Reserh Report

DEVELOPMENT OF WOOD BASE MATERIAL FOR RAPID PROTOTYPING PROCESS

Short Term Grant

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ABSTRACT

This document presents initial development of wood-based composites with the aim to develop an alternative material at low cost for rapid prototyping process. Powder blends containing wood powder (90-120μm) with commercial ZP102 as a plaster powder material from ZCorporation were mechanically blended to produce different composition of (vol. %) 25:70, 50:50 and 75:25 respectively. The blended material were successfully processed on 3D printers (Z406) which was used as a rapid prototyping machine to produce three-dimensional components and followed by post-treatment with ZMax solution to improve the mechanical properties. The mechanical properties, dimensional accuracy and surface quality of the build components were evaluated and the results were compared with the unfilled ZP102 material. The result shows that the mechanical properties were improved with the increasing of wood powder content to 50 vol. %. However, dimensional accuracy and surface quality were decreased as the wood content increased. Further work on powder preparation is required in order to fully realize these performance benefits particularly for surface quality improvement.

CONTENTS

CHAPTER I

INTRODUCTION

Rapid prototyping (RP) is a technology utilizing a layer by layer manufacturing technique. The term "rapid prototyping" refers to a number of different but related technologies that can be used for building very complex physical models and prototype parts directly from 3D CAD model. This technology takes information from a three-dimensional (3D) computer-aided design (CAD) database and produces a solid model (prototype) of the design. Among these technologies are three dimensional printing (3DP), stereolithography (SLA), fused deposition modeling (FDM), laminated object manufacturing (LOM), selective laser sintering (SLS) and inkjet-based systems. This technique provide alternative for producing prototypes and functional models with complex geometry without the need of tooling as compare to the conventional routes.

The Three-Dimensional Printing (3DP) process is a manufacturing technology for the rapid and flexible production of prototypes, parts, and tooling directly from a CAD model. It is an extremely flexible system, capable of creating parts of any geometry and using any material including ceramics, metals, polymers, and composites. This process is also capable of having local control over the material composition, microstructure, and surface texture [1].

RP technologies gave significant contribution in the field of wood base material. In particular, this technology is suitable for rapid production of new product base on wood dust. This material is considered as one of the optional material for 3D printer. The main advantage of wood dust is can use waste material, easy to find, and low cost.

In recent years, Three Dimensional Printing (3DP) came to the foreground as a very competitive process in terms of cost and speed, and sales of related equipment have increased significantly compared to other RP machine.

1.1 Background of the Problem

3D printer (3DP) is important in manufacturing process for fabricates models, quickly print a prototype and show it to engineering, sales, and marketing groups as well as to toolmakers.

Since this method become too important for manufacturing, faculty of mechanical engineering at UTHM was provide a Z406D 3D printer for student to make research. However, 3DP currently limited in the choice of materials and it is involved high cost which is faculty needs to spend around RM3000 to buy the material that use in the operation. So that, developing a new material like wood dust can make the cost are less than before.

As we know, wood dust is waste material, so reusing waste product in 3D printer is a better way to less cost of product and give more benefit to prevent pollution and environment friendly.

1.2 Objectives

The objectives outlined from the current work are as below:

i. To research suitable type of wood base material for RP process.
ii. To determine the properties of wood material for 3D printing in particular of mechanical properties, surface quality and dimensional accuracy.

1.3 Scopes of the Study

The scopes outlined to achieve the objectives above are as follows:

i. Study the characteristic of different type of wood material which suitable for rapid prototyping (RP) process.
ii. Prepare raw material for 3D printing process using recycle material from wood.
iii. Fabrication of sample component using 3D printing process.
iv. Evaluate different post processing technique.
v. Analyze the quality of the fabricated of product on mechanical properties, surface quality and dimensional accuracy.

1.4 Important of the Study

The propose study is to investigate the suitability of using wood base as a raw material for 3D printing process.

1.5 Expected result

The purpose of this research is to develop a new raw material for RP process using wood base material. Besides that, this study will determine suitable type of wood base material for RP process and the properties of wood material for 3D printing in particular of mechanical properties, surface quality and dimensional accuracy.

1.6 Rationale

Nowadays, cost operations of the rapid prototyping are expensive. In this study, it will using alternative material and can reduce operation cost. So, the RP system using this wood base material can be made at a low cost, the material are also ease to find and available locally.

CHAPTER II

LITERATURE REVIEW

2.1 Overview of Rapid Prototyping

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. It is called rapid prototyping because it can prototype parts very rapidly and a special class of machine technology that quickly produces models and prototype parts from 3-D data using an additive approach to form the physical models. The unique characteristic of RP is that it makes prototypes one layer at a time or layer by layer.

