the literature review on investigation of optimum parameters of FDM rapid tooling pattern for sand casting. Secondary sources such as books, journals and online researches were used to get related information regarding the project. This chapter would provide a preliminary insight regarding the additive manufacturing (AM), Fused Deposition Modeling (FDM), sand casting and ANSYS simulation software.

### 2.2 Additive Manufacturing (AM)

The word of additive manufacturing (AM) is derived from rapid prototyping (RP). AM has been studied and grown up for more than 30 years. AM has vast applications such as developing prototypes for product development process, manufacturing functional and end-use parts for other applications (Zhang et al., 2014). According to Nagnath et al. (2012), "additive manufacturing is the use of additive fabrication technology like rapid prototyping (RP) to produce useable products or parts." Additive manufacturing is also known by other names such as rapid manufacturing, direct fabrication and direct digital manufacturing. Meanwhile, Achillas et al. (2014) defines that AM is an advanced technology where products are designed by computer-aided design (CAD) software and then developed by thin layers of materials. Hence, AM has no boundaries on design and its manufacturability.

### 2.2.1 Prototype

Prototype is an early product built for concept realization in design, production and analysis. Prototyping is one of the most essential parts for product development and production cycle to evaluate the shape, size and performance of a design. Meanwhile, rapid prototyping is usually uses additive manufacturing technologies to produce a prototype for difference usages such as functional models, fit and assembly, pattern for prototypes tooling and etc. According to Villalpando et al. (2014), additive manufacturing (AM) processes are practiced to develop three-dimensional (3D) computer-aided design (CAD) models. Villalpando et al. (2014) described that “a solid model or water-tight surface model is used as the input, which is sliced into layer, and travel paths are created for each layer. The object is built by layer by layer stacking, with supporting structures for overhanging geometry and undercuts being created where necessary (process dependent)”.

Prototype is important for communication and testing purposes. This is due to three-dimensional object is easier to understand than two-dimensional drawings. Hence, communication is conducted easily by the help of prototype. Prototype plays a main role in concurrent engineering. With the help of prototype, manufacturing department can start production planning and followed by packaging planning. For testing purpose, engineer can analysis the prototype to determine whether it achieves the desired outcome or needs improvement (Deepika et al., 2013).

### 2.2.2 Rapid Prototyping (RP)

Rapid prototyping (RP) is one of the earlier additive manufacturing processes. According to Gibson et al. (2010), rapid prototyping (RP) is defined as “a process for rapidly developing a system or product before launching into the market”. Meanwhile, Nagnath et al. (2012) defines that RP is a technique to develop three dimensional models without involvement of machine and tool. Moreover, RP develops product by adding material layer by layer, in contrast of machining the shapes by removing materials. From view of management consultants and software engineers, RP is one of methods to develop business and software solutions. RP tests the ideas and provides feedback to customers. RP is an advanced technology which develops physical prototype directly from CAD data (Gibson et al., 2010). It creates layer by layer models by using computer-aided design (CAD). RP helps realization of product that engineers have in mind. Not only the models, it is also allows for the creation of printed parts.

With the help of RP, engineer can rapidly build and analyse models for the sake of studies. For example, doctors can develop a model of damaged body to analyse it, market researchers can analyse on the prototype based on customer requirements. RP helps user easily to explore their ideas (Wong et al., 2012). Therefore, RP reduces product development time by developing prototype that is directly applied in assemblies, product testing and tooling (Anitha et al., 2001). Figure 2.1 shows product development process by using rapid prototyping technique.

