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JUDUL: **QUALITY STUDY OF PARTS PRODUCED BY 3D PRINTER**
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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Quality Study Of Parts Produced By 3D Printer

Thesis submitted in accordance with the requirements of the Universiti Teknikal Malaysia Melaka for the Degree of Bachelor of Engineering (Honours) Manufacturing (Design)

By

Kevin Jok Sageng

Faculty of Manufacturing Engineering

April 2007

DECLARATION

I hereby, declare this thesis entitled "Quality Study Of Parts Produced by 3D Printer" is the results of my own research except as cited in the reference.

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APPROVAL

This thesis submitted to the Faculty of Manufacturing Engineering of UTeM and has been accepted as partial fulfillment of the requirement for the degree of Bachelor of Manufacturing Engineering (Honours) (Manufacturing Design).

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ABSTRACT

The "Quality Study of Parts Produced by 3D Printer" is based on Rapid Prototyping (RP) concept where RP model named Master Pattern is designed by Computer Aided Engineering (CAD) modeling software. The Master Pattern consists of shape and features of triangular and circular protrusion as well as triangular and circular hollow cavity and also part features consists of sections with draft angle were designed by using Solidwork CAD software. ZCorp ZPrinter 310 Plus 3D Printer Apparatus is used to produce three Master Pattern's physical prototype. This study investigates the surface finish, dimensional accuracy, flatness and straightness of the three Master Pattern samples produced using 3D Printer apparatus by using appropriate measuring equipment for quality testing namely the Digital Caliper, Coordinate Measuring Machine (CMM) and Portable Surface Roughness SJ-301 Measuring Instruments. The result of the study shows that the 3D Printer has a process capability to produce parts with a dimensional tolerance of $\pm$ 0.1000 to $\pm$ 0.2000mm and the surface roughness, Ra is correlated to the flatness and straightness. The findings shows that shape, surface and dimensional irregularities as the main defects and problem to parts produced by 3D Printer and the problem can be reduced by ensuring the process parameter such as part orientation, part hardening period, post processing method and curing time is properly adhered to produce parts with the highest quality.

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CHAPTER 1
INTRODUCTION

3D Printing process is a technique which used the resin binder as the main medium to cure the powder ceramic material compound. In this study, a mixture of powder material will be cured using the resin bonding curing technique in 3D Printing method. The method of construction is of layer by layer construction of which a layer or powder will be resurfaced by a layer of binder or bonding agent on top and the two layer will bond together to form a solid surface and the process is repeated by the application of a new layer of powder and binder from bottom until the top of the design. Recently, there is a high demand in faster development time for parts and product before manufacturing substituting conventional methods thus scientists and engineers is turning their attention to Rapid Prototyping (RP) method to initiate the Rapid Tooling (RT) application to produce the physical prototype of a part which is then to be examined and analyzed for further improvement to the part design with the aim of high quality finish.

The selection of Quality Study of Parts Produced by 3D Printing Application for study is because of the necessity to understand its importance in terms of product development especially in tooling where the accuracy, surface finishing and the reliability of parts that can be produced in multiple production process especially in terms of the ability in holding close tolerance can affect the production in a whole. 3D Printer is the most effective means of tooling production which integrates RP and RT application for faster product development. The process offers lots of advantages compared to the conventional technique in production tooling such as by Stereolithogrpahy (SLA). It seems that 3D Printer application is fast gaining recognition and popularity as a modern technology and starts to stirs up the interest

of product manufacturer, developer, scientists and engineers to develop a study on the effectiveness of the method in RP and RT field in aid to manufacturing. Thus, it is the right time to study and understand this technique and hopefully it can contribute to the improvement and promote better understanding to the 3D printing process.