2.2 Classification of RP System

Rapid prototyping systems can be classified in a variety of ways, depemding on the physics of the process, the source of energy, type of material, size of prototypes and the like. Accordingly, all RP system can be classified as liquid-base, powder-base and solid-based systems.

Fundamentally, the development of RP can be seen in four primary areas, input, methods, materials and applications. There are many different ways of classifying RP systems according to the different methods used, as shown in Table 2.1.

Table 2.1: Classification of RP process by method [4]

Photopolymerisation					
Laser curing	Masked lamp	Sheet lamination	Laser sintering	Droplet deposition	Adhesion bonding
3D System's SLA	Cubital's SGC	Helisys' LOM	DTM's SLS	Fraunhoner's MJS	3D System's MJM
Teijin Seiki's Soliform		KIRA's SAHP		Stratasys' FDM	Soligen's DSPC
Mitsubishi's SOUP		Kinergy's Zippy System			MIT's 3D Printing
EOS's Stereos System					
Meiko's RP System					

2.3 Three Dimensional Printing (3DP)

The three dimensional printing (3DP) based on MIT's (Massachusetts Institute of Technology) ink jet technology and utilised by Z-Corporation in a variety of printers is considered to be one of the most future oriented rapid prototyping (RP) systems. It is classified as a typical "concept modeller", a low-end system, and represents the fastest RP-process.

2.3.1 The Basic Process of 3 Dimensional Printing

The 3D Printer process uses ink-jet printing technology to build parts in layers. A slicing algorithm draws detailed information of the layer from the CAD model of the part. Each layer begins with a thin distribution of powdered material over the surface of a powder bed. Using the ink-jet printing technology, a binder material selectively joins the particles where the object is formed. A piston than supports the powder bed and part-in-program, lowest the platform, deposits a fresh layer of powder, and binds the powder again. This layer-by-layer process continues until the part is completed.

During the build process, loose powder surrounding the bonded area serves as the support material. The 3D Printer process is a powerful prototyping process useful for the creation of functional parts and tooling directly from a CAD model.

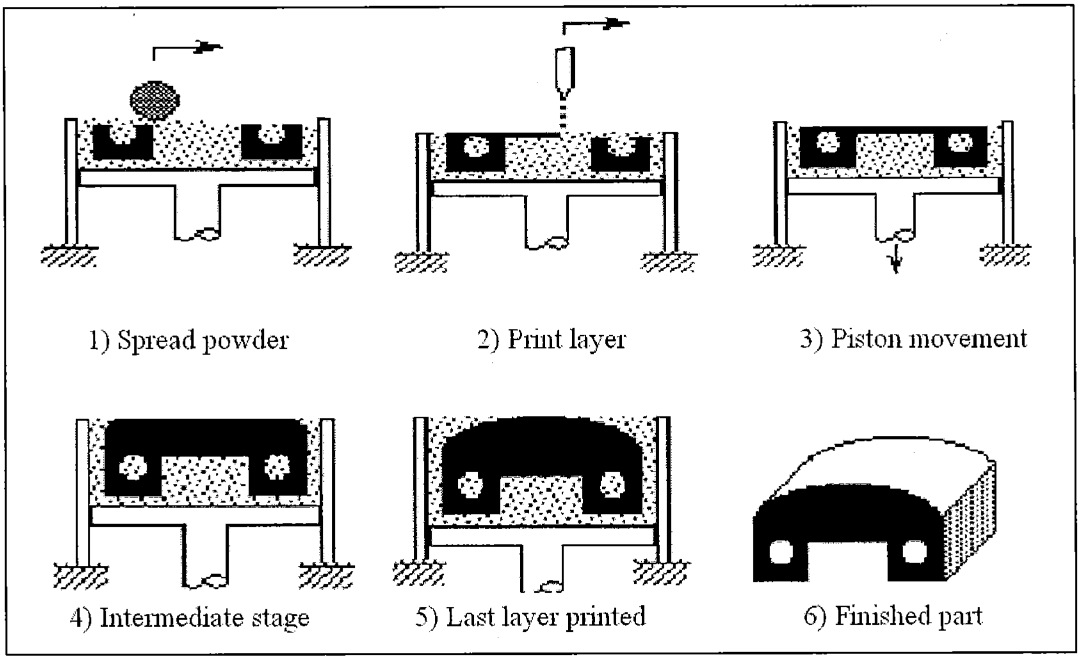

Figure 2.1: Schematic Illustration of Three Dimensional Printing Process

2.3.2 Important Processing Parameters

The quality of building parts and building performance of 3D Printer are strongly related to its process parameters including binder setting saturation value (shell & core), binder setting saturation level, layer thickness, shrinkage, and location of made-up parts of the rapid prototyping machine. [5]