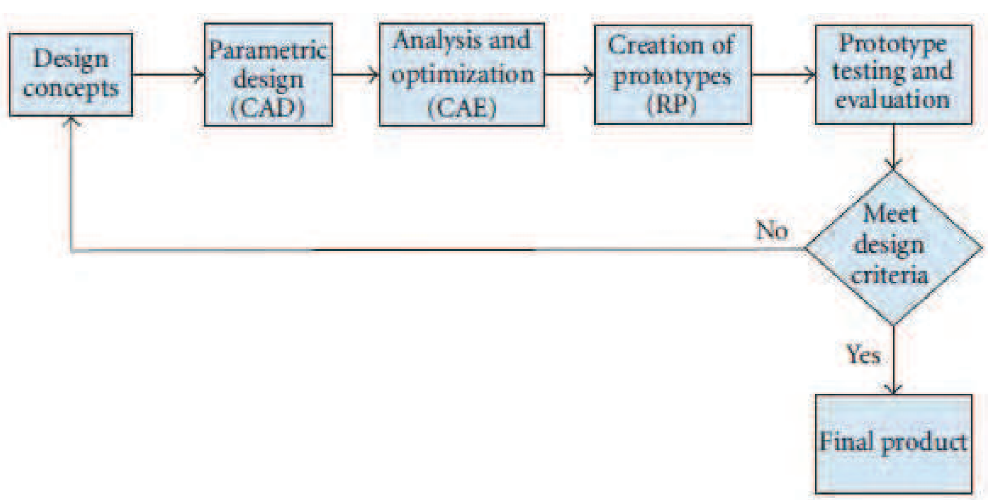


Figure 2.1: Product development cycle (Wong et al, 2012)

### 2.2.3 Rapid Tooling

Tooling is a slow and expensive manufacturing process which it produces high quality of machine tool. Most of the tools have high complex geometries together and its dimension accuracy within hundredth of millimetre. Besides, machine tool is hard, wear-resistant and low surface roughness. Conventional methods such as CNC-machining and electro-discharge machining are used to produce machine tools. However, these methods consume high cost and time wasting. Recently, prototyping techniques are applied to reduce cost and time consumption. Rapid Tooling is an automatic fabrication way to produce machine tools (Deepika et al., 2013). Peter Hilton, president of Technology Strategy Consulting in Concors, MA, believes that tooling costs and product development times can be decreased by more than 75 percents with the aid of rapid tooling and related technologies.

Rapid tooling is categorised into two classes, which are indirect tooling and direct tooling (Deepika et al., 2013). Indirect tooling is defined as usage of additive manufacturing (AM) pattern which produced by AM techniques in mould and die making model. For example, AM patterns are used for sand casting, vacuum casting, investment casting and injection moulding. Direct tooling is an intermediate replication process for tool production. It is directly produce hard tooling from CAD data. Hence, this method reduces accuracy and increases building time.

### 2.2.4 Additive Manufacturing Processes

Figure 2.2 shows an overview of additive manufacturing (AM) processes. AM process is classified into three categories, which are molten based, solid based and powder based. Liquid based process is related to melting and polymerization while powder based process is about melting and binding. There are total of nine processes involved in additive manufacturing, such as fused deposition modelling (FDM), stereolithography (SL), polyjet, laminated object manufacturing (LOM), selective laser sintering (SLS), electron beam melting (EBM), laminated engineered net shaping (LENS), 3D printing (3DP) and Prometal (Wong et al., 2012).