The extensive use of RP and RT technique can help to reduce a products production time using the 3D Printer prototyping process. Besides that, the print bonding curing is a process which utilizes the epoxy resin to increase the viscosity of the powder ceramic material thus produced a strong bond among the molecules of the material to hold each interlinked layer of surface together achieving a hard molded compound. Generally, the liquid resin material is coated onto the surface inducing a chemical process that causes the liquid to undergo a phase transition to a solid state once it is bonded with the powder ceramic material. Traditionally, this process has been accomplished by conventional heating in oven which involves extra cost and time. The resin material to be deposited is printed and applied to atop the surface of powder layer and cured layer by layer to finally construct a full physical prototyping model of the part.

This study emphasizes on the quality study of the parts produced using 3D Printer in RP and RT application. The quality study is based on criterion such as the dimensional accuracy, surface finish, flatness and straightness. Further study is conducted to investigate and to analyze the effect of the design in relation to the process capability of the 3D Printer machine in order to maximize the overall surface finish of the part.

1.1 Objectives of the Study

The purpose of this investigative study is to achieve the following:

(1) To identify the quality study including the dimensional accuracy, surface finish, flatness and straightness of the resulting parts by metrological means

(2) To study the effect and causes of the 3D Printing process in relation to constructed part's quality in order to maximize dimensional accuracy, surface finish, flatness and straightness of each resulting part

1.2 Scope of the Study

(1) Design the virtual part which is the Master Pattern using the Solidwork software

(2) Convert the CAD drawing file into STL data file format recognized by the 3D Printer

(3) Produce the part using the 3D Printer Machine

(4) Produce three Master Pattern samples using the 3D Printer Machine

(5) Study the dimensional accuracy of the three Master Pattern samples

(6) Study the surface finish of the three Master Pattern samples

(7) Study the flatness and straightness of the three Master Pattern samples

(8) Analyzed the results and make future work recommendations

1.3 Problem Statements

Manufacturing and production has evolved into a competitive and challenging proposition to produce the best tooling product with the best design and cost effective with high function ability. The needs for fast and productive manufacturing production must be synchronized with the utilization of rapid prototyping development in manufacturing to enhance design function and workability to the maximum.

Rapid Prototyping (RP) is one of the tools that utilize the CAD concept to create the mechanical structure of the part in visual prototyping. The 3D Printer Machine manages the manufacture process of the physical prototype as an application of Rapid Tooling (RT) concept under the Direct Tooling classifications. 3D Printer production operation uses the STL format to program instructions that controls the layer by layer construction of the 3D Printer machine and subsequently produced the complete designed part.

Tooling now days is very important in product development. The accuracy, durability, finishing and the amount of parts that a tool can produce affect the production. Tool manufactured by conventional methods usually offers good quality of the product but the cost of these tolls could be up to hundreds pound and the time required for their manufacture up to months.

This study investigates the surface finish, dimensional accuracy, flatness and straightness of the parts produced using 3D Printer in rapid tooling application.

CHAPTER 2
LITERATURE REVIEW

2.1 Rapid Prototyping Background

Rapid Prototyping (RP) is a fast tracked and advanced manufacturing tool which relies on the Computer Aided Design (CAD) and Computer Manufacturing Application (CAM) to produce prototypes by using various advanced manufacturing apparatus and method. Prototype part is usually in the form of solid and cost effective physical model which can be produced in a fast production steps. Parts produced are highly precise and detailed with good dimensional stability and tolerances that resembles the actual concept of the designed product.

Rapid Prototyping in general is referred to as "Fabrication of a physical, three-dimensional part of arbitrary shape directly from a numerical description typically a CAD model by a quick, highly automated and totally flexible process." **(Rapid Prototyping Report, October 1992)**

RP is an excellent tool for communicating and interacting ideas among the personnel involved in the design of the part and also the research and development personnel right up to the management. RP presents as visual aids to enable the relaying and conveying of vital information between the product development phase and the full production run of which data are obtained through design testing and production test run of the prototype model of the part.

In addition to prototypes, RP techniques can also be used to make tooling which can be referred to as rapid tooling. For small production runs and complicated objects,

(5) A production tool used to examine manufacturing methods of fabricated parts and assembly processes and procedures to obtain the best and most effective manufacturing methods.

