UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: EXPERIMENTAL STUDY OF RAPID PROTOTYPING OF MANUFACTURING PLASTIC PRODUCT USING RESPONSE SURFACE METHODOLOGY.

SESI PENGAJIAN: 2012/2013

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EXPERIMENTAL STUDY OF RAPID PROTOTYPING OF MANUFACTURING PLASTIC PRODUCT USING RESPONSE SURFACE METHODOLOGY

SYED MOHD NOR IRSYAD B SAYED MOHD NORDIN

Report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

FACULTY OF MANUFACTURING ENGINEERING
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree Bachelor of Manufacturing Engineering.

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STUDENT'S DECLARATION

I Syed Mohd Nor Irsyad Sayed Mohd Nordin declared that this dissertation entitled *"Experimental Study of Rapid Prototyping Of Manufacturing Plastic Product Using Response Surface Methodology"* is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature : . . . .
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Date : 12 JUNE 2013

To my beloved family

Sayed Nordin

Siti Meriam

Noor Diana

ACKNOWLEDGEMENT

Praise to ALLAH S.W.T, the Most Merciful and the Most Compassionate for giving me healthy and strength to finish my final year project and completing the writing thesis. Peace upon Him, Muhammad S.A.W, the messenger of ALLAH.

Firstly, I would like to thanks to my supervisor Dr Ahmad Razlan Yusoff for his guidance, supporting, advising and his richest idea and concept during the duration of this final year project. I am very grateful to him for his patience and his constructive comments that enriched this research project. His time and efforts have been a great contribution during the preparation of this thesis that cannot be forgotten. His contribution and cooperation during my research was really helpful and I really appreciate it.

Secondly, I would like to thanks all lectures and associate in Faculty of Manufacturing Engineering, University Malaysia Pahang and my thanks also extend to all my friends who helped me in many ways especially for supporting which gave me a lot of confidence to finish this project. I would also like to thank En Muhammed Nafis Osman Zahid as my academic advisor. This study would not be complete without the support from her. Finally, I wish to convey my heartfelt thanks to my beloved parents, Sayed Nordin and Siti Meriam who gave me encouragement and constant supports during my study in UMP and my siblings who keep supporting me. Thank you for all the help and advice given.

ABSTRACT

This study basically shows a detailed study to manufacture Coffee Maker using Rapid prototyping using Response Surface Methodology. Fused deposition modeling (FDM) is a process for developing Rapid Prototyping (RP) objects by depositing fused layers of material according to numerically defined cross sectional geometry. The quality of FDM produced parts is significantly affected by various parameters used in the process. This dissertation work aims to study the effect of three process parameters such as layer thickness, build orientation, and air gap on mechanical property of FDM processed parts. In order to reduce experimental runs, Response Surface Methodology (RSM) based on central composite design (CCD) is adopted. Specimens are prepared for tensile and surface roughness test as per ASTM standards. Empirical relations among responses and process parameters are determined and their validity is proved using analysis of variance (ANOVA). Response surface plots are analyzed to establish main factor effects and their interaction on responses. Optimal factor settings for maximization of each response have been determined. Major reason for weak strength of FDM processed parts may be attributed to distortion within the layer or between the layers while building the parts due to temperature gradient. To this end, mechanical properties like tensile strength and surface roughness finish of the produced parts are considered as multiple responses and simultaneous optimization has been carried out with the help of response optimizer. Coffee Maker parts are manufacture using optimum parameter determines. The Coffee Maker then been assemble and test its function ability.

ABSTRACT

Kajian ini pada asasnya menunjukkan kajian terperinci untuk menghasilkan Coffee Maker menggunakan Rapid Prototyping menggunakan Response Surface Methodology. Fused Deposition Modelling (FDM) merupakan salah satu proses Rapid Prototyping (RP) untuk menghasilkan produk dengan mendepositkan bahan satu per satu mengikut kerangka yang ditakrifkan mengikut geometri keratan rentas. Kualiti produk FDM yang dihasilkan dipengaruhi oleh pelbagai parameter yang digunakan dalam proses tersebut. Kajian tesis ini bertujuan untuk mengkaji kesan tiga parameter proses seperti ketebalan lapisan, orientasi produk, dan ruang udara ke atas sifat mekanikal produk yg dihasilkan dari FDM. Dalam usaha untuk mengurangkan jumlah eksperimen, Response Surface Methodology (RSM) yang berasakan Central Composite Design (CCD) digunakan. Spesimen disediakan untuk ujian tegangan dan kekasaran permukaan mengikut piawaian ASTM. Hubungan empirikal antara tindak balas dan parameter proses ditentukan dan kesahihan mereka dibuktikan dengan menggunakan analisis varian (ANOVA). Plot Response Surface dianalisis untuk mewujudkan kesan faktor utama dan interaksi faktor lain terhadap tindak balas. Faktor optimum ditetapkan untuk memaksimumkan setiap tindak balas. Sebab utama kelemahan produk dihasilkan FDM adalah kerana gangguan dalam lapisan atau di antara lapisan ketika produk dihasilkan kerana suhu yang menurun. Untuk tujuan ini, sifat-sifat mekanikal seperti kekuatan tegangan dan kekasaran permukaan bahagian produk yang dikeluarkan dianggap sebagai pelbagai tindak balas dan pengoptimuman serentak telah dijalankan dengan bantuan pengoptimasi tindak balas. Bahagian Coffee Maker dihasilkan menggunakan optimum parameter yang telah ditentukan. Coffee Maker seterusnya dipasang untuk menguji sama ada Coffee Maker berfungsi atau tidak.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In recent years, opening up local market for worldwide competition has led to a fundamental change in new product development (NPD). In order to stay competitive, manufactures should be able to attain and sustain themselves as “World Class Manufactures“. The manufactures should be capable in delivering products in fulfilling the total satisfaction of customers, product in high quality, short delivery time, at reasonable cost, environmental concern and fulfill all safety requirements.

In many fields, there is great uncertainty as to whether a new design will actually do what is desired. New design often have unexpected problems. A prototype is often used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theory and confirm performance prior to starting production of new products.

Manufacturing cost is something that manufactures most concern about. In order to reduce producing product cost. It starts from the beginning of process until finishing process. Waste the money on maintenance is something costly. Rather than that, they have preferred to put the cost from the start of manufacturing process so that there is no product defect in future. Parameter control would be a significant role to reduce plastic product defect in every production.

In rapid manufacturing process, methodically designed to provide a mass-customized product to achieve a desired balance among cost, throughput, and quality is a mass challenge for engineers and designers.

Three stage of intriguing problem in rapid manufacturingis shown in Figure 1.1 below:

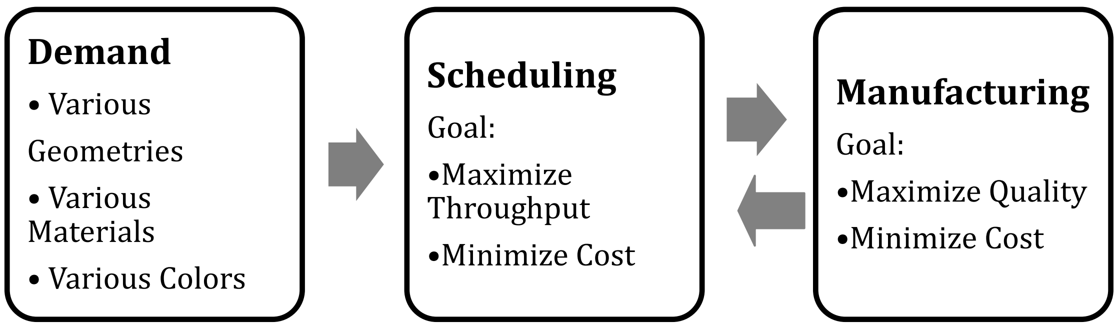


Figure 1.1: Three stage of intriguing in rapid manufacturing

In some applications, the system behavior and performance depends on certain parameters. These parameters may be real values or functions and can only be chosen after extensive realistic simulations. The traditional rapid prototyping methodology is hard to be used because different sets of parameters give different implementations.We propose a prototyping framework for such systems which allows designers to rapidly create a prototype and efficiently test against parameters. For a given system specification, the collected parameters are determined in software to facilitate the modification during system tuning. The other parts represent the core computations that are required to compute a correct solution. This portion can be implemented as an early partial prototype and is, then, connected to the software part that computes parameter values. By doing so, designers can find satisfactory parameters under realistic computing situations. These parameters, together with the early prototype, form the design solution which can be sent to the manufacture process. That approach provides the benefits of rapid specification, flexible tuning, hardware/software capability, and shorter development process.

Since the introduction of rapid prototyping technology as a tool for time compression and concurrent engineering in the design and manufacturing process, many enhancements and refinements have been made based on the experience of users and manufacturers of rapid prototyping equipment. These improvements contribute significantly to better production of quality output from rapid prototyping systems. This project reviews the role of several of these parameters in the process.

1.2 PROBLEM STATEMENT

Rapid Prototyping (RP) or Layer Manufacturing (LM) refers to fabrication of layer-by-layer. Additional layer or fewer layers will affect to plastic product defect. Mostly, plastic product defect happened during process time. Plastic product defect play a significant role in increasing production cost. Therefore, parameter control during RP process is compulsory in order to reduce plastic product defect. This study will focus on modeling and optimization suitable parameter of RP of plastic product manufacturing using Response Surface Methodology (RSM).

1.3 PROJECT OBJECTIVES

Basically, this study required the student to apply the concept of compulsory and cost reduction in producing plastic product. The study is on manufacturing of coffee maker using rapid prototyping (RP) using response surface methodology (RSM). Material use in manufacturing coffee maker is ABS. Objective of this projectis:

i. To analyze parameter effect to manufacturing of coffee maker such as, build orientation, layer thickness, and air gap.
ii. To implement Response Surface Methodology (RSM) in RP process for producing coffee maker parts.
iii. To testtensile strength, surface roughness finish, function ability and accuracy to assemble the coffee maker parts.

1.4 SCOPE OF STUDY

This project require proper plan in order to achieve the project objective. There is some scope of study:

i. Initial study about Rapid Prototyping process
ii. Study on importance of parameter in manufacturing process
iii. Initial study and implementing Response Surface Methodology on RP process
iv. Manufacture of Coffee Maker Machine using Rapid Prototyping
v. Assemble coffee maker part accuracy, tensile test, surface roughness finish and function ability of coffee maker

Gantt chart for project schedule is attached in Appendix A.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A rational method to fabricate coffee maker and easy to assembly the part is the most important selection for producing these products. Basically 20 to 30 percent defects of product occur during manufacturing process. So, a design engineer should be concerned with the defects that cost manufacturing process. Thus, concept of response surface methodology (RSM) applied on rapid prototyping (RP).