Each process parameter may affect the quality of a RP part and the build time. Unsuitable process parameters setting may make RP prototypes with poor quality and may waste materials and building time. The manufacturing process parameters of Z406 3D Printer system are illustrated as follows [5]:

i. Binder setting saturation value (shell & core): The building method of the Z406 3D Printer system uses a powder bound with binder to shape RP parts. From 2D sectional layers that are sliced by slicing algorithm system software, each 2D section is composed of shells and cores. As the setting value increases, the better the quality of the RP parts; however the binding time will be increased, too.

ii. Binder setting saturation level: Binder setting saturation level is the thickness of infiltration, when the binder is filtering.

iii. Layer thickness: The process layer thickness means the height of the powder bed that dropped down along Z-axis in processing. It can be set within the range of 0.003" – 0.009" (or 0.0762mm to 0.2286 mm). If the layer setting is thinner, the quality of the RP parts will be finer; however the tradeoff is the building time will be increased.

iv. Shrinkage: Z406 3D Printer machine generally works at normal atmospheric temperatures. Because the climate of each place of the world is different, the powder will suffer from volume swell or shrinkage by getting hot or cold and by getting wet or dry. It has caused the RP parts quality to worsen.

v. Location of made-up parts: The working direction of the Z406 3D Printer system's spray-nozzle is from right to left on the powder bed. If the location of RP parts is put on the right side, the path of the spray-nozzle may be shortened; thus decreasing the part building time.

2.3.3 Commercial 3D Printing Process

a. Z406 System

The Z406 System is the concept modeling solution for leading companies and universities. The Z406 System is a premium 3D Printer with the capability of printing in full-color, communicating important information about parts, including engineering data, labeling, highlighting and appearance simulation. The system is fast, convenient and easy to operate, allow accelerating the design process and getting the products to market ahead of the competition.

The Z406 3D Printer offers a variety of materials. There are two materials used with Z406 machine; the plaster based powder and the starch based powder. The plaster based powder deliver high strength and detail. The starch-based powder delivers in high speed at a very low cost.. Features of the Z406 System are as follows:

Table 2.2: Detail for Z406 System [2]

Feature	**Detail**
Build Speed	Color mode: 2 layers per minute Monochrome mode: 6 layers per minute
Build Volume	8" x 10" x 8" (203 x 254 x 203 mm)
Layer Thickness	User-selectable at the time of printing: 0.003"-0.010" (.076-.254 mm)
Color	RGB Full Color (Millions of Colors)
Equipment Dimensions	40" x 31" x 44" (102 x 79 x 112 cm)
Equipment Weight	470 lbs. (210 kg)
System Software	Z Corporation's proprietary System Software accepts solid models in STL, PLY, VRML (WRL) and SFX file formats as input. System Software runs on Microsoft Windows* 2000 and NT.

b. How The Z406 System Works?

Firstly, the Z406 machine must be checked and made ready before any part can be printed. The feed piston should have sufficient powder, and the build area needs to be scraped by the wiper blade until it is level with the powder. All instructions regarding the safe and efficient use of the Z406 system should be known for the optimum performance of the system.

Before the printing of any part, the Z406 system software imports the STL file and slices it into hundreds of 2D cross sections of certain slice thickness. To print a part, the following steps are taken:

1. The machine spreads a layer of powder from the source piston to cover the surface of the build piston.
2. The machine than print binder solution onto the loose powder, forming the first cross section where the binder is applied, and the powder is glued together. The remaining powder remains loose and supports the layers that will be printed above.
3. When a cross section is complete, the build piston is lowered slightly, a new layer of powder is spread over its surface and the process repeated.
4. The parts grow layer by layer on the build piston until the part is complete while it remains surrounded and covered by loose powder. Finally the build piston is raised and the loose powder is vacuum away, exposing the completed part.