(6) A communications tool for internal design reviews and also for design reviews with the customer

(7) RP is a design verification and optimization tool to qualify the form, fit and function of individual parts and assemblies where its physical visualization concept enables verification of design details as a mean to gain internal design acceptance and justification.

However, RP also have several disadvantages where part may have size and geometry limitation for example a part volume is generally limited to 0.125 cubic meters or less, depending on the RP machine. Metal prototypes are difficult to make and for metal parts with large production runs, the conventional manufacturing techniques are usually more economical. RP generated tools may not easily be modified or corrected using typical tool making or conventional techniques.

2.3 Classification of Rapid Prototyping

Generally, there are five main RP processes most commonly used in the industry. These processes are described and listed as the following:

(1) 3D Printer

3D design built using 3D CAD is converted into cross section or slices and the printer then prints the cross sections one atop another from bottom to top of the design. The printer spreads a layer of powder based material and the print head applies a mixture of resin solution to the powder causing powder particles to bind to one another to the printed cross section one layer below. The process is continuous with new layer of powder and resin binder applied to complete the shape design.

(2) Stereolithography Apparatus (SLA)

Selective curing of a photopolymer resin by an ultraviolet laser, built on a descending platform, in a vat.

(3) Selective Laser Sintering (SLS)

A laser traces the shape of the part to be modeled in a thin layer of powder. The laser softens and bonds the powder particles together. This process is repeated over layers of powder.

(4) Laminated Object Manufacturing (LOM)

A laser cuts the outline of a cross section of the CAD file into an ultra thin layer of modeling material. A new layer of material is then indexed, bonded to the previous layers, and cut. This process is repeated using very thin layers of material.

(5) Fused Deposition Modeling (FDM)

Fused Deposition Modeling Process (FDM) Thermoplastic modeling material such as ABS plastic, polycarbonate is fed into the temperature-controlled FDM extrusion head and heated to a liquid state. The head extrudes and deposits the material in ultra thin layers onto a fixtureless base.

(6) Solid Ground Curing (SGC)

CAD model of the part is created and it is sliced into layers using Cubital's Data Front End® (DFE®) software and the flat work surface is sprayed with photosensitive resin in the beginning of each layer. For each layer, a photomask is produced using Cubital's proprietary ionographic printing technique. The photomask is positioned over the work surface and a powerful

UV lamp hardens the exposed photosensitive resin. After the layer is cured, all uncured resin is vacuumed for recycling, leaving the hardened areas intact. The cured layer is passed beneath a strong linear UV lamp to fully cure it and to solidify any remaining particles. Then, wax replaces the cavities left by vacuuming the liquid resin. The wax is hardened by cooling to provide continuous, solid support for the model as it is fabricated. In the final step before the next layer, the wax/resin surface is milled flat to an accurate, reliable finish.

2.4 Basic Processes of Rapid Prototyping

There are numerous rapid prototyping techniques commonly used. Each of these techniques can be simplified by five basic step processes that define the rapid prototyping concept in a whole. These steps are listed as the following:

(1) Creation of a CAD model of the intended design and features of the part
(2) Conversion of the CAD model to STL format
(3) Slicing of the STL file into thin cross sectional layers
(4) Construction of the model one layer atop another
(5) Finishing and clean editing the model

The above step processes can be briefly described in this following section:

2.4.1 CAD Model Creation

The part is modeled using a Computer Aided Design (CAD) software package such as Solidworks or Catia. The Solidwork software is specifically used in the design of the part because Solidwork is solid modelers that represent the part in 3D features with more precise details and characteristic of the assemblies and sub assemblies of the part. Solid modeling concept is important because of its high accuracy in defining the surfaces of the part to be produced in rapid prototyping. Wire frame modeler such as AutoCAD is deemed not suitable for the CAD model creation simply because Solidwork is a better option in generating a solid model of the part with all the design

parameters such as surface curves or geometry specification of the part is fully represented as 3D Solid modeling.