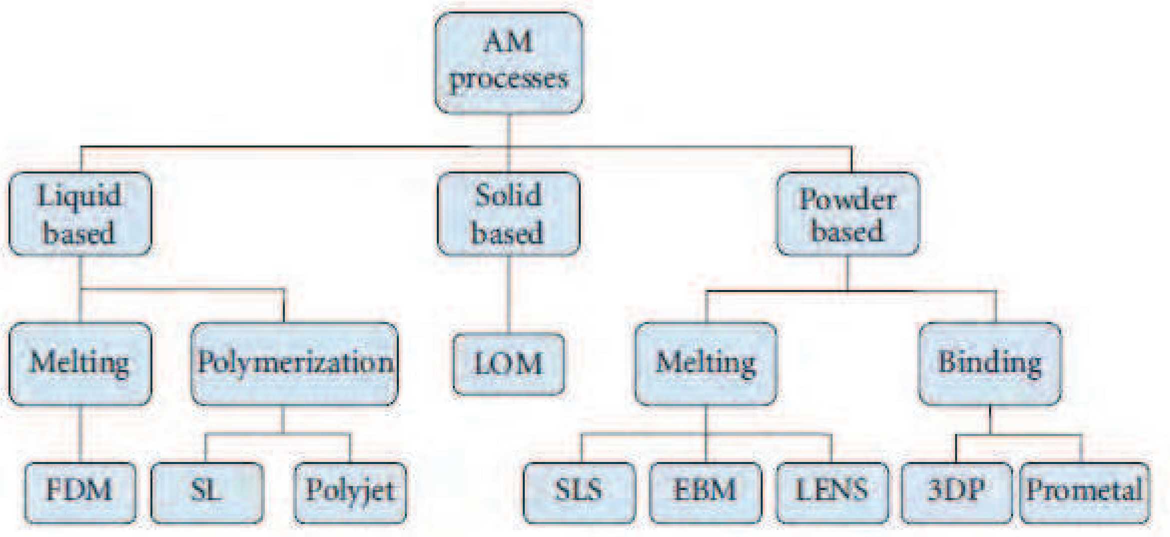


Figure 2.2: Three-dimensional printing processes (Wong et al, 2012)

### 2.2.5 Advantages and Disadvantages of AM

Benefits of using AM are this method is able to produce functional parts with high added value. This is a “clean” process as AM uses exact material quantity to develop functional products (Florent et al., 2014). Besides, AM is able to manufacture model within a short period of time. User can rapidly build the model. According to Gibson et al. (2010), building time for conventional machine depends on the features of design. If the design contains more features, the numbers of building steps are increased together with building time. Compared to conventional machining, the building step for AM machine is one. According to Florent et al. (2014), he states that functional part can be produced directly from one manufacturing step. Besides, AM is able to build complex design of model which is difficult to be done in machining. Gibson et al. (2010) states that AM can remove or simplify multi-stage processes. AM is capable to produce a big range of parts with different characteristics. Moreover, AM reduces tooling cost as there is no tool required for AM process (Wong et al, 2012). The number of manpower is reduced because AM is an automated process. There is no need for workers to develop a prototypes based on CAD drawing. Hand carving and moulding technology are challenging and easy to cause mistake (Gibson et al., 2010).

Disadvantages of using AM are limitation of material selection. There are only selected materials available for AM machine. For example, ABS and nylon are the only materials used for FDM. Meanwhile, the materials suitable for SLS are thermoplastics and metals. For EBM process, high strength alloys, titanium and stainless steel are the suitable materials. Lastly, photo reactive resin is the only material used for SLA. In addition, the size of prototype is limited for AM process as it is depend on the machine size. AM process is unable to build a big size of product.

### 2.2.6 Fused Deposition Modelling (FDM)

Fused deposition modelling (FDM) is an additive manufacturing process that forms a model from thin layers of extruded filaments. According to Villapando et al. (2014), "mechanical properties of FDM part are influenced by different factors like deposition orientation of materials, flow rate of filament, separation of rasters and extrusion temperatures". In FDM, a plastic filament is unwound from a coil and it provides material to an extrusion nozzle which moves over the table in the required geometry and deposits a thin bead of extruded plastic to form each layer of the desirable geometry (Pranjal et al., 2013). According to Hitesh et al. (2014), FDM is also referred as a rapid prototyping (RP) process that integrates computer aided design (CAD), polymer science, computer numerical control (CNC), and extrusion technologies to develop the three dimensional solid objects directly from a CAD model using a layer by layer deposition or molten thermoplastics extruded through a very tiny nozzle. FDM is able to use different materials such as metals and composites in order to produce solid objects. FDM systems, recently manufacture parts in ABS (P400), investment casting wax (ICW044) and polyamide plastic (P301). Figure 2.3 shows process of fused deposition modelling.