2.2 MODELING AND OPTOMIZATION PARAMETER

In general, parameter is used to identify a characteristic, a feature, a measurable factor that can help in defining a particular system. A Parameter is an important element to take into consideration for the evaluation or for the comprehension of an event, a project or any situation.Parameters are dimensionless, or have the dimension of time or its reciprocal. In order to modeling and optimize suitable, industrial engineer should take many factors when deciding the applicability of product design, including quality of product, rational use of parameter, applicability of manufacturing process and so on.

2.3 RAPID PROTOTYPING

RP is a generic term for a number of technologies that enable components to be made without the need for conventional tooling in the first instance or indeed without the need to engage the services of skilled model-makers. Many manufacturing processes are subtractive, in that they modify the geometry of a mass of material by removing parts of the material until the final shape is achieved. Conventional milling and turning are good examples of subtractive processes. By contrast, RP techniques are additive processes. RP components are built-up gradually in layers until the final geometry is obtained. The way in which the layers are produced, however, and the materials in which parts can be built vary significantly between the different RP processes.

The starting point for the RP process is typically a 3D CAD model prepared and exported to meet the requirements of a given technology. Various other “inputs”, in addition to CAD, can be used to create RP components; these include medical applications such as MRI and CAT scanning as well as point cloud data generated by engineering scanning or digitising systems. Whatever be the source of the original data it is reformatted into anstl file and sliced horizontally, each individual slice is subsequently presented to the selected RP manufacturing process. The RP system will subsequently reproduce the sliced data thereby creating a physical example of the original “CAD” data.

Each RP technique has its own advantages and disadvantages. These must be understood thoroughly before an RP process is selected; otherwise, a part that does not completely fulfill the requirements of the end-user may be produced, and disappointment in the use of RP technology is likely to occur.

2.3.1 Types of Rapid Prototyping Systems

Various types of Rapid Prototyping systems had been developed, in order to coordinate with the highly demands of new products from the market. The most common types of RP systems that available in the market are Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), and Three Dimensional Printing (3D printing). In this study, FDM is used. Different types of machines have their strength and weakness in producing the products. Below are shown the details of operation principle for five common types of RP systems.

Figure 2.1 shows that the stereolithography technique. The building process begins with the vat filled with the photopolymer liquid and the elevator table set just below the surface of the liquid. Then the mirror is directed to focus the laser beams so that it solidifies a two dimensional cross section on the surface of the photopolymer. The elevator table then drops enough to cover the solid polymer with another layer of the liquid, which is solidified by laser. This process continues, building the part from the bottom up, until the system completes the product. The part is then raised out of the vat and removal of excess polymer begins by wicking, which uses a blotting material to absorb uncured polymer, immersion in an alcohol bath, or ultrasonic cleaning. It then proceeds to the Post Curing Apparatus (PCA) for the final cure.

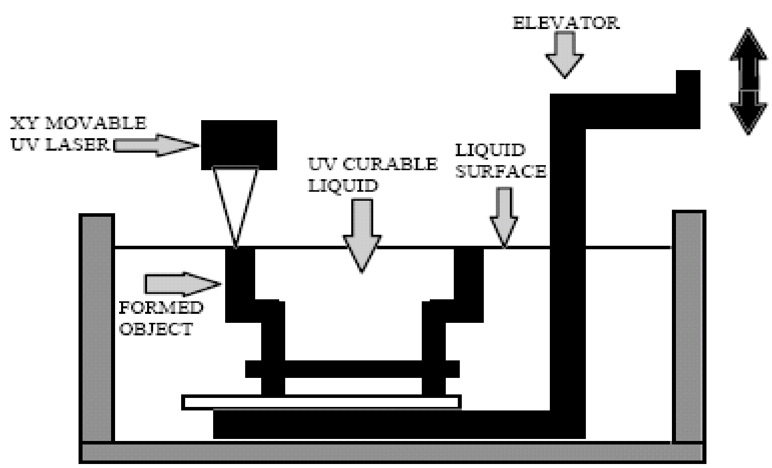


Figure 2.1: Schematic of Stereolithography Technique.

(Source: http://cgm.cs.mcgill.ca/~godfried/clipart/stereolithography)

Next technique is Fused Deposition Modeling. The plastic filament is wounded in the material spool and supplied directly into the heated extrusion head, where the material is melted. The molten material will be extruded from the extrusion nozzle. The nozzle is mounted on a mechanical stage which allows the nozzle move in axis X and axis Y. Then nozzle will be move according to drawing in STL format, and will deposit the thin bead of molten plastic based on the required geometry layer by layer. The molten plastic will solidified immediately after squeezed out from the nozzle and directly bond with the layer below. The whole operation process is held in an oven chamber with the melting temperatures just below the melting point of the materials. This technique requires small amount of additional thermal energy to melt the material. For any model that design have overhanging geometry, support structure need to be create before start the fabrication processes and the support will be remove in the post processing stage. Types of materials available for this RP system are Acrylo-nitrile Butadiene Styrene (ABS), elastomer, polycarbonate, wax, and polysulphones. The implementation of Fused Deposition Modeling (FDM) technique is shown in Figure 2.2.

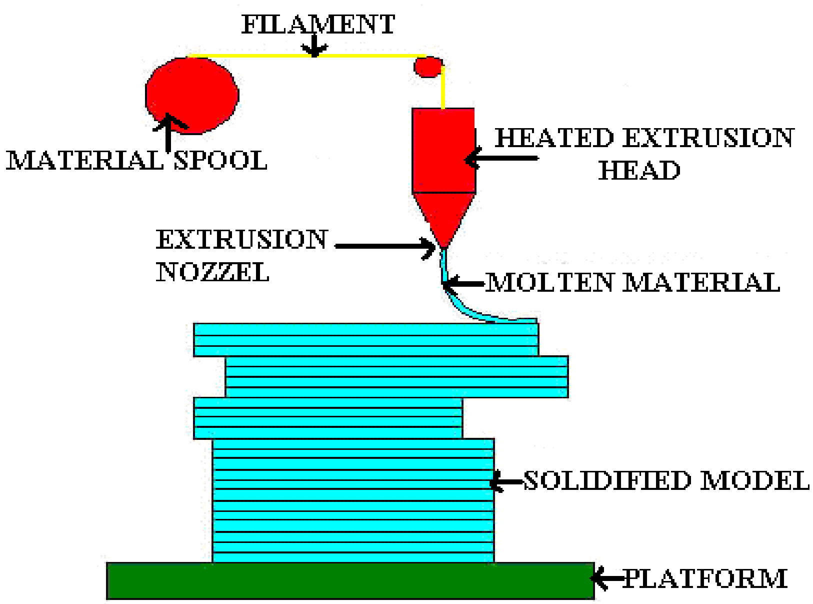


Figure 2.2: Schematic of Fused Deposition Modeling Technique.

(Source: http://www.maxfac.com)

Third technique in this RP is Selective Laser Sintering. This RP technique begins with the building process with a thin layer of powder first deposited in the part build envelope. While the process is carried out, the piston of the powder feed cartridge will move up in order to supply the powder. However, laser beam is guided by a process-control computer using instruction generated by the 3D CAD program of the desired part; is then focused on that layer, tracing and sintering a particular cross section into a solid mass. The roller will spread the powder into the part of build envelope in order to build-up the first layer according to the cross section had been traced by the laser beam. The powder in others area must remain loose, in order to support the sintered part. Another layer of powder is now deposited; this cycle is repeated again and again until the entire three-dimensional part is produced. The loose particles are then shaken off, and the part is removed. The part produced from this technique does not require the further curing, excepted ceramic. The implementation of SLS is shown in Figure 2.3.

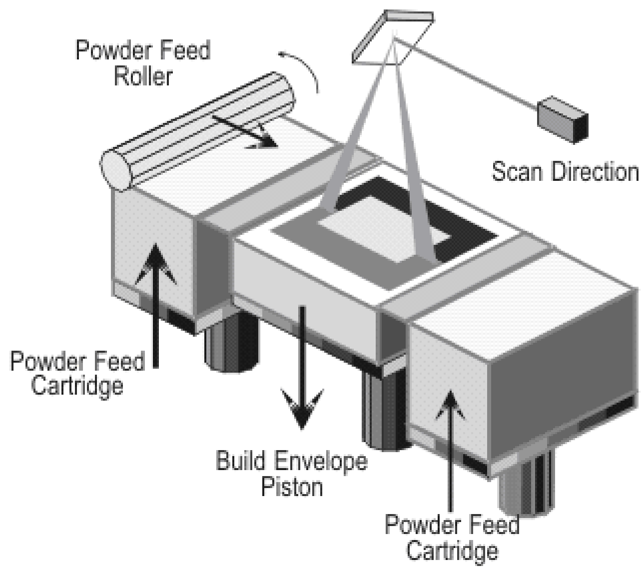


Figure 2.3: Schematic of Selective Laser Sintering Technique

(Source:http://www.azom.com/details.asp?ArticleID=1648)

As shown in Figure 2.4, Laminated Object Manufacturing technique begins with the material is fed onto the material supply roll and is heated by the laminating roller in order to bond the material on the previous material. The laminating roller melts the plastic coating on the bottom side of the paper to create the bond. The profile of the model is traced out by the optic systems, which consist from laser and optics that mounted on the X-Y positioning stage. This process will generate smokes so the chamber needs to seal during the building process carries out. After completed the cutting process, the extra paper will be wound on the take up roll. This method also not required to create the support structure before the fabrication because extra papers become the support structure during the building process. Areas of cross sections which are to be removed in the final model are heavily cross-hatched with the laser to facilitate removal. It’s take quite long time of the removal process for certain geometry of models.

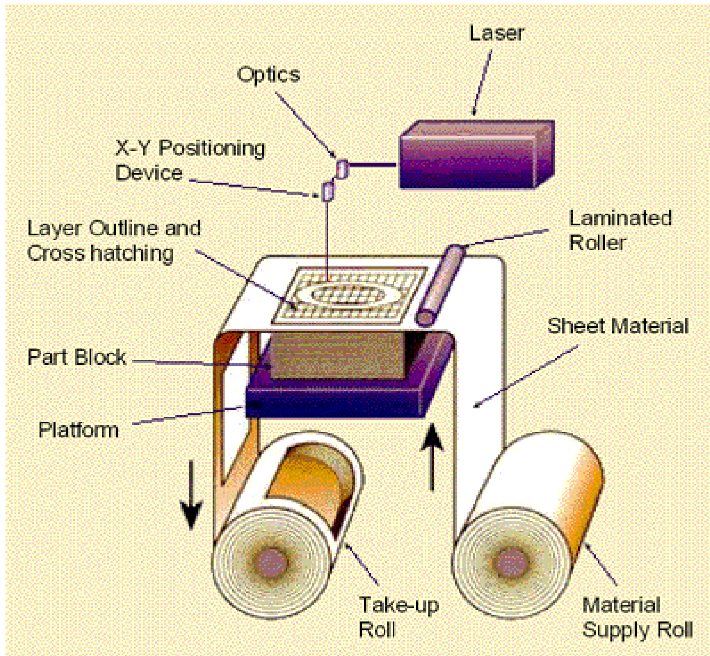


Figure 2.4: Schematic of Laminated Object Manufacturing

(Source: AshutoshChouksey, 2012)

Fifth technique available in RP process is Three Dimensional Printing. The systems will read the drawing in STL format like others of the RP systems and the print head deposit the cross section of the model according the STL file. The multi channel inkjet head will deposit the liquid adhesive from the supply to bond the powder together. The material used in 3D printing systems is powdered material. The powder is filled in the powder deliver system and the powder deliver piston will move up slowly to supply the material. Then the roller will spread and compress the material from the powder delivery supply into the partition of build cylinder. Then the fabrication piston will lower layer by layer in a distance of the layer thickness during the building process. The printing processes are repeated layer by layer that the binder continues to bond the layer into the previous layer until the whole model is completed. This technique also does not need create any support structure before the fabrication process; this is because, just like the Selective Laser Sintering technique, the excess powdered material will support the model until the model is completed. In order to achieve the desired hardness in order to prevent any damage before handling, the model needs be infiltrated with a hardener. The implementation of 3D Printing is shown in Figure 2.5.