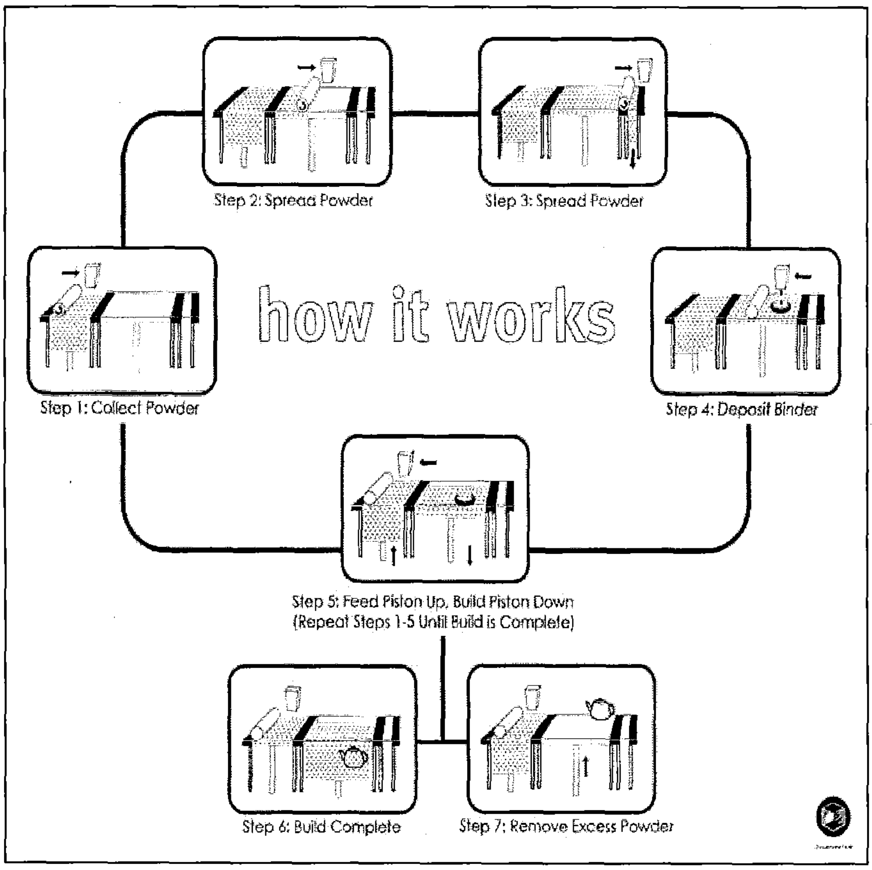

Figure 2.2 : The Printing Process [2]

c. Advantages of a Z406 System

The Z406 System builds speed and efficiency into the design process and the highest quality into the products. The printers are professional, complete physical modeling solutions delivering full-color communication. Other advantages of 3DP for rapid product development:

i. Speed

Each layer is printed in seconds, reducing the time it takes to print a hand-held part to 1-2 hours.

ii. Color

The Z406 System can create parts from a full 24-bit palette of colors, resulting in multiple color prototypes. Color can be used to communicate important information including engineering data, labeling, and highlighting and appearance simulation.

iii. Simplicity

The Z406 System is straightforward to operate, eliminating the need for a designated technician. The Z406 System is based on standard, off the shelf components developed for the ink jet printer industry resulting in a reliable, dependable 3D Printer.

iv. Versatility

Companies are using Z406 System parts in every step of the design process for communication, design review and functional testing. The option of infiltrating parts offers customers the opportunity to produce parts with a variety of material properties to serve a range of modeling needs.

2.4 Material

3D printers have the widest range of material, as a large number of binder-powder mixtures is imaginable. All processes operating with a bath or a powder bed need to contain more material than is necessary for the model, depending on the size of the build chamber.

i. Plaster Material System

The plaster material system has been found to remain dimensionally accurate during printing and thus, the recommended anisotropic scaling values are one (1) in all axes. If the infiltrant system being used changes the accuracy of the part, the values must alter as needed. The shell and core saturation values for the plaster material system are generally constant values, meaning that there is only one value for all geometry types.

ii. Starch Material System

The shrinkage found in the starch material system is proportional to the part geometry and the drying time of the part. The longer the part is left to dry, the larger the shrinkage value. The part is most stable in the X and Y axis and shrinks more in the Z axis. Thus, the anisotropic scaling factor of the Z axis will always be greater than the values for both the X and Y axis. The shell and core saturation values for the starch material system depend on part geometry. A thick walled part will have lower shell saturation than a thin walled part. Core saturation is dependent on the wall thickness of the part. The thinner the wall thickness the higher the core saturation; the thicker the wall thickness the lower the core saturation. The ZPrint Software will recommend shell and core saturation values based on the part geometry. If parts come out weak, increase the saturation values by 10%; if parts are difficult to depowder, decrease the saturation values by 10%.

iii. ZCast Material System

The ZCast material system has been found to remain dimensionally accurate during printing and thus, the anisotropic scaling values are one (1) in all axes. The shell and core saturation values for the ZCast material system are generally constant values, meaning that there is only one value for all geometry types.

