ABSTRACT

Prototyping is used to demonstrate aspects of design. Basically, personnel in charge in protoyping simply convert a virtual design into a physical design. There are several prototyping method which are mock-ups, fabrication and rapid prototyping. Rapid prototyping is a highly beneficial technique as this technique can save cost and time up to 90%, and one of the rapid prototyping technique is vacuum casting. The project with entitled Vacuum Casting: A Pipe Reducer Prototype is about exploring vacuum casting technique, fabricating a pipe reducer prototype and analyzing the surface roughness of the prototype by comparing with master pattern. The project development starts with fabricate a silicone rubber mould which referenced to be master pattern. Then, a prototype was fabricated by using the silicone rubber mould. Surface roughness measurement was taken for both master pattern and prototype to be analyzed. Tools that were used to analyze the data are One-way ANOVA and MS Excel 2010. Based on the findings, it showed that vacuum casting product has lower surface roughness compared to fused deposition modelling. Eventhough there was slighltly variants in collected data, the difference is insignificant as the value is lower that 0.05%, according to One-way ANOVA analysis. In conclusion, the student manages to achieve the objectives which are exploring vacuum casting process, fabricating a protoype and runninng surface roughness analysis.

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ABSTRAK

Protototaip digunakan untuk menunjukkan aspek reka bentuk. Umumnya, individu yang ditugaskan di dalam prototaip akan menukarkan reka bentuk visual kepada rekabentuk fizikal. Terdapat beberapa kaedah di dalam membentuk prototaip, iaitu olok-olok, fabrikasi dan prototaip pantas. Prototaip pantas merupakan teknik yang amat berguna kerana kos dan masa dapat dijimatkan sehingga mencapai 90% dan salah satu contoh prototaip pantas ialah pemutus vakum. Projek yang bertajuk Vacuum Casting: A Pipe Reducer Prototype adalah mengenai pendedahan teknik pemutus vakum, memfabrikasi prototaip pengecil paip and menganalisis permukaan kasar prototaip dengan membandingkan dengan paten induk. Pembangunan projek bermula dengan memfabrikasi pencetak getah silikon dengan menggunakan paten induk sebagai panduan. Kemudian sebuah prototaip difabrikasi dengan menggunakan pencetak getah silikon. Kiraan kekasaran permukaan diambil untuk kedua-dua paten induk dan prototaip yang akan dianalisis. Alatan yang digunakan untuk menganalisis data ialah One-way ANOVA dan MS Excel 2010. Berdasarkan penemuan, ia menunjukkan produk pemutus vakum mencapai kekasaran permukaan yang rendah apabila dibandingkan dengan permodelan pengeluaran fius. Walaupun terdapat banyak perbezaan di dalam data yang dikumpul, perbezaan tersebut tidak memberi impak kerana nilai yang lebih rendah berbanding 0.5% menurut, One-way ANOVA analisis. Secara kesimpulan, pelajar berjaya mencapai objektif-objektif iaitu pendedahan proses pemutus vakum, fabrikasi sebuah prototype dan menjalankan analisis kekasaran permukaan.

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DEDICATION

With honest, special thanks dedicated to my beloved parents, fellow friends and lecturers and also to every single person who has provide the opportunities with all your love, patience and understanding.
All your blessing will be granted.

Thank you.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

3-D	-	Three Dimension
3- DP	-	Three Dimensional Printing
ABS	-	Acrylonitrile butadiene styrene
ANOVA	-	Analysis of Variance
C	-	Carbon
CAD	-	Computer Aided Design
Cl	-	Chlorine
CMM	-	Coordinated – Measuring Machine
CNC	-	Computer Numerical Control
FDM	-	Fused Deposition Modelling
g	-	Gram
H	-	Hydrogen
HCl	-	Hydrochloric acid
ISO	-	International Standard Organization
mm	-	micrometer
Ra	-	Average Roughness
RTV	-	Room Temperature Vulcanisation
RP	-	Rapid Prototyping
PP	-	Polypropylene
PPE	-	Personnel Protective Equipment
Pt	-	Platinum
SLA	-	Stereolithography
SLS	-	Selective Laser Sintering
(-O")	-	Alkoxide
µ	-	Micro
˚C	-	Celcius
Π	-	Pi bond

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<	-	Less than
>	-	More than

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CHAPTER 1

INTRODUCTION

This chapter will basically provide an overview to the viewer regarding with the entire research. This section consists of seven subchapters which are background, motivation, problem statement, objectives, and scope of work.