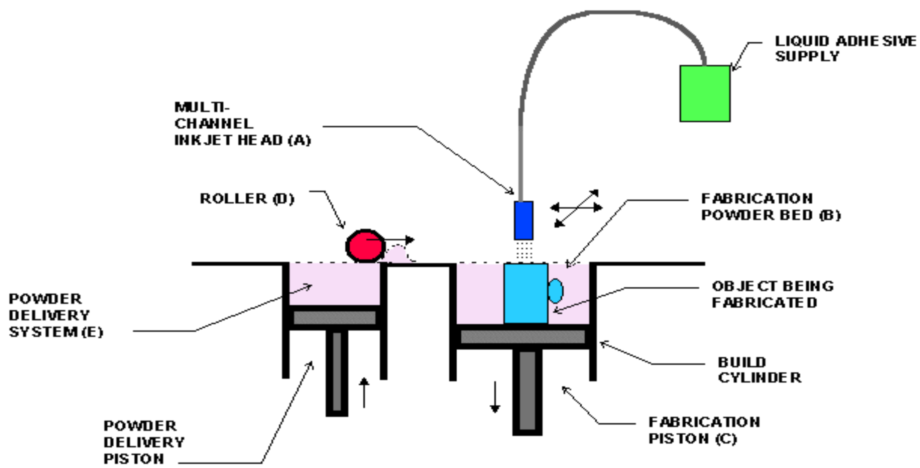


Figure 2.5: Schematic of Three Dimensional Printing

(Source: http:home.att.net/~castleisland/)

2.3.2 Material and Properties

Acrylonitrile Butadiene Styrene (ABS) chemical formula ($C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$) is a common thermoplastic used to make light, rigid, molded products such as piping (for example Plastic Pressure Pipe Systems), musical instruments (most notably recorders and plastic clarinets), golf club heads (used for its good shock absorbance), automotive body parts, wheel covers, enclosures, protective head gear, buffer edging for furniture and joinery panels, airsoft BBs and toys, including Lego bricks. ABS plastic ground down to an average diameter of less than 1 micrometer is used as the colorant in some tattoo inks. Tattoo inks that use ABS are extremely vivid. This vividness is the most obvious indicator that the ink contains ABS, as tattoo inks rarely list their ingredients.

ABS can be used between −25 and 60 °C. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix. Production of 1 kg of ABS requires the equivalent of about 2 kg of oil for raw materials and energy. It can also be recycling. Table 2.1 shows properties of ABS:

Table 2.1: Properties of ABS

(Source: AshutoshChouksey, 2012)

Properties	Specifications
Structure	Amorphous
Specific density	1.05
Water absorption rate (%)	0.27
Elongation (%)	20
Tensile strength (MPa)	29.64
Compression strength (MPa)	62.05
Flexural strength (MPa)	63.43
Flexural modulus (MPa)	2068.48
Impact (joules)	8.94
Hardness	R110
Ultrasonic welding	Excellent
Bonding	Excellent
Machining	Good
Min. utilization temperature (deg. C)	40
Max. utilization temperature (deg .C)	90
Melting point (deg.C)	105
Coefficient of expansion	0.000053
Arc resistance	80
Dielectric strength (KV/mm)	16
Transparency	Translucent
UV Resistance	Poor
Chemical resistance	Good

2.3.3 Literature Study on Rapid Prototyping Process

First literature study is from journal written by Ahn Sung Hoon, at all (2002). This research is focused on raster orientation and air gap parameter. This research uses design of experiment method and concluded that the air gap and raster orientation affect the tensile strength of FDM processes. They further compare the measured tensile strength of FDM part processed at different raster angles and air gap with the tensile strength of injection moulded part. Material use for both type of fabrication is ABSP400. With zero air gap FDM specimen tensile strength lies between 10%-73% of injection moulded part with maximum at 0° and minimum at 90° raster orientation with respect to loading direction. But with negative air gap there is significant increase in strength at respective raster orientation. All specimens failed in transverse direction except for specimen whose alternate layer raster angle varies between 45° and -45°. This type of specimen failed along the 45° line. Compression test on the specimen build at two different orientations revealed that this strength is higher than the tensile strength and lies between 80 to 90% of those for injection moulded part.

Second literature study is from journal written by P. Vijay at all (2011). In the study, surface finish is critical as it can affect the part accuracy, reduce the post-processing costs and improve the functionality of the parts. This paper presents an experimental design technique for determining the optimal surface finish of a part built by varying build orientation, layer thickness. The procedure for the analysis of the surface roughness response in this research was performed as follows:

- The response variable was chosen.
- The effects were calculated.
- Significant effects were chosen from the graph.
- The model graphs were analyzed.

From figure 2.6 below, we can observe that as the layer thickness is increased, the roughness value also increased. From the figure 2.7, we can observe that as the layer thickness is increased, the roughness value decreased. In conclusion, we can conclude that at this layer thickness the roughness value Rz increased slightly and then started reducing accordingly with the increase in orientation.

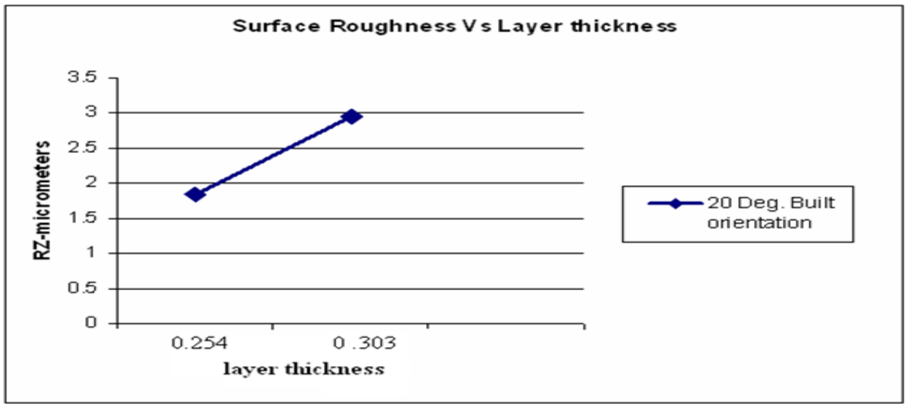


Figure 2.6: Variation of Surface Roughness with Layer Thickness for 20 Deg Build Orientation

(Source: P. Vijay at all, 2011)

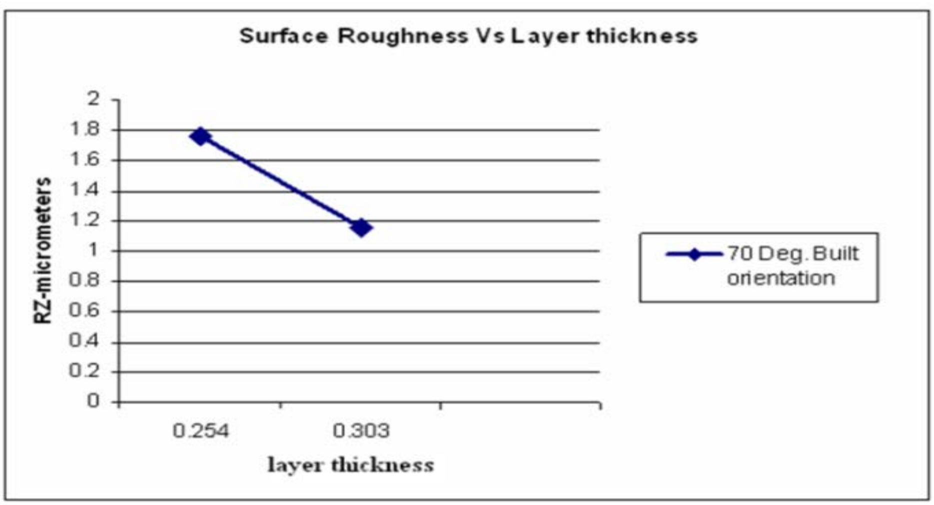


Figure 2.7: Variation of Surface Roughness with Layer Thickness for 70 Deg Build Orientations

(Source: P. Vijay at all, 2011)

Third literature study is taken from journal written by P.M.Pandey, and K.thrimurthulu on 2004. In this research they found Orientation for part deposition is one of the important factors as it affects average part surface roughness. In the present work, two objective functions, namely average part surface roughness and build time, are formulated. The results obtained for different parts that there exist two limiting situations. One is minimum average part surface roughness with maximum production time and another is minimum production time with maximum average part surface roughness. The developed system of part deposition orientation determination also gives a set of intermediate solutions in which any solution can be used depending upon the pre-ference of user for the two objectives. The present system can be used for any class of component, which may be a freeform or a regular object.

This literature review concluded that layer thickness, and air gap are found to significantly effect elastic properties of FDM ABS prototype. The experimental results indicate that the best layer thickness which can be adopted for the building up of high strength prototypes with high accuracy and surface finish. With negative air gap there is significant increase in strength at respective raster orientation. Their observations indicate that raster orientation effect the strength as polymer molecules align themselves along the direction of flow.