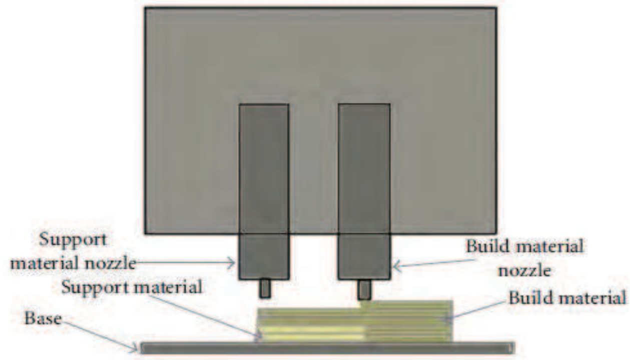


Figure 2.3: Fused deposition modelling (Wong et al, 2012)

### 2.2.6.1 Materials Used in FDM

ABSplus material is suitable to be used for all FDM machines. Acrylonitrile butadiene styrene (ABS) is the earliest material used in FDM machine. Later in technology improvement, ABSi material is created for translucent effect. While some ABS mixed with polycarbonate for another function. Table 2.1 below shows the variation in properties for the ABS range of FDM materials (Gibson et al., 2010).

Table 2.1: Variation in properties for the ABS range of FDM materials (compiled from Stratasys data sheets)

| **Property** | **ABS** | **ABSi** | **ABSplus** | **ABS/PC** |
|---|---|---|---|---|
| Tensile Strength (MPa) | 22 | 37 | 36 | 34.8 |
| Tensile modulus (MPa) | 1627 | 1915 | 2265 | 1827 |
| Elongation (%) | 6 | 3.1 | 4 | 4.3 |
| Flexural strength (MPa) | 41 | 61 | 58 | 50 |
| Flexural modulus (MPa) | 1834 | 1820 | 2198 | 1863 |
| IZOD impact($J/m^2$) | 106.78 | 101.4 | 96 | 123 |
| Heat deflection @ 66psi (°C) | 90 | 87 | 96 | 110 |
| Heat deflection @ 264psi (°C) | 76 | 73 | 82 | 96 |
| Thermal expansio2n (in/in/F) | 5.60E-05 | 6.7E-6 | 4.90E-05 | 4.10E-5 |
| Specific gravity | 1.05 | 1.08 | 1.04 | 1.2 |

#### 2.2.6.2 Advantages and Disadvantages of FDM

Advantages of FDM process are no chemical post-processing required and resins to cure. Besides, FDM has low cost process compared to other additive manufactured processes. Next, disadvantages of FDM are the resolution on the z axis is low in FDM compared to other additive manufacturing processes. If a smooth surface is required, the processing process becomes slow. Besides, it takes days to develop large and complex part (Wong et al., 2012).

## 2.3 Sand Casting

Casting is a process of producing desired parts by pouring metal or alloy which is in liquid form into a prepared mould. Then, the liquid in the mould is allowed to cool and solidify to form pieces of metal or alloy. This process is called as sand casting. The modern casting industries demand a less defect and dimensional accuracy of product. Therefore, it is important for them to produce components with good properties and good accuracy (Khirsariya et al., 2014).

A moulding flask has a two piece moulds. The upper part is called cope and bottom part is called drag. The parting line is the seam between two piece moulds. Meanwhile, pattern is the duplication of casting part. The pattern is used to mould the sand mixture into the shape of casting. Sand is compacted around the pattern. Then, mould cavity is produced by removing the pattern. The mould cavity will be used to make a casting pattern. A pattern is usually made of wood, plastic and metal. There are few criteria of selecting suitable material for casting pattern which are size, shape, dimensional accuracy, number of castings and moulding process. The strength and durability of material are important criteria as it needs to withstand repetition usage of pattern. In addition, patterns are coated with parting agent for easy removal (Singh, 2012).