1.1 Background

The research is about fabricating a pipe reducer prototype as shown in Figure 1.1 by using rapid prototyping. The rapid prototyping technique that is used here is vacuum casting which currently can be considered as an emerging technique in the world.

Figure 1.1: A pipe reducer

Besides exploring vacuum casting technique as the technique is new, this research also includes a comparison of surface quality between pipe reducer master pattern and pipe reducer prototype by using One-way Analysis of Variance (ANOVA).

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1.1.1 Prototypes within Product Development

Basically a product will undergo development before fabrication. The product development system comprises of comprises of six generic phases which are concept development, design development, engineering development, validation development, manufacturing development and product development.

Among all, one of the most significant phases is design development, especially when designing a product that is related to physical human interface. Usually, it is a compulsory to develop a physical three-dimensional form- fit model compare with a virtual computer-based version. This is because initial physical modelling may ensure proper human interface conformance. The final design is produced by rapid prototyping.

Lim and Stolterman (2008) stated designers gradually learn, discover, create and refine design through prototypes. Having a prototypes leads to earlier problem identifications which is one helpful situation to the inventor as it is still feasible to redesign.

1.1.2 Rapid Prototyping

Rapid prototyping can be described as producing 3-D objects right away from a computer model, where material is deposited only when required (Additive Manufacturing: Pursuing a Promise, August 2012). This technique values for the intense returns that it offers on manufacturing. Such returns are design flexibility, higher energy efficiency and shorten time to market as well as reduction cost in prototyping development. It also aids to detect and correct flaw design at the early stage. Additive manufacturing is highly utilized in aerospace industry, automotive industry and military application before, but now this technique is becoming more commonplace in the governmental, academic institutions, consumer products and medical industries. Vacuum casting is a part of rapid prototyping.

1.1.3 Vacuum Casting

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Vacuum casting is broadly utilize technique in rapid prototyping industry, commonly applied for producing 20 and up to 40 pieces of functional prototypes made from various range of polymers. Initially, the process begins with creating an accurate and highly finished master model by using rapid prototyping technologies such as Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Stereolithography (SLA), Computer Numerical Control (CNC) or existing part. This model is well-positioned inside a mold box and liquid silicone rubber is poured over the master. After silicon is completely cured, the mould is separated in as split line established and master model is getting rid, leaving precisely formed cavities. This allows fast production of high quality parts in a short lead-time.

1.2 Motivation

The development of this project is to explore vacuum casting in order to enhance the knowledge and the technique as the technique currently is not widely applied by most of the industry.

Apart from vacuum casting, physical model also can be fabricated by CNC machining which is categorized as subtractive manufacturing. Subtractive manufacturing remove undesired materials to achieve desired form. CNC machining offers the most accurate prototyping process, however CNC machining deals greater design constraint, higher cost and longer lead time compare with vacuum casting. Handling CNC machining also need a highly-skilled programmer which may induce high labor cost.

1.3 Problem Statement

People can see that the world is currently getting more complex and more interconnected place than it was then in 1980s (Weck et al., n.d).Due to this complexity and time constraints, manufacturers discover a method in a way that it can produce intricate product in a shorter time. Interests in advance manufacturing

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technologies have risen up for the advantages that it offers compared with the conventional manufacturing. One factor that induces this changing is the urge to produce complex products in limited time. Using conventional method, multiplex products require a lot of time while the quality offered by those methods are not sublime. Besides the higher quality, rapid prototyping also reduces waste. In rapid prototyping, only required materials are deposited, which manages to cut off material needs and costs by up to 90% (Additive Manufacturing: Pursuing a Promise, August 2012). Despite of all those promising offers, people are still lack of its exposure. Through the development of pipe reducer prototype, a deepen knowledge and technique about vacuum casting can be acquired. In addition, the surface quality of pipe reducer prototype would be compared with pipe reducer master pattern as both of these products apply different advance manufacturing process.

1.4 Objectives

The main objective of this research is to explore rapid prototyping method, specifically vacuum casting process. The specific objectives are as follows:

a) To explore the vacuum casting technique.
b) To fabricate the pipe reducer prototype by using vacuum casting technique.
c) To evaluate the surface quality of pipe reducer prototype by comparing with master by using One-way ANOVA.

1.5 Scope of work

The scope of this research is to fabricate a prototype of pipe reducer from vacuum casting process. Special attention of this work is given to the mechanism occurred during the process such as polymerization, outgassing and curing. Figure 1.2 shows the scope of work. Surface quality of the prototype also be included in scope of work.