2.4 RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. The most extensive applications of RSM are in the particular situations where several input variable potentially influence some performance measure or quality characteristic of the process. This performance measure or quality characteristic is called the response. The input variables are sometimes called independent variables. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, Empirical statistical modelling to develop an approximated relationship between the yield and the process variables. Also, with the help of response surface methodology, optimization can be done for finding the values of the process variables that produce desirable values of the response.In general, the relationship between the response y and independent variables $\mathcal{E}_1, \mathcal{E}_2, \dots, \mathcal{E}_k$is,

$$\Upsilon = f(\mathcal{E}_1, \mathcal{E}_2, \dots, \mathcal{E}_k) + \epsilon \tag{2.1}$$

Where ϵ includes effects such as measurement error on the response, background noise, the effect of other variables, and so on. Usually ε is treated as a statistical error, often assuming it to have a normal distribution with mean zero and variance σ2. Then,

$$\mathrm{E}(y) = \eta = \mathrm{E}[f(\mathcal{E}_1, \mathcal{E}_2, \dots, \mathcal{E}_k)] + \mathrm{E}(\epsilon) = f(\mathcal{E}_1, \mathcal{E}_2, \dots, \mathcal{E}_k) \tag{2.2}$$

The variables $\mathcal{E}_1, \mathcal{E}_2, \dots, \mathcal{E}_k$ in equation (4.2) are usually called the natural variables, because they are expressed in the natural units of measurement, such as degrees Celsius, pounds per square inch, etc. In much RSM work, it is convenient to transform the natural variables to coded variables $x_1, x_2, \dots, x_k$, which are usually defined to be dimensionless with mean zero and the same standard deviation. In terms of the coded variables, the response function equation (2.2) can be written as,

$$\eta = f(\, x_1, x_2, \dots, x_k) \tag{2.3}$$

Because the form of the true response function is unknown, it should be approximated. In fact, successful use of RSM is critically dependent upon the experimenter’s ability to develop a suitable approximation. Usually, a low-order polynomial in some relatively small region of the independent variable space is appropriate. In many cases, either a first-order or a second-order model is used. The first-order model is likely to be appropriate when the experimenter is interested in approximating the true response surface over a relatively small region of the independent variable space in a location where there is little curvature in response function. For the case of two independent variables, the first-order model in terms of the coded variables is given by,

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \tag{2.4}$$

The form of the first-order model in equation (4.4) is sometimes called a main effects model, because it includes only the main effects of the two variables $x_1$andx_2. If there is an interaction between these variables, it can be added to the model easily as expressed below:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 \tag{2.5}$$

This is the first-order model with interaction. Adding the interaction term introduces curvature into the response function. Often the curvature in the true response surface is strong enough that the first-order model (even with the interaction term included) is inadequate. A second-order model will likely be required in these situations. For the case of two variables, the second-order model is:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1 x_1 + \beta_{22} x_2 x_2 + \beta_{12} x_1 x_2 \tag{2.6}$$

This model would likely be useful as an approximation to the true response surface in a relatively small region. The second-order model is widely used in response surface methodology for several reasons:

- The second-order model is very flexible. It can take on a wide variety of functional forms, so it will often work well as an approximation to the true response surface.
- There is considered to be practical experience indicating that second-order models work well in solving real response surface problems. In general, the first-order model is:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 +, \dots, + \beta_k x_k \tag{2.7}$$

And the second-order model is:

$$\eta = \beta_0 + \Sigma_{j=1}^{k} \beta_j x_j + \Sigma_{j=1}^{k} \beta_{jj} x_j x_j + \Sigma_k \Sigma_{j=2}^{k} \beta_{ij} x_i x_j \tag{2.8}$$

Finally, it should be noted that there is a close connection between RSM and linear regression analysis. For example, say, the following model is considered:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 +, \dots, + \beta_k x_k + \epsilon \tag{2.9}$$

Theβ's are a set of unknown parameters. To estimate the values of these parameters, the experimental data must be needed.

2.4.1 Literature Study on Response Surface Methodology

Three journals have been study and were used as references for literature review in this chapter.First journal is from journal written by Amit Kohliand Hari Singh (2011). Since 1980's the processes of surface strengthening (hardening) of steel with the use of high frequency induction (Miller &Lagoudas 1980) have found ever-increasing applications to improve the performance and life of parts used in aerospace and automobile engineering. Thin surface layers (0.25 to 2.3 mm) of the work piece made of steel or cast iron is hardened by induction hardening process. Most important characteristic for the material hardening is the hardness value (Bodart*et al* 2001). Kayacan (2004) took distance between coil and material, cooling time, applied power and frequency as effecting parameters. Optimized fuzzy solution of the induction hardening has been compared with the experimental results conducted by Kayacan (1991).

For this analysis, four factors have been studied and their low and high levels are shown in the Table 2.2. Based on preliminary investigation and review of literature, the range of input parameters which were finally selected is given in Table 2.2. These values of process parameters of induction hardening were utilized for conducting design of experiments in induction hardening machine of AISI 1040 steel, based on design of experimental process. The response variable investigated was hardness at two different conditions of the material as mentioned earlier.

Model equations were simultaneously solved to find the optimal process variables. Design-Expert software was used for maximizing hardness both in rolled and normalized condition. The optimal value for hardness obtained were 56.4 HRC and 57.8 HRC respectively for rolled and normalized condition at feed rate of 3.21 mm/s, dwell time 5 sec, current 135 Amperes and gap between material and inductor coil 5.29 mm as optimum value of process parameters. Validation experiments conducted at optimal parameters gave 55.8 HRC and 57.6 HRC values of hardness at rolled and normalized condition, in agreement with the predicted responses. All the values were within 95% prediction interval. Thus the optimum value of hardness desired was obtained in normalized condition of the material.

Table 2.2: process parameter with their values at three levels:
(Source: Amit Kohliand Hari Singh, 2011)

Factors	Process Parameter	Level 1	Level 2	Level 3
A	Feed rate (mm/s)	2	3	4
B	Dwell time (sec)	5	6	7
C	Current (Ampere)	125	130	135
D	Gap between work piece and induction coil (mm)	5	6	7

Second literature study is taken from journal written by P.K. Bharti (2010).Injection molding has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. Faced with global competition in injection molding industry, using the trialand- error approach to determine the process parameters for injection molding is no longer good enough. Determining optimal process parameter settings critically influences productivity, quality, and cost of production in the plastic injection molding (PIM) industry. Previously, production engineers used either trial-and-error method or Taguchi's parameter design method to determine optimal process parameter settings for PIM. However, these methods are unsuitable in present PIM because of the increasing complexity of product design and the requirement of multi-response quality characteristics.

Response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model. Figure 2.8 below shows cause and effect diagram:

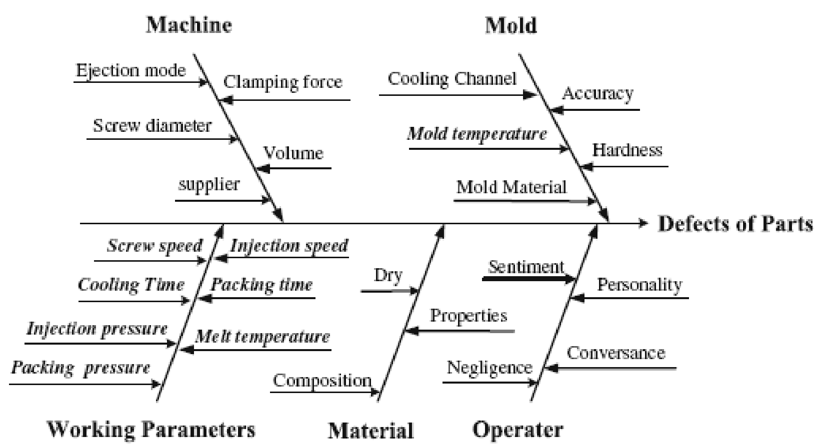


Figure 2.8: Cause and effect diagram shown in fishbone diagram

(Source: P.K. Bharti, 2010)

A review of literature on optimization techniques has revealed that there are, in particular, successful industrial applications of design of experiment-based approaches for optimal settings of process variables. Response surface methodology approach has potential for savings in experimental time and cost on product or process development and quality improvement. There is general agreement that off-line experiments during product or process design stage are of great value. Reducing quality loss by designing the products and processes to be insensitive to variation in noise variables is a novel concept to statisticians and quality engineers. Table 2.3 shows the difference between taguchi method and response surface methodology

Table 2.3: Summary of plastic injection molding optimization techniques**:**
(Source: P.K. Bharti, 2010)

Technique	**References**	**Tools used**	**Remarks**
Taguchi technique	Chung-Feng JeffreyKuo and Te-Li Su (2006)	Design of experiments, Orthogonal arrays, ANOVA	Based on actual experimental work and determination of optimum conditions using statistical tools
Response surface methodology	D. Mathivanan&N. S. Parthasarathy [2009]	Design expert software (DX6)	Based on a injection molding model developed by mathematical and statistical techniques

Third literature study is taken from jornal written by B. Sidda Reddy, and J. Suresh Kuma (2011). End milling is the widely used operation for metal removal in a variety of manufacturing industries including the automobile and aerospace sector where quality is an important factor in the production of slots, pockets and moulds/dies (Mike *et al*, 1999; John and Joseph, 2001). The quality of surface is of great importance in the functional behavior of the milled components. The factors affecting the surface roughness are the machining conditions work piece material and tool geometry. Therefore in order to obtain better surface finish of a milled product, the optimal machining parameters and tool geometry are to be selected.

The response surface methodology comprises regression surface fitting to obtain approximate responses, design of experiments to obtain minimum variances of the responses and optimizations using the approximated responses.

So 50 experiments were conducted and the average surface roughness of all these components was measured and was used to build mathematical model using RSM. The second order response surface representing the surface roughness can be expressed as function of cutting parameters such as nose radius (mm), cutting speed (m/min), feed (mm/tooth), axial depth of cut (mm) and radial depth of cut (mm). The relationship between the surface roughness and machining parameters has been expressed as follows:

$$R_a = \beta_0 + \beta_1(R) + \beta_2(V) + \beta_3(f) + \beta_4(d) + \beta_5(rd) + \beta_6 R^2 + \beta_7 v^2 + \beta_8 f^2 + \beta_9 d^2 + \beta_{10} rd^2 + \beta_{11} R \times v + \beta_{12} R \times f + \beta_{13} R \times d + \beta_{14} R \times v + \beta_{15} v \times f + \beta_{16} v \times d + \beta_{17} v \times rd + \beta_{18} d \times rd \tag{2.10}$$

The multiple regression coefficient of the second order model was found to be 0.506. This shows that second order model can explain the variation of the extent of 50.6%. Table 2.4 shows parameters result before and after the optimization.

Table 2.4: Surface roughness parameters before and after optimization

(Source: A. TolgaBozdana at all, 2011)

	R mm	V m/min	f mm/tooth	d mm	rd mm	Ra µm
Before optimization	1.2	90	0.125	1.5	0.3	0.5
After optimization	0.8	95	0.1	1.5	0.7	0.2789

The response surface methodology analysis has been reviewed. RSM can be used for the approximation of both experimental and numerical responses. Two steps are necessary, the definition of an approximation function and the design of the plan of experiments. A review of different designs for fitting response surfaces has been given. A desirable design of experiments should provide a distribution of points throughout the region of interest, which means to provide as much information as possible on the problem.