2.4.2 Conversion to STL Format

Various CAD software package uses different algorithms to represent solid object modeling. The STL format has been adopted as the benchmarking format in rapid prototyping. It is the standard format used universally in the rapid prototyping industry. The next process involves the conversion of the CAD file into STL format which can where the 3D printer machine will read and process the data file specifically as STL format. STL format defines a 3D dimensional surface is made of an assembly of planar triangles. The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. However, the STL files cannot represent curved surfaces to the exact detail because it uses planar elements. While increasing the number of triangles improves the approximation, the size of the file also increases requiring more time to process and build the part design. Therefore, it is important to balance the accuracy with manageability to produce a useful STL file in terms of development time effectiveness.

2.4.3 Slicing of the STL file into thin cross sectional layers

In the third step, a pre processing program prepares the STL file to be built. The size, location and the orientation of the model is adjusted by the user according to the types of programs used. Build orientation of the model is very important considering the fact that properties of rapid prototypes vary from one coordinate direction to another. The part orientation partially determines the time required to build the model because it will define the number of layers needed to construct the model. An example of this is when placing the shortest dimension in the z (vertical) direction reduces the number of layers thus shortening the model build times. The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick depending on the build technique. The program may also generate an

auxiliary structure to support the model during the build. Supports are useful for complex features such as overhangs, internal cavities, and thin-walled sections.

2.4.4 Construction of the model one layer atop another

The actual construction of the part occurs during this stage. The RP machines will build the model one layer at a time from constructing materials such as polymers, plastic or powdered metal. The process is an auto run by the RP machine needing minimum human supervision. The most common and advanced RP machine used in building the actual model is the 3D Printing and Stereolithography (SLA) machine which will be described in the next section. There are also other types of RPO machine such as the Selective Laser Sintering (SLS) or the Fused Deposition Modeling (FDM) machine.

2.4.5 Finishing and clean editing the model

The final step involves the post processing of the model where the model is taken out of the RP machine and removed the model from its supporting base and support structure. Minor cleaning is done and some heat treatment process may be applied to the model for extra strength and durability. Sanding, sealing or painting the model will improve its overall appearance to be presented as high quality surface finishing. Some photosensitive materials need to be fully cured before use.

2.5 STL File

The .STL file format has become the Rapid Prototyping industry's standard data transmission format and is the format required to interact with 3D Printed parts. This format approximates the surfaces of a solid model with triangles. The more complex the surface, the more triangles produced in the STL file format. All modern CAD software system such as Solidworks, CATIA and Pro Engineers can generate STL file to be applied to any Rapid Prototyping (RP) machine.

2.6 3D Printer Apparatus

3D Printing is a rapid prototyping process which produces a physical parts which embodies the three dimensional conception of an object or product in design. It is an advanced manufacturing technology method that can produces high quality product with good surface finish and high dimensional accuracy.

3D Printing in general is a process where a visual conception of a product is produced from a 3D computer modeling which is then generated into a physical geometry from the data derived in the 3D modeling. 3D Printer allows the creation of solid, plastic and 3D objects in CAD drawings in a short time. 3D Printing method involves building plastic parts layer by layer at a time using a resin binding agent to cure plaster ceramic powder to finally create the solid physical as conceptualized in the 3D drawing.

2.7 3D Printer Components

3D Printer apparatus consists of two main important components. These are:

(1) 3D Printer Main Unit

3D Printer Main Unit as shown in Figure 2.1 consists of main components such as the Binder Cartridge which supply and print the bonding agent on top the layer of powder, the Feed Piston that moves up to supply powder for printing, the Build Piston that moves down once a layer of powder resin material is bonded to initiate a new layer, a roller attached to the Gantry which spreads the powder and lastly the Build Box which is filled with powder ceramic material as the main material for construction of model.