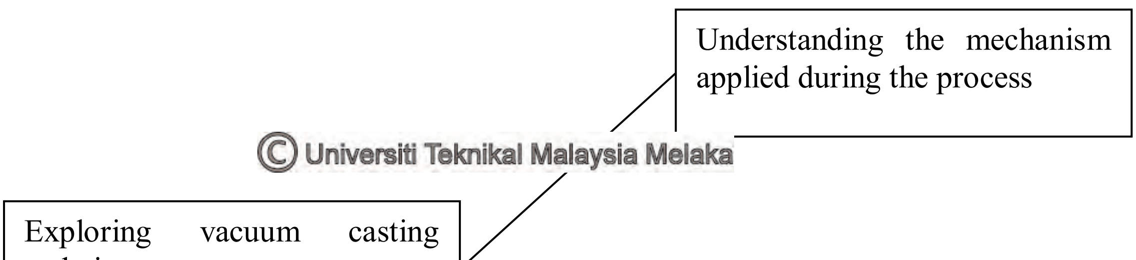

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Figure 1.2: Scope of work

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CHAPTER 2

LITERATURE REVIEW

As the current world market becomes more intensely competitive day by day, manufacturers keep looking for new solutions to adapt with the challenges. There are huge challenges encountered by those manufacturers, and one of them is reducing lead time for new product development without badly affecting its quality.

2.1 Prototype

Beaudouin-Lafon & Mackay (nd) defined a prototype as a concrete representation of part or all of an interactive system. The definition is varied according to the field it referred.

Lim *et.al* (2008) stated designers gradually learn, discover, create and refine design through prototypes.

2.2 Reverse Engineering

According to Raja (2013), reverse engineering is a process of precisely copying an existing part, subassembly or product without drawings, documentation, or a computer model.

Ali (2005) affirmed that reverse engineering is totally different form forward engineering, where Computer aided design (CAD) model is developed from an

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existing part, with the purpose of modification or reproduction to the design aspect of the product.

Meanwhile Sivarasu *et al.* (2010) described reverse engineering as a systematic process in gaining significant design factors and information regarding engineering aspect from an existing product, involving dismantling and disclosing the particular related method.

2.3 Advantages of Reverse Engineering

Reverse engineering is greatly beneficial for some reasons. Reverse engineering is applied when original design data is not readily available, either due to part vintage, legal restriction or trade secrecy. During research and development period, computer modeling is used by loading the data directly from 3D scanning, followed by digital prototyping through computer simulation. Manufacturers acquire the data from the existing part, thus the time required for research and development stage can be reduced (Chikofsky & Cross, 1990).

This advantage of computer modelling also supported and enhanced by Robinson (June, 1996) as he added computer models facilitate in lessening communication errors between design and manufacturing, undoing changes and storing the information. Pal et al (2005) enunciated modelling time can be closely removed by reverse engineering if the part already exists.

In addition, customer and manufacturer are able to communicate efficiently with a rapid turn-around prototypes to meet customer’s expectations. Besides that, prototyping cost significantly can be cut down by starting with an obsolete noncompliant model that is already existed as a base to generate the new model.

2.4 Steps in Reverse Engineering

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There are a few steps in reverse engineering as shown in Figure 2.1. The step basically and roughly illustrates the way data is obtained, transformed and generated. The first step in reverse engineering is digitizing the part, in which Coordinated-Measuring Machine (CMM) is employed to assemble the raw geometry of the project in the form of coordinate points of the objects (Liou, 2008).