2.5 SUMMARY

In this chapter, rapid prototyping process is briefly described. Rapid prototyping literature also discuss together with response surface methodology literature. In this project, response surface methodology is applied to optimize on rapid prototyping process (fused deposition modeling technique) to manufactured coffee maker parts.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the aim is to find method to manufacturing the Coffee Maker part using Rapid prototyping using Response Surface Methodology. This chapter consists of flow chart diagram, experiment sequence, design of experiment (DOE) and testing methods.

3.2 PROCESS OF RAPID PROTOTYPING

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

First, the object to be built is modeled using a Computer-Aided Design (CAD) software package. CATIA V5 is used to design the model and it is finally converted to STL (stereolithography) format.STL format is imported to FDM software.

Second, the various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL (stereolithography), the first RP technique) format has been adopted as the standard of the rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles. The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Large, complicated files require more time to pre-process and build, so the designer must balance accuracy with manageability to produce a useful STL file. Since the .stl format is universal, this process is identical for all of the RP build techniques.

In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location and orientation of the model. Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening build time.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. Supports are useful for delicate features such as internal cavities and thin-walled sections.

The fourth step is the actual construction of the part. Using one of several techniques (described in the next section) RP machines build one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention.

The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.Figure 3.1 show the flow chart of RPand Figure 3.2 show coffee maker to be manufacture.

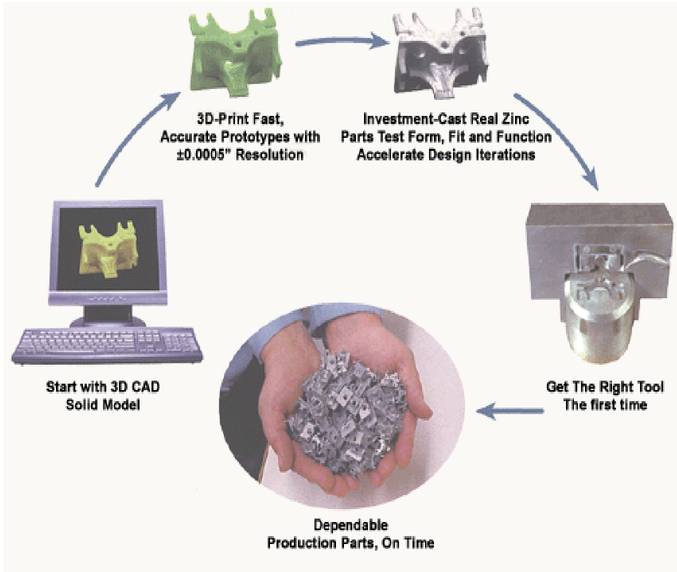


Figure 3.1: Flow chart of rapid prototyping.

(Adopted from journal: Study of parametric optimization of fused deposition modeling)

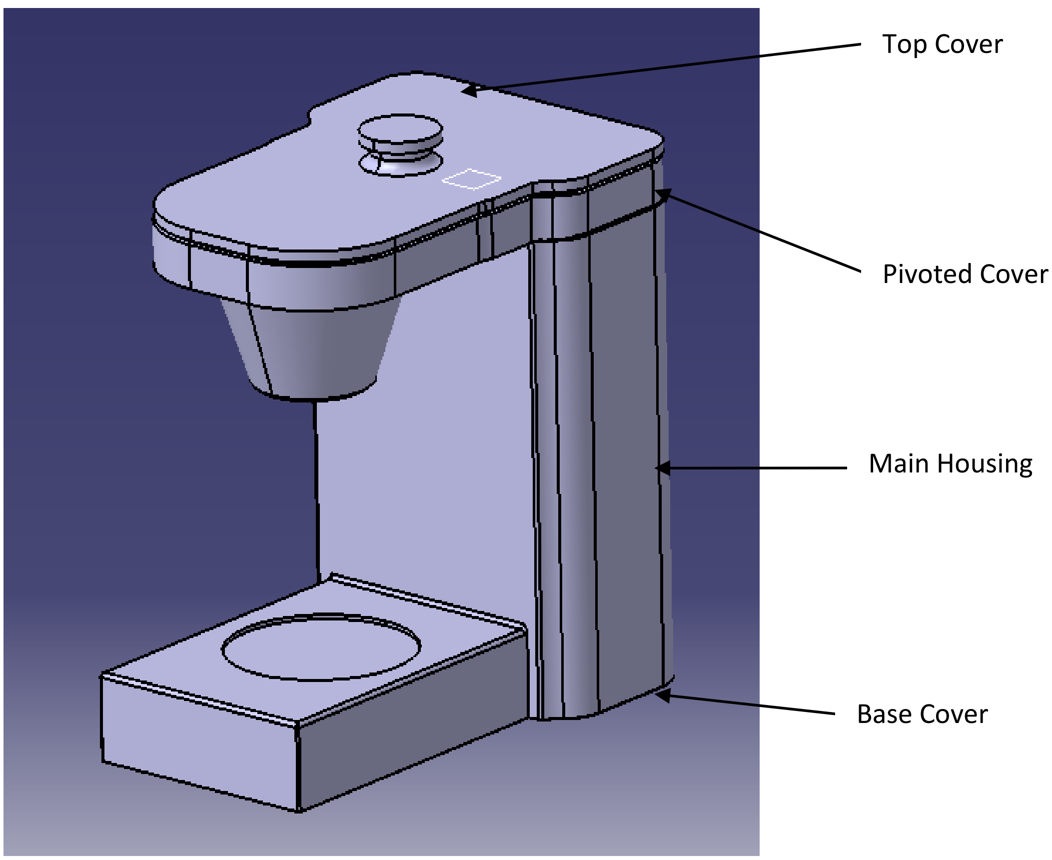
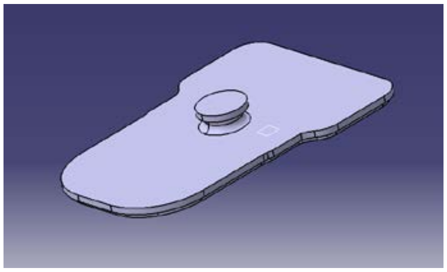
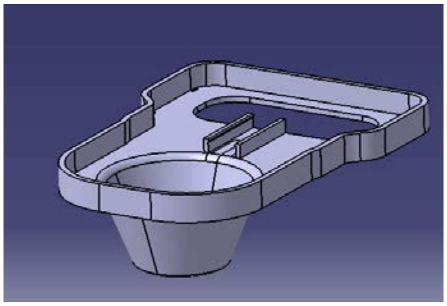
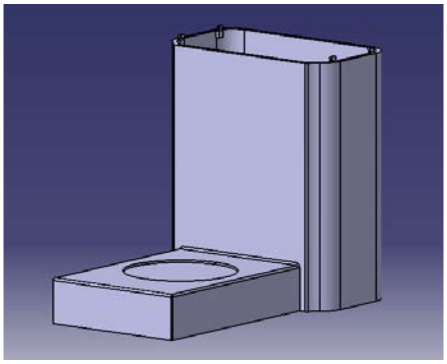
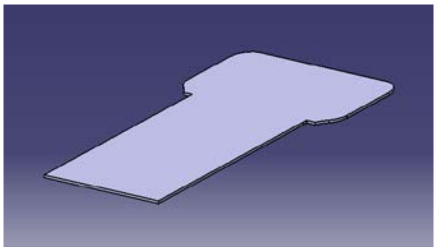


Figure 3.2: Coffee maker to be manufacture

The detail name of part can be seen in Table 3.1 which state all components name and descriptions of each part.

Table 3.1: Design evaluation

Component	Descriptions
1) Top cover 	Sharp and thin curve. Small pin needed to manufacture well.
2) Pivoted cover 	Complex part, involve small and thin wall to be manufacture. Radius shape needed to be control well.
3) Main housing 	Complex pin and thin wall. Small diameters need accurate parameter.
4) Base cover 	Simple part to be manufactured. No complex edge or corner.

3.3 RESPONSE SURFACE METHODOLOGY AND ROBUST DESIGN

RSM is an important branch of experimental design. It is also a critical technology in developing new processes and optimizing their performance. The objectives of quality improvement, including reduction of variability and improved process and product performance, can often be accomplished directly using RSM. It is well known that variation in key performance characteristics can result in poor process and product quality. During the 1980s, considerable attention was given to process quality, and methodology was developed for using experimental design, specifically for the following:

- For designing or developing products and processes so that they are robust to component variation.
- For minimizing variability in the output response of a product or a process around a target value.
- For designing products and processes so that they are robust to environment conditions.
- By robust means that the product or process performs consistently on target and is relatively insensitive to factors that are difficult to control.

3.4 THE SEQUENTIAL OF RESPONSE SURFACE METHODOLOGY

Most applications of RSM are sequential in nature. Phase 0, at first, some ideas should be generated concerning which factors or variables are likely to be important in response surface study. It is usually known as a screening experiment. The objective of factor screening is to reduce the list of candidate variables to a relatively few so that subsequent experiments will be more efficient and require fewer runs or tests. The purpose of this phase is the identification of the important independent variables.

Phase 1, the objective of the experiment is to determine if the current settings of the independent variables result in a value of the response that is near the optimum. If the current settings or levels of the independent variables are not consistent with optimum performance, then a set of adjustments must be done to the process variables that will move the process toward the optimum. This phase of RSM makes considerable use of the first-order model and an optimization technique called the method of steepest ascent /descent.

Phase 2, when the process is near the optimum, it is required to develop a model that will accurately approximate the true response function within a relatively small region around the optimum. As the true response surface usually exhibits curvature near the optimum, a second-order model (or perhaps some higher-order polynomial) should be used. Once an appropriate approximated model has been obtained, this model may be analyzed to determine the optimumconditions for the process. This sequential experimental process is usually performed within some region of the independent variable space called the operability region or experimentation region or region of interest.

3.5 VARIABLE SELECTION AND MODEL BUILDING IN REGRESSION

In response surface analysis, it is customary to fit the full model corresponding to the situation at hand. It means that in steepest ascent, the full first-order model is usually fitted, and in the analysis of the second-order model, the full quadratic is usually fitted. Nevertheless, in some cases, where the full model may not be appropriate; that is, a model based on a subset of the regressors in the full model may be superior. Variable selection or model-building techniques usually is used to identify the best subset of regressors to include in a regression model. Now, it is assumed that there are K candidate regressors denoted $x_1, x_2, \ldots, x_k$ and a single response variable y. All models will have an intercept term β_0, so that the full model has (K + 1) parameters. It is shown that there is a strong motivation for correctly specifying the regression model: Leaving out importantregressors introduces bias into the parameter estimates, while including unimportant variables weakens the prediction or estimation capability of the model.