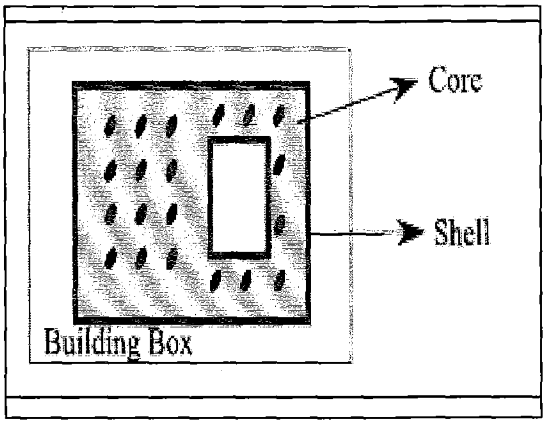

Figure 2.3: Definition of shell and core. The dark areas around the boundary of each layer of a 3DP built part are the shells. The inside area with light color of each layer of a 3D Printer built part is the core.

2.5 Previous Studies by Students

i. Development of an Optional material for 3D Printer by Using Aluminium Powder (Wilson Tay, 2007)

Studied have been focused on the effects of process parameter including layer thickness, ratio Aluminium powder versus ZP102 plaster based powder, and binder setting saturation value (shell and core) on the machining characteristic including accuracy dimension, surface roughness, and the hardness for the part that build by mixture ZP102 plaster based powder and Aluminium powder. The result shown that ratio Aluminium powder versus ZP102 plaster based powder 1:3 achieved best accuracy dimensional and 1:4 achieved best surface finish and hardness value in the ratio 1:3, 1:4 and 1:5. In this researched, part 100% Aluminium powder build with Binder Zb56 was very brittle and not suitable to do the testing.

ii. Developing New Material for 3D Printing by Using A Rice Flour (Mohd Syahril Mohd Sumery, 2007).

The main interest of this research is to study the effect of the machining process parameter include layer thickness, ratio of mixing and saturation value-core and shell on the model characteristic including surface roughness, dimensional accuracy and flexural strength. An implementation of Design of Experiment (DOE) will be done by using Taghuchi Method, Qualitek-4 software to obtain the parameter contribute and optimum parameter setting for the best building of models. Based on the result gain from the experiment, part build from ZP 102 plaster-based powder give better quality in most of the machining characteristic compare to the part build from RF starch-based powders. Based on the result gain from the experiment, part build from ZP 102 plaster-based powder give better quality in most of the machining characteristic compare to the part build from RF starch-based powders.

CHAPTER III

METHODOLOGY

This chapter addresses the research methodology, experiment and test involved in this research work. The earlier topic explains in general the research methodology. Further on, this chapter describes the rationale on the material, parameters and level selection. The methodology and procedures is important to determine the flow, direction and method to work in this research study. With list down all the element of the procedures and method of the project progress, the specific plan are clarify.

3.1 Research methodology

In this research work the methodology is divided into several stages as shown in Figure 3.1 The methodology of previous research consists of several stages.