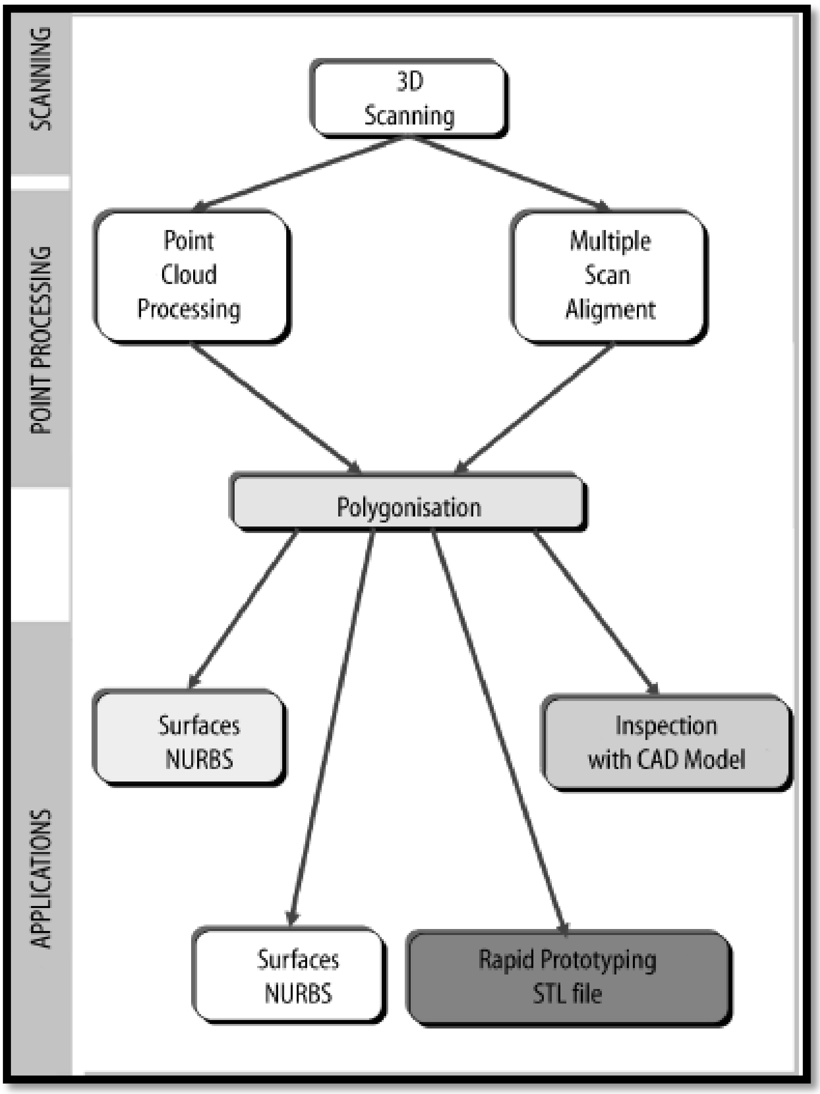

Figure 2.1: Reverse engineering- the generic process (Raja,nd)

Sokovic and Kopac (2005) classified digitizing technique in two groups, the mechanical technique and optical technique. The difference between both is mechanical technique involves with physical contact whilst none for optical technique. Less correction such as only few numbers of scanned points, boosting particular part of scanned sections, combining distinct scanned models, and wiping

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parts of the model so that a wide range of geometric can be achieve from the scanned data. Through a CAD- surface data, altered data are transmitted to model reconstruction system software and changed into a conceptual model (Sokovik et al., 2005).

Apart from that, Raja (2007) enlisted the accurate scanning technique which starts with preparing the part to be scanned and proceed with performing the actual scanning to record details that traces all geometric feature of the part such as steps, slot, pockets, and holes.

The next phase is point processing which involves transmitting the point cloud data, minimizing noise in the data collected and lessening the number of points. Multiple scan data can be combined to ensure that there are no required features are missed during scanning. Good datum planning for multiple scanning will cut the effort required in the point processing phase and also hinder introduction of errors from adjoining multiple scan data (Raja, 2007).

2.5 Definition of Rapid Prototyping

Liou (2008) reviewed rapid prototyping as a physical modelling of a design that is generated from a distinct machine technology, implicating adding and bonding materials in layers to form object.

Meanwhile Gibson (2005) defined rapid prototyping as a representation of technologies that allow the automated fabrication of physical objects instantaneously from virtual 3D CAD data without require any process planning that are relate with part feature and geometry.

Removing material from bar, sheet or rod stock until the right geometry is achieved is considered as subtractive manufacturing. In contrast with subtractive manufacturing, additive manufacturing utilizes less material and therefore minimum waste and manufacturing costs (Meissner, March 2012).

2.6 Advantages of Rapid Prototyping

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Rapid prototyping is a quick process since human effort is not required to run the machine. The process starts by pushing several buttons after completing a virtual model (Liou, 2008).

In an article entitled Additive Manufacturing: Pursuing the Promise (August 2012), the writer discussed additive manufacturing is not only applicable for various materials but also does not bear the cost, time, tooling and overhead as are consumed in the traditional machining. Materials such as metals, polymers, composites, or other powders are applicable to print variant of functional components, layer by layer, including intricate structures that are hardly to be manufactured by other means. Rapid prototyping offers new design flexibility, minimizing energy use with a promising 50% or greater energy saving, and shorten time to market.The applications of rapid prototyping are vastly implemented in defense, aerospace, healthcare industry, and automotive industry (Additive Manufacturing, August 2012).