3.5.1 Stepwise regression methods

As the evaluation of all possible regressions can be burdensome, various methods have been developed for evaluating only a small number of subset regression models by either adding or deleting regressors one at a time. These methods are generally referred to as stepwise-type procedures. They can be classified into three broad categories:

1) Forward selection,
2) Backward elimination, and
3) Stepwise regression, which is a popular combination of procedures (a) and (b)

3.6 DESIGN OF EXPERIMENT

3.6.1 Rapid Prototyping

Most commercially available rapid prototyping machines use one of six techniques. At present, trade restrictions severely limit the import/export of rapid prototyping machines**.** In this study, Fused Deposition Modelling (FDM) technique is uses. FDM is one of the RP technology developed by Stratasys, USA. But unlike other RP systems which involve an array of lasers, powders, resins, this process uses heated thermoplastic filaments which are extruded from the tip of nozzle in a temperature controlled environment. For this there is a material deposition subsystem known as head which consist of two liquefier tips. One tip for model material and other tip for support material deposition both of which works alternatively. The article forming material is supplied to the head in the form of a flexible strand of solid material from a supply source (reel).

One pair of pulleys or rollers having a nip in between are utilized as material advance mechanism to grip a flexible strand of modeling material and advance it into a heated dispensing or liquefier head. The material is heated above its solidification temperature by a heater on the dispensing head and extruded in a semi molten state on a previously deposited material onto the build platform following the designed tool path. The head is attached to the carriage that moves along the X-Y plane. The build platform moves along the Z direction. The drive motion are provided to selectively move the build platform and dispensing head relative to each other in a predetermined pattern through drive signals input to the drive motors from CAD/CAM system.

The fabricated part takes the form of a laminate composite with vertically stacked layers, each of which consists of contiguous material fibres or rasters with interstitial voids. Fibre-to-fibre bonding within and between layers occurs by a thermally-driven diffusion bonding process during solidification of the semi-liquid extruded fibre.Main process parameters involved in part manufacturing are:

1) Build Orientation

Part builds orientation or orientation referrers to the inclination of part in a build platform with respect to X, Y, Z axis. Where X and Y-axis are considered parallel to build platform and Z-axis is along the direction of part build.

2) Layer Thickness

It is a thickness of layer deposited by nozzle.

3) Air Gap

The gap between inner most contours and the edge of the raster fill inside of the contour.

3.6.2 Response Surface Methodology

Analysis of the values obtained on experiment is done on MINITAB 15 software which develops quadratic response design according to following equation:

$$y = \beta_0 + \Sigma_{i=1}^{k}\beta_1 x_1 + \Sigma_{i=1}^{k}\beta_{ii}x_i x_i + \Sigma_{i<j}\Sigma\beta_{ij}x_i x_j \qquad (3.1)$$

In order to build empirical model**,** experiments were conducted based on central composite design (CCD). The CCD is capable of fitting second order polynomial and is preferable if curvature is assumed to be present in the system. To reduce the experiment run, half factorial (two levels) is considered. Maximum and minimum value of each factor is coded into +2 and -2 respectively using, so that all input factors are represented in same range

CATIA V5 is used to design the model and it is finally converted to STL(stereolithography) format.STL format is imported to FDM software.CCD (central composite design) is used to design the experimental runs and empirical modelling of the process. Table 3.2 shows the example of levels of process parameter. In order to model the experiment it is conducted based on CCD.To reduce the experiment run, half factorial (two levels) is considered.A CCD of second order polynomial is used because it takes into account all the interaction factors.Maximum and minimum value of each factor is coded into +2 and -2 according to the following equation:

$$\mathcal{E}_{ij} = 2 \times \frac{x_{ij} - \left(x_{i,max} + x_{i,min}\right)/2}{\left(x_{i,max} - x_{i,min}\right)/2} \qquad (3.2)$$

Where $\mathcal{E}_{ij}$ and x_{ij} are coded and actual value of j^{th} level and i^{th} factor respectively.

Table 3.2: Example of levels of process parameter

(Source: AshutoshChouksey, 2012)

Factor	Symbol	Unit	Levels				
			Lowest(-2)	Low(-1)	Middle(0)	High(1)	Highest(2)
Layer Thickness	A	mm	0.127	0.158	0.190	0.222	0.254
Orientation	B	degree	0	15	30	45	60
Air gap	C	mm	0	0.002	0.004	0.006	0.008

3.6.3 Testing Methods

Each of the specimen will undergo to test which is tensile test and surface roughness test. Tensile test will be undergo using an Instron 1195 series IX while surface roughness finishes will be capture and measure using Optical Video Measuring System and Surfcom 130A. Where ever the specimen is done undergo tensile test and surface roughness test, data will be taken. Response Surface Methodology will undergo analysis of each test. For tensile test, highest value is better and for surface roughness, lowest value is better. When the optimum parameter is determine, each part of redesign coffee maker part will be manufacture. Each part needs to be check their dimension as well as drawing so that every part can be assembles with best accuracy. Otherwise, every part should be function well because function ability for this product is the main objectives. Function ability means, every product can function well as real product in term of movement, water flow, and assemble and re-assemble. Figure 3.3 shows flow chart for manufacturing this coffee maker parts.

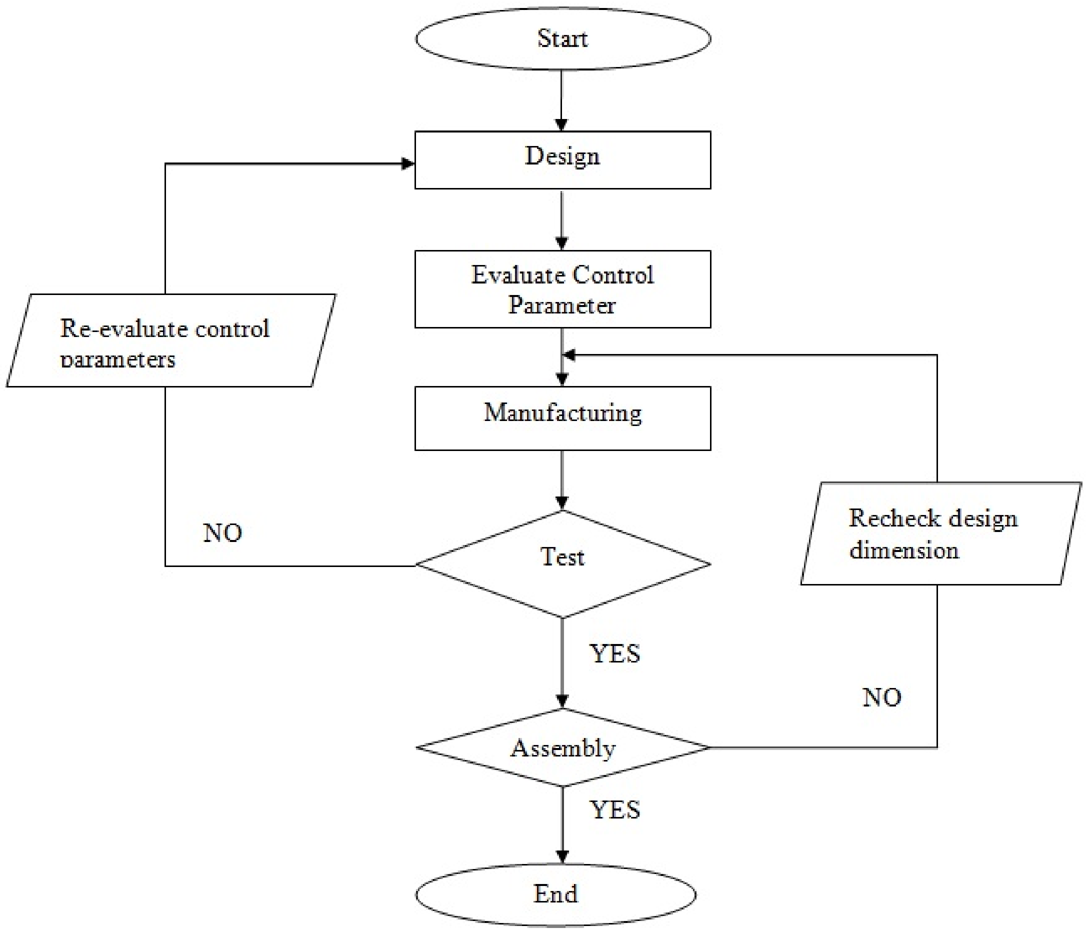


Figure 3.3: Flow chart for manufacturing of coffee maker parts.

3.7 SUMMARY

Effect of three process parameters layer thickness, build orientation, and air gap are studied on three responses surface roughness finish, accuracy assemble and function ability of coffee maker. Experiments were conducted using centre composite design (CCD). Empirical relations between each response and process parameters were determined. To get the optimal level concept of simultaneous optimization of two responses desirability function is used for maximizing the all the responses and found out the optimal parameter.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the aim is to find the optimum parameter of Rapid Prototyping process using Response Surface Methodology where the Coffee Maker should have high tensile strength and low surface roughness. Specimens were prepared using different level of parameter based on DOE of RSM. Results of tensile and surface roughness test were analyze using MINITAB 15.

4.2 SPECIMEN PREPARATION

Tensile test and surface roughness specimens having dimensions 33mm x 19mm x 2mm. Since orientation is an important parameter for part strength, tests have been conducted by changing the orientation for measuring tensile strength according to ASTM D638 (IV), (Material Testing System Manufacturer). STL file is imported to FDM software (Insight centre and Control centre). Here, factors are set as per experiment plan. One part per experiment is manufactured using FDM Fortus 360mc machine. The material use for part manufactured is ABS M30. Parts are modeled and experiment is conducted. Figure 4.1 show line diagram of specimen for tensile test. Table 4.1 shows the domain of the experiments.

Table 4.1: Domain of the experiments

Factor	Symbol	Unit	Levels				
			Lowest(-2)	Low(-1)	Middle(0)	High(1)	Highest(2)
Layer Thickness	A	mm	0.127	0.158	0.190	0.222	0.254
Orientation	B	degree	0	15	30	45	60
Air gap	C	mm	0	0.002	0.004	0.006	0.008

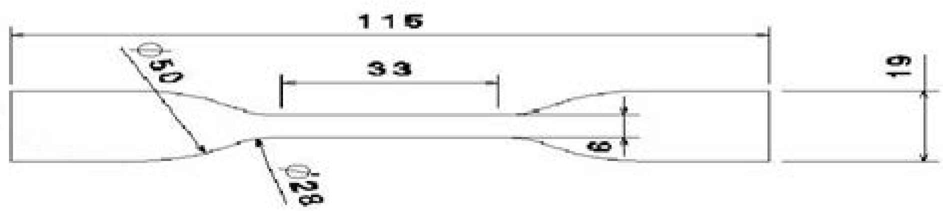


Figure 4.1: Line diagram of specimen for tensile and surface roughness test

After making the test specimen According to response surface design 20 runs on the FDM Fortus 360mc RP machine, these specimens were tested.

4.3 TESTING OF SPECIMENS

4.3.1 Testing of specimen for tensile test

Tensile strength at break is determined according to ISO R527:1966 for plastic product shows the shape of the test specimens. For this specimen is supported by two supports and loaded in the middle by force, until the test specimen fractures. The tensile testing were performed using an Instron 3395 series IX automated material testing system with crosshead speeds of 1mm/s and 2mm/s respectively. Figure 4.2 show how tensile test were done and figure 4.3 and 4.4 shows the specimen before and after fracture.