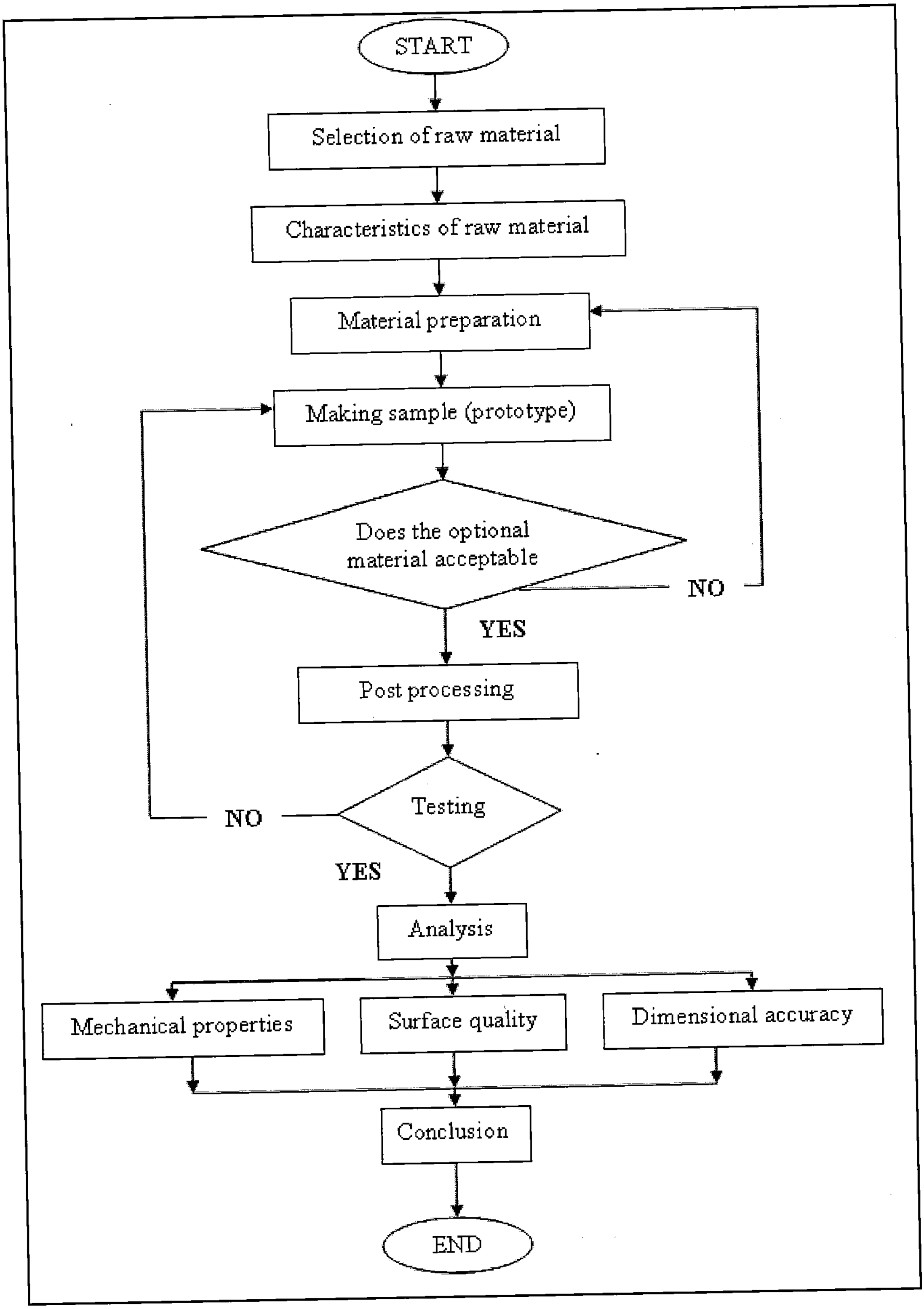

Figure 3.1: Research methodology flow chart

3.2 Raw Material

Before experiments were starting, material needs to prepare. It's important to make sure the material characteristic suitable for Z406 3DP.

i. Powder preparation

In this study, the materials will be use in ZP 102 plasters based powder and wood dust based powder. Particle size of wood dust using in this study still in research and the particle size of ZP 102 plasters based powder is between 50~250μm.

As an initial, a pure of wood dust will be use and analysis will be run to the finishing product. As the result that can be predicted, a certain change of the percentage of composition will be considered to the powders. The mixture powders that will be use together is ZP 102 plaster base that was provide by the manufacturer.

The wood dust is can be found from Sindora Timber Sdn. Bhd. located at Bandar Tenggara. In this study, wood dust is used as a powder for material preparation. Figure 3.2 shows the wood dust is looks like which are having rough surface and large in particle size. The wood dust needs to sieve to get the suitable range in particle size before it is used as a powder in Z406 3D printer.

Figure 3.2: Bottom wood dust

Scanning electron microscope (SEM) model Jeol JFM-6380 LA is a microscope that uses electrons rather than light to form an image which is can be found in the Science Material Laboratory at UTHM. It will used in this research to measure the microstructure composition of ZP 102 plaster based powder and wood dust. Microstructure composition of the both materials will be comparing and this data will be use in data analysis.