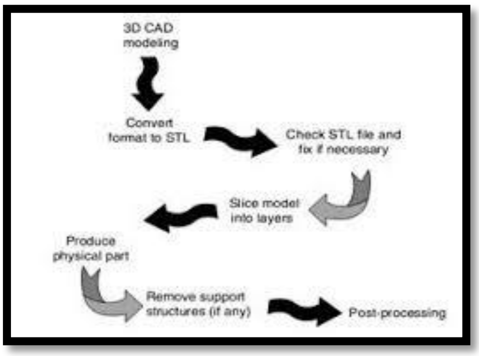

Figure 2.2.: The data flow of the basic rapid prototyping (RP) process (Liou, 2008).

2.7 Vacuum Casting

According to Radu and Fratila (2012), vacuum casting is a modern technique that allows the manufacturing of pieces in small batches and individual fabrication at

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minimum price and shorter time. This technique aids to build intricate prototype parts with similar form details and surface quality of the duplicate master model.

Gebhardt (2003) added that vacuum casting is able to offer an excellent quality of ingot without blow-holes, flaws or any other defect. Others state that vacuum casting is soft tooling method that replaces conventional method such as investment casting.

Meanwhile Mugan (2009) defines vacuum casting representing a method in which silicone molds are fabricated based on prototype and the mold is employed to form several similar parts. Prototype that is generated by this method is closely perfect production quality.

Denoual *et al.* (2004) describe that vacuum casting process composed of silicon female mould with an original part, followed by resin casting under vacuum to produce the duplicated parts.

Jijociya *et al.* (2013) enlisted vacuum casting system into two which embodies of vacuum chamber and heat chambers. Vacuum chamber enable for producing silicon rubber moulds and resin free of air bubbles formed during mixing. This system is significant in casting of resins, waxes and other plastics in silicon mould which formed in the initial step from rapid prototyping models. Vacuum chamber is equipped in driver which taking charges all processes such as pumping out air from chamber, mixing resin component, and unloading ready resin to mould.

Chua *et al.* (2010) regards vacuum casting as one of the most flexible form of rapid prototyping and tooling for consumer products. Besides it is simpler to be applied and inexpensive tools and materials, vacuum casting increases the potential of silicone rubber mould in the batch production of functional prototype.

Vacuum casting is a method that provides sublime properties to other casting methods which form limited run of parts (Chung et al., 2003). It is a method that offers good surface finish, void-free interior structure, and clarity or desired colour as well as close tolerance to a predetermined size (Chabra& Singh, 2011).

The close dimensional tolerance and void-free interior structure induce similar physical properties that can be expected from injection moulded thermoplastic shapes (Eyers&Dotchev, 2010). Eyers and Dotcher (2010) also claim that this technology offers higher consistency and faster processing at about thirty to forty minutes.

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2.7.1 Vacuum Casting Process

In term of process, vacuum casting begins with forming an accurate and highly finished master model. This master model is fabricated by utilizing rapid prototyping technologies like SLS, SLA, FDM, CNC or existing part. Next, the model is cautiously positioned in a mold box and liquid silicone rubber is poured over the master. Remove the master model once the item is cured by cutting the split line, prompting precisely formed cavities. The mould cavities are applicable for casting variant materials.

Various plastics and polymers can be used for casting, which will closely replicate the production material plastic such as Acrylonitrile butadiene styrene (ABS) and polypropylene (PP) materials. Mould pattern is fabricated through FDM, SLS, SLA or three dimensional printing (3 DP). The master is used in order to build mould for vacuum casting. Parameters that can impact vacuum casting quality are pressure difference and pressure time. Quality issues that are corresponding with vacuum casting are shrinkage mark, insufficient filling and gas pocket (Xu *et al.*, 2012).

The pressure difference occurs inside the vacuum chamber during the degassing stage before casting material flowing through. In the degassing process, the speed of liquid flowing down runner and the speed of the material mixture filling into the mould are determined by the speed of gas pressure without considering the action of gravity. Speed of filling of silicone mould cavity becomes faster as the speed of pressurized gas existing the chamber faster.

Pressure time is the other parameter that can affect prototype quality. The pressure time is proportional to the filling speed of the mould cavity. Thus, it is vital to observe the pressure time during the process in order to accomplish a high-quality casted prototype.

2.7.2 Vacuum Casting Mould

In rapid prototyping industry, silicone moulding or also known as Room Temperature Vulcanizing (RTV) is employed to produce small series of functional plastic prototypes. This is because silicone rubber mould has the edge of its

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