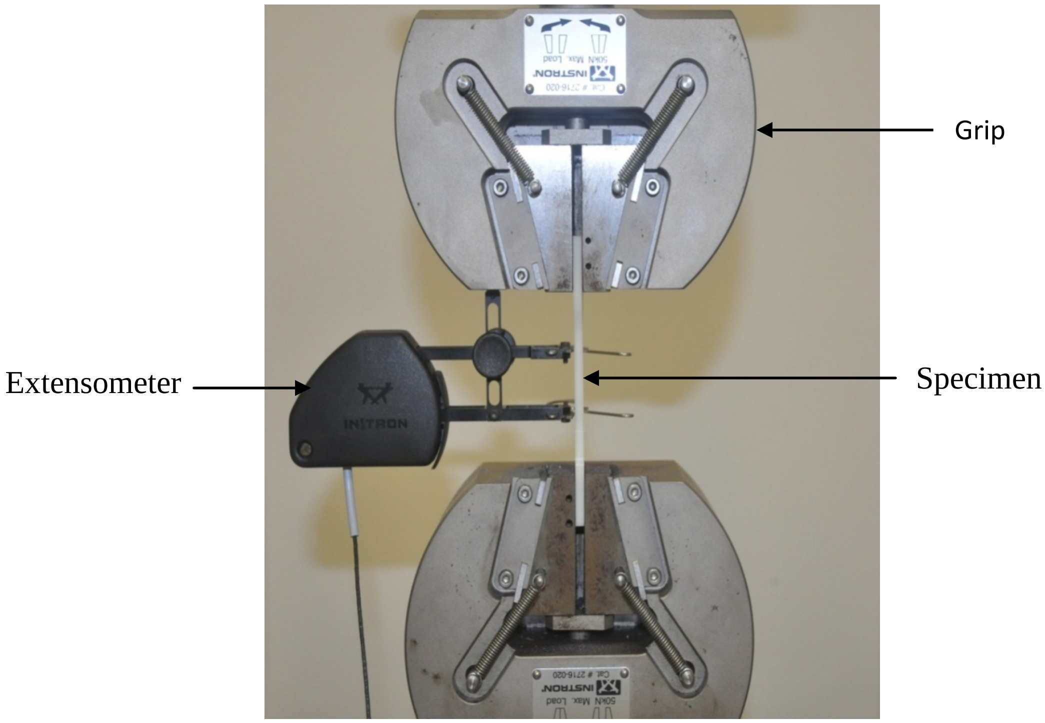


Figure 4.2: Tensile test.

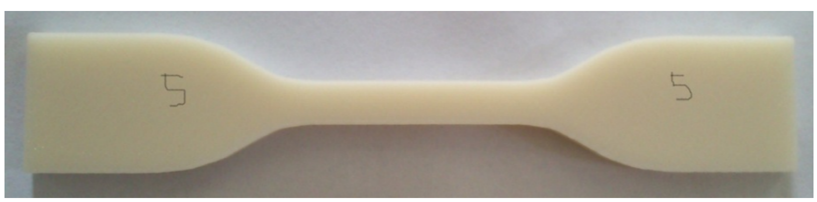


Figure 4.3: Specimen before fracture.

Figure 4.4: Specimen after fracture.

In order to build empirical model for tensile strength and surface roughness, experiments were conducted based on central composite design (CCD). The CCD is capable of fitting second order polynomial and is preferable if curvature is assumed to be present in the system. To reduce the experiment run, half factorial (two levels) is considered. Maximum and minimum value of each factor is coded into -2 and +2 respectively using, so that all input factors are represented in same range.

$$\mathcal{E}_{ij} = 2 \times \frac{x_{ij} - (x_{i,max} + x_{i,min})/2}{(x_{i,max} - x_{i,min})/2} \tag{4.1}$$

Where $\mathcal{E}_{ij}$ and x_{ij} are coded and actual value of j^{th} level and i^{th} factor respectively. Table 4.2 shows an experimental data obtained from the CCD runs.

Table 4.2: Experimental data obtained from the CCD runs.

Run Order	Factors (coded units)			Tensile Strength (N/mm^2)	Surface Roughness (µm)
	A	B	C		
1	-1	-1	1	11.54	5.21
2	1	-1	-1	17.76	4.63
3	-1	1	-1	10.04	4.98
4	1	1	1	13.69	2.17
5	-1	-1	-1	14.29	3.45
6	1	-1	1	12.35	2.87
7	-1	-1	-1	16.73	5.22
8	1	-1	1	16.17	3.94
9	-1	1	1	11.04	6.08
10	1	1	-1	11.86	4.50
11	-1	-1	1	12.94	4.68
12	-1	1	-1	10.05	5.39
13	-2	0	0	11.14	4.32
14	2	2	0	16.10	1.74
15	0	-2	0	16.55	4.91
16	0	2	0	11.04	5.63
17	0	0	-2	15.60	6.12
18	0	0	2	14.17	3.96
19	0	0	0	9.11	3.86
20	0	0	0	13.40	4.72

4.3.2 Testing of specimen for surface roughness test

Parameters for rapid prototyping machine such as layer thickness, build orientation and air gap would result in an accurate and useful model to predict surface finish. For surface roughness test, Optical Video Measuring System and Surfcom 130A were used to measure surface toughness and get the image of the surface. Three main specimens were taken as sample to compare which are the lowest, middle and the best surface roughness. Figure 4.5 and 4.6 showOptical Video Measuring System and Surfcom 130A. Figure 4.7, 4.8 and 4.9 are the sample taken.

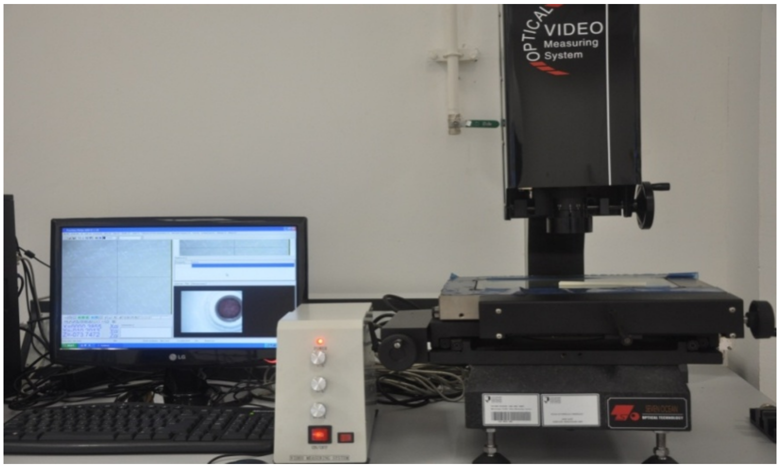


Figure 4.5 Optical video measuring system used to capture image of surface

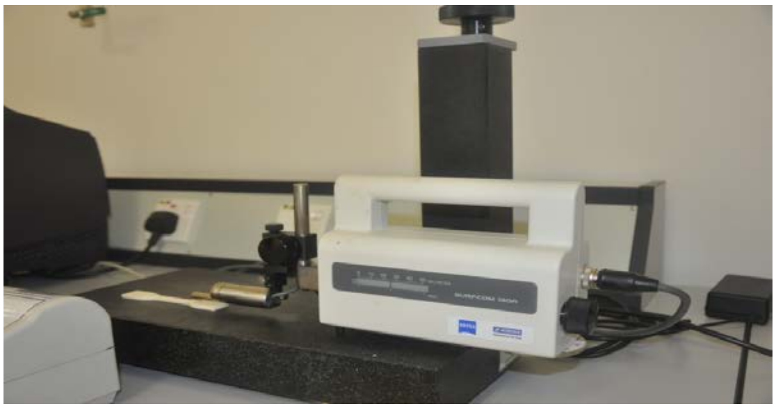


Figure 4.6: Surfcom 130A used to measure surface

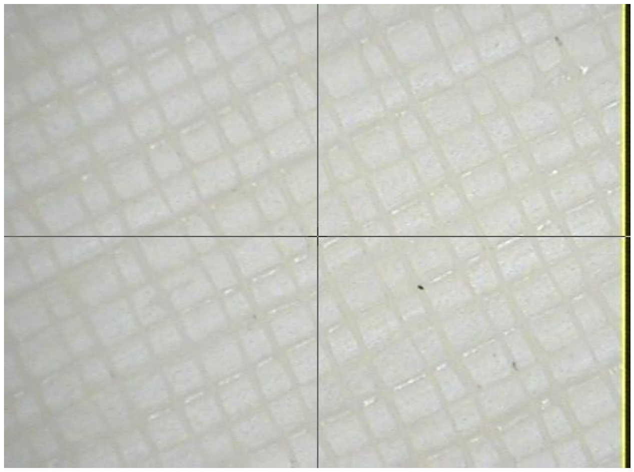


Figure 4.7: High surface roughness (6.12µm)

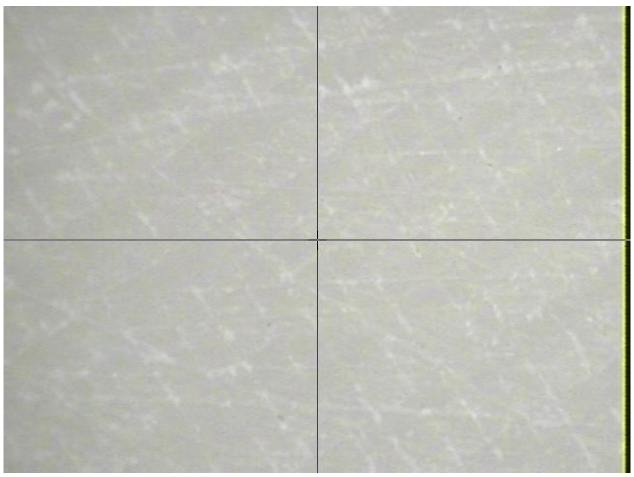


Figure 4.8: Moderate surface roughness (3.45µm)

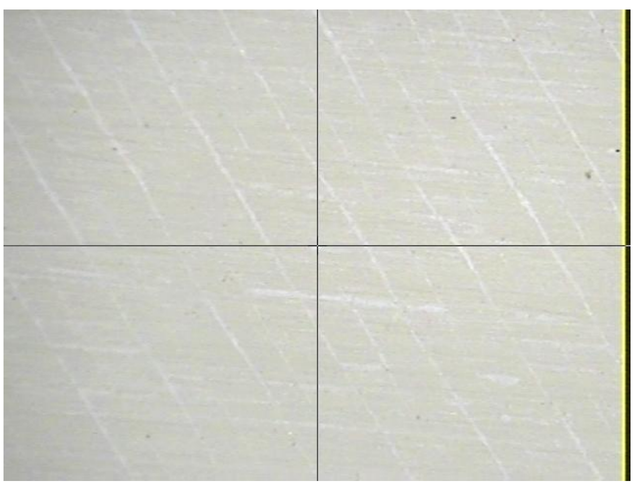


Figure 4.9: Good surface roughness (1.74µm)

4.4 ANALYSIS OF EXPERIMENT

4.4.1 Analysis for tensile test

Analysis of the experimental data obtained from CCD design runs is done on MINITAB R15 software using full quadratic response surface model as given by.

$$y = \beta_0 + \Sigma_{i=1}^{k} \beta_1 x_1 + \Sigma_{i=1}^{k} \beta_{ii} x_i x_i + \Sigma_{i<j} \Sigma \beta_{ij} x_i x_j \tag{4.2}$$

Where y is the response, x_i is i^{th} factor

For significance check *F* value given in ANOVA table is used. Probability of *F* value greater than calculated *F* value due to noise is indicated by *P* value. If *P* value is less than 0.05, significance of corresponding term is established. For lack of fit *P* value must be greater the 0.05. An insignificant lack of fit is desirable as it indicates anything left out of model is not significant and develop model fits.