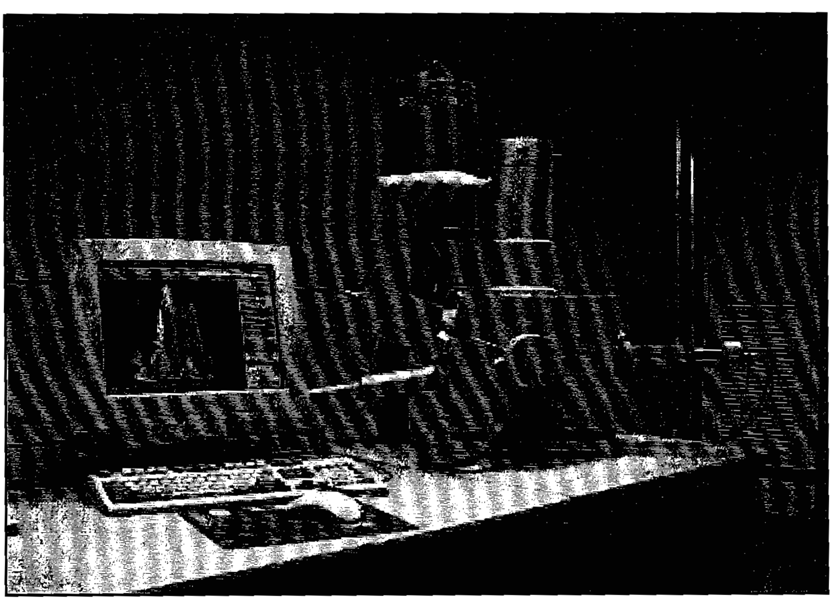

Figure 3.3: Scanning Electron Microscope Machine

3.3 Parameter Setting

In this experiment, the process parameters including layer thickness, saturation value (shell), saturation value (core), location make-up part and ratio wood dust based powder with ZP102 plaster based powder. Table 3.1 shows the setting condition.

Table 3.1 : Recommended Parameter from Corp. Inc.

Machine parameter	**Level**		
	1	**2**	**3**
Layer thickness (inches)	0.0035	0.004	0.005
Ratio (wood dust)	1:3	1:4	1:5
Saturation value (shell)	1:5	1:7	2
Saturation value (core)	0.7438	0.85	1.0625

3.4 Powder Setting

i. Anisotropic Scaling Value

Anisotropic scaling values scale the model to accommodate any shrinkage or expansion of the part either due to characteristic of the material system or infiltrate system. The plaster material system has been found to remain dimensionally accurate during printing an thus, the recommended anisotropic scaling values are one (1) in all axes.

ii. Saturation Value

The saturation value determine how much binder is placed on the powder to print the part and the part is made up two areas, the shell and the core. The shell and core saturation values for the plaster material system are generally constant values, meaning that there is only one value for all geometry type.

iii. Powder preparation

Before experiments were starting, material needs to prepare. It's important to make sure the material characteristic suitable for Z406 3DP. In this study, the materials will be use is ZP 102 plaster based powders and wood dust based powder. ZP102 powder is one of the plaster based material being used now for Z406 3D printer.

Table 3.2 : Physical and Chemical Properties of ZP102 Plaster Based Powder

Spec Gravity (H_2O=1)	1.3 – 3.0
Color	White/Off-White Powder
Ph	4-8 (aqueous solution)
Melting Point	Minimum 1450°C
Solubility	0.67 to 0.88/100 g solution

Microstructure composition of ZP 102 plaster based powder and wood dust will measure by using scanning electron microscope (SEM). Microstructure composition of these materials will be comparing. These data will be used in data analysis. Because the materials are non-conductive specimens, this material will be coated with a thin layer of platinum before measurement are doing by using SEM.

iv. Binder Preparation

Zb56 binder was selected in this study. This binder is suitable for powder based materials. But if the binder is not adhesive with the wood dust, it will change with the suitable binder.

3.5 Specimen Preparation

Based on the test conducted, there will be only one drawing using Solid Work software to fabricate specimen by using 3D printer. The Solid Work software is in STL. This specimen will be use to measure the value of surface roughness and flexure strength (three point bending test) value. The dimension of test specimen based on the ASTM E18 standard as figure below.

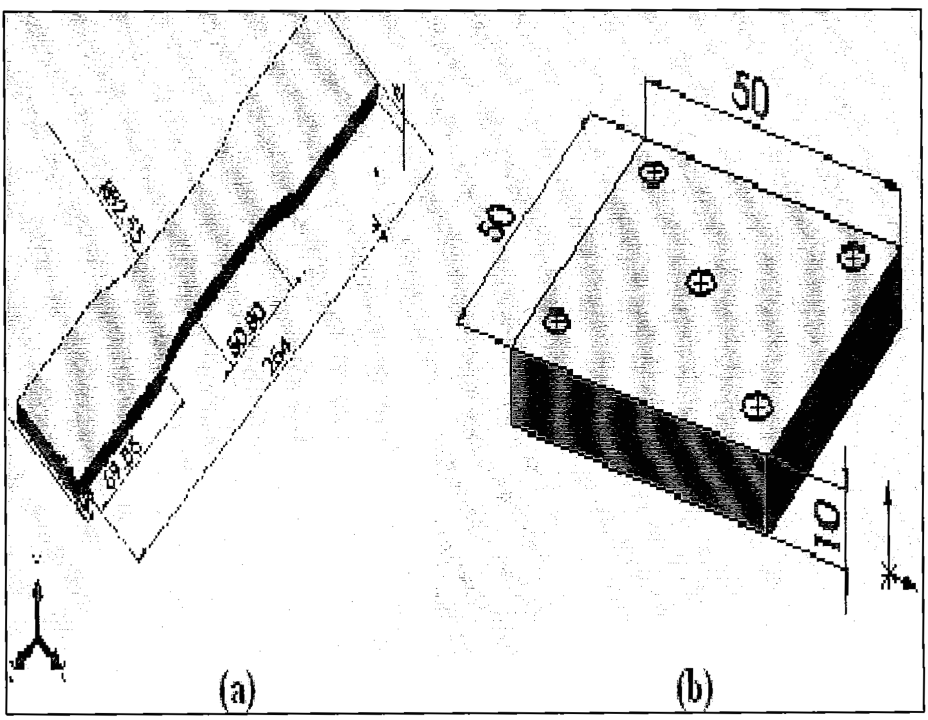

Figure 3.4: Dimension of the Test Specimen (a) ASTM E1037-72a (b) ASTM E18

a. Post-processing

In this process part from the 3D printer will be carry out to process for the next process. This includes depowdering, drying and infiltrate the part.

i. Removing the finishing part

The part will be removing from the build box after the building is complete as follow:

a. Powder-based parts: wait approximately 10 to 15 minutes to ensure that the uppermost layer of the part have had a chance to dry. Plaster-based parts: leave the part in the bed for approximately 30 to 60 minutes. Zcast parts: same period as plaster-based parts.
b. The machine should turn off by pressing the online button.
c. Lift the top cover.
d. Vacuum off any powders on the deck.
e. Press the Feed Down button to lower the feed piston.
f. Place a tray on the top of the Feed area.
g. Take a moment to look at the computer screen and determine exactly where parts lie in the build box.
h. Without raising the build piston, begin vacuuming powder out of the box.
i. Vacuum powder away from the buried parts, and clean powder out of the margins against the wall of the Build Box
j. Raise the Build Piston by holding down the Build Up button to gain access to the sides of the parts.
k. The part and place on the tray will remove. The part is now ready to be depowdering.

ii. Depowdering the part

The purpose of this process is to clean up the parts from the existing powders by using a depowdering unit. The steps to do this process are given as below:

a. Place parts inside the depowdering unit.
b. Using the compressed air system included in the Depowdering Station, remove any excess powder that remains in any concave surface. The air pressure in the Depowdering Station is adjustable. For bulky parts, turn the air pressure up and fro delicate parts, turn the air pressure down.

iii. Drying the part

To infiltrate starch or plaster parts with wax, the part must be hot and dry. The part will be preheated at 165 degrees Fahrenheit in the Automated Waxer or in the drying oven and the drying time are regarding to the part thickness. The related between the time and wall thickness show in chart below.

Table 3.3: The related between time and wall thickness of the part

Average Wall Thickness	Drying Time
1/8 inch	15 minutes
1/4 inch	30 minutes
1/2 inch	45 minutes
1 inch or greater	90 minutes

iv. Infiltrating the part

The infiltrate processes are important to produce extra and variable material properties to the finishing parts. But for as an early stage design tool, it may not be necessary to infiltrate the parts at all. For this stage, infiltration must use a resin that recommended by the manufacturer, Z Corp company which is Cyanoacrylate 502. The step to infiltrate the part a given as below.

a. Read and understanding the Safety Information on the resin container label.
b. Dry the part in the Automated Waxer or dry drying oven
c. Then place the part on the waxed paper or on the non- stick surface.
d. Apply a thin coat of resin to the entire part by gently squeezing the bottle and letting the resin drip onto the part.
e. Once the entire part is coated, let it dry for 45 minutes to 1 hour. To stop the part from sticking to the wax paper, pick it up and move it every 10 minutes until dry.
f. Once the part is dry, it can be sanded to improve the surface finish.
g. To further improve the surface finish, the part can be waxed. To wax a part infiltrated with resin, the part must be heated at 165 degree Fahrenheit for 1 to 3 minutes before waxing.

3.6 Product Analysis

An analysis will be conduct to the finish product to perform the necessary condition. During this analysis, some of the criteria will be judge like microstructural characteristic and particle size, dimension accuracy, surface roughness, and mechanical properties.

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