Based on analysis of variance (ANOVA) test full quadratic model was found to be suitable for tensile strength with regression *P* value less than 0.05 and lack of fit more then 0.05. Table 4.3 shows an estimated regression coefficient for tensile test.

Table 4.3: Estimated regression coefficients for tensile test

Term	Coefficient	SE Coefficient	T	*P*
Constant	11.1524	0.8754	12.739	0.000
A	2.2543	0.7311	3.083	0.012
B	-2.9744	0.6363	-4.675	0.001
C	-0.8585	0.6698	-1.282	0.229
A*A	2.3581	1.4802	1.593	0.142
B*B	2.7007	1.3319	2.028	0.070
C*C	3.7104	1.4245	2.605	0.026
A*B	0.4481	1.4438	0.310	0.763
A*C	0.2854	1.7346	0.165	0.873
B*C	4.7223	1.7321	2.726	0.021

S =1.454 R^2 = 83.13% R^2 (adj) = 67.94%

In tensile test analysis, factors A, B and interaction C*C, and B*C are important because their *P* value is less than 0.05. The coefficient of determination R^2 which indicates the goodness of fit for the model so the value of R^2 =83.13% which indicate the high significance of the model. Table 4.4 shows an analysis of variance for tensile test. With the above analysis we found the following regression equation:

$$Ts = 11.1524 + 2.2543*A - 2.9744*B + 3.7104(C*C) + 4.7223(B*C) \quad (4.3)$$

Table 4.4: Analysis of variance for tensile test

Source	Degree of Freedom	Tensile strength			
		Sum of Square	Mean Sum of square	*F*	*P*
Regression	9	104.165	11.5739	5.47	0.007
Linear	3	64.434	20.0480	9.48	0.003
Square	3	22.735	5.7613	2.73	0.100
Interaction	3	16.996	5.6654	2.68	0.104
Lack of fit	5	0.686	0.1372	0.03	0.999
Residual error	10	21.141	2.1141		
Error	5	20.455	4.0910		
Total	19	125.306			

In the above table we can see*P* value of all the term is more than 0.05, so these all term are non significant, and significance of linear is desired in this case value of linear is 0.003 which is less than 0.05 and significant. From the above analysis, result of predicted and actual will be a bit difference. With the interaction effect is more than 0.05, it will affect the result of predicted value. Using determination value, R^2 = 83.13%, this experiment would be balance in term of predicted and actual value of tensile strength analysis which means actual result would not have too much difference with predicted value. Figure 4.10 shows the graph of tensile test result for predicted and actual.

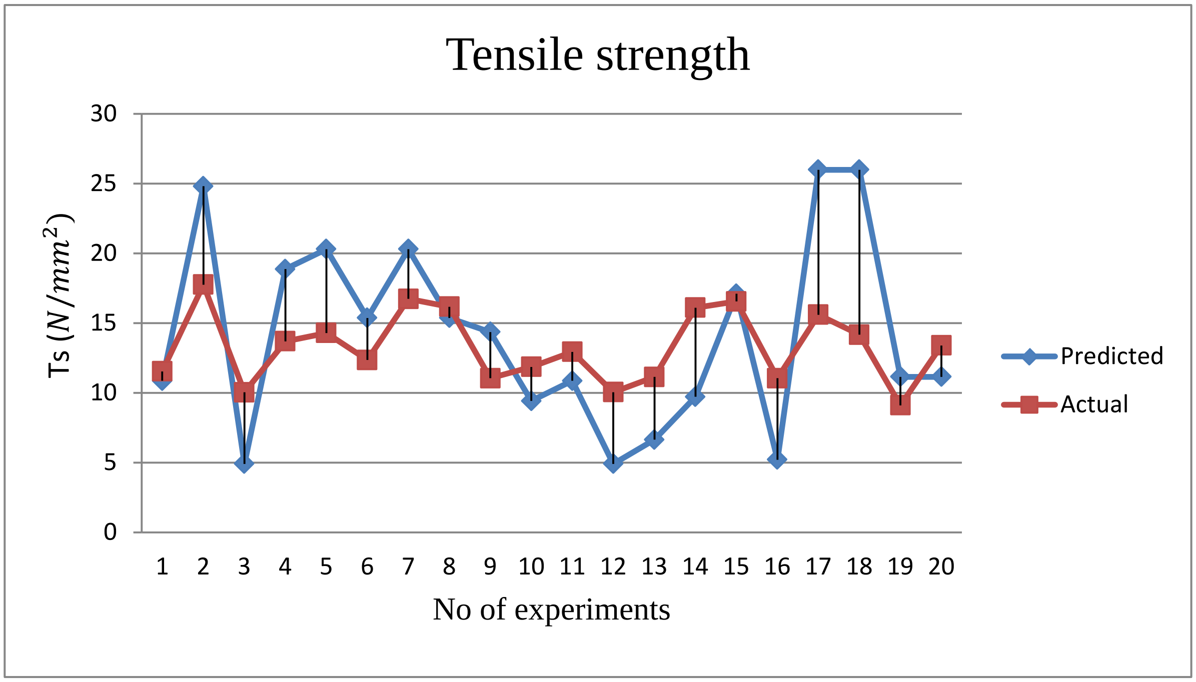


Figure 4.10: Graph of tensile test result for predicted and actual.

The actual result is tabulated from the data obtained from the tensile test experiment. Where the predicted result is obtain from the regression equation of RSM analysis. Result of actual shows that there is a lot of difference between the predicted results. This occurs because of the R^2tensile test is 83.13% which is high but not the highest. From the graph, we can observe that the highest tensile test for predicted is 25 N/mm^2 and the lowest is 5N/mm^2. For actual result, the highest is 17.76 N/mm^2 and the lowest is 9.11N/mm^2. It can be concluded that, tensile strength increases with layer thickness increasing and air gap decreasing whereas increase in value of orientation value of tensile strength decreases. The most factors contributed for tensile test is layer thickness (A).The reason may be that at smaller layer thickness numbers of layers are more resulting in increase in heat conduction towards the bottom layers therefore strong bonding between adjacent raster is expected. But this also increases the distortion in bottom layers which is responsible for weak bond strength, so with increase in layer thickness distortion in layer thickness decreased and tensile strength increased.

4.4.2 Analysis for surface roughness

For analyzing the surfaces roughness we use the Optical projector and Surfcom 130A. This is an instrument used for capturing and imaging of surface and measuring surface roughness (Ra). The relationship between the surface roughness and machining parameters has been expressed as follows

$$R_a = \beta_0 + \beta_1(A) + \beta_2(B) + \beta_3(C) + \beta_4(A * A) + \beta_5(B * B) + \beta_6(C * C) + \beta_7(A * B) + \beta_8(A * C) + \beta_9(B * C) \tag{4.4}$$

The tests for significance of the regression and individual model coefficients were performed to verify the goodness of fit for the obtained model. The analysis of variance (ANOVA) was applied to summaries these tests. Analysis of variance essentially consists of partitioning the total variation in an experiment into components ascribable to the controlled factors and error. The statistical significance of the fitted quadratic models was evaluated by the *P*-values of ANOVA. The model is adequate at 95% confidence level since the *F* calculated value is greater than the *F*-table value. When *P*-values are less than 0.05 (or 95% confidence), the obtained models are considered to be statistically significant.

The other important coefficient is the determination coefficients, R^2, which defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. The more R^2 approaches to unity, the better the response model fits the actual data. The *F* ratios are calculated for 95% level of confidence and the factors having *P* value more than 0.05 are considered insignificant. For the appropriate fitting of SR, the non-significant terms are eliminated by some process. The regression model is re-evaluated by determining the unknown coefficients, which are tabulated in Table 4.5.

Table 4.5: Estimated regression coefficients for surface roughness test

Term	Coefficient	SE Coefficient	T	*P*
Constant	4.2408	0.3604	11.766	0.000
A	-1.2816	0.3010	-4.258	0.002
B	0.2111	0.2620	0.806	0.439
C	-0.7480	0.2758	-2.712	0.022
A*A	-1.1206	0.6094	-1.839	0.096
B*B	1.0701	0.5484	1.952	0.080
C*C	0.7951	0.5865	1.356	0.205
A*B	-1.4699	0.5944	-2.473	0.033
A*C	-2.4722	0.7141	-3.462	0.006
B*C	-0.3931	0.7131	-0.551	0.594

S =0.598624 R^2 = 86.44% R^2 (adj) = 74.24%

In surface roughness analysis, factors A, C and interaction of A*C are important because their *P* value is less than 0.05. The coefficient of determination R^2 which indicates the goodness of fit for the model so the value of R^2 =83.13% which indicate the high significance of the model. Table 4.6 shows an analysis of variance for surface roughness. With the above analysis we found the following regression equation:

$$Ra = 4.2408 - 1.2816*A + 0.2111*B - 0.7480*C - 1.1206(A*A) + 1.0701(B*B) + 0.7951(C*C) - 1.4699(A*B) - 2.4722(A*C) - 0.3931(B*C) \quad (4.5)$$

Table 4.6: Analysis of variance for surface roughness

Source	Degree of Freedom	Tensile strength			
		Sum of Square	Mean Sum of square	*F*	*P*
Regression	9	22.8469	2.5385	7.08	0.003
Linear	3	10.7738	3.4867	9.73	0.003
Square	3	6.1253	1.2153	3.39	0.062
Interaction	3	5.9477	1.9826	5.53	0.017
Lack of fit	5	0.8503	0.1701	0.31	0.887
Residual error	10	3.5835	0.3584		
Error	5	2.7332	0.5466		
Total	19	26.4304			

In the above table we can see P value of all the term is less than 0.05, so these all term are significant, and significance of square is desired in this case value of square is 0.062 which is more than 0.05 and not significant. Figure 4.11 show the graph of surface roughness result for predicted and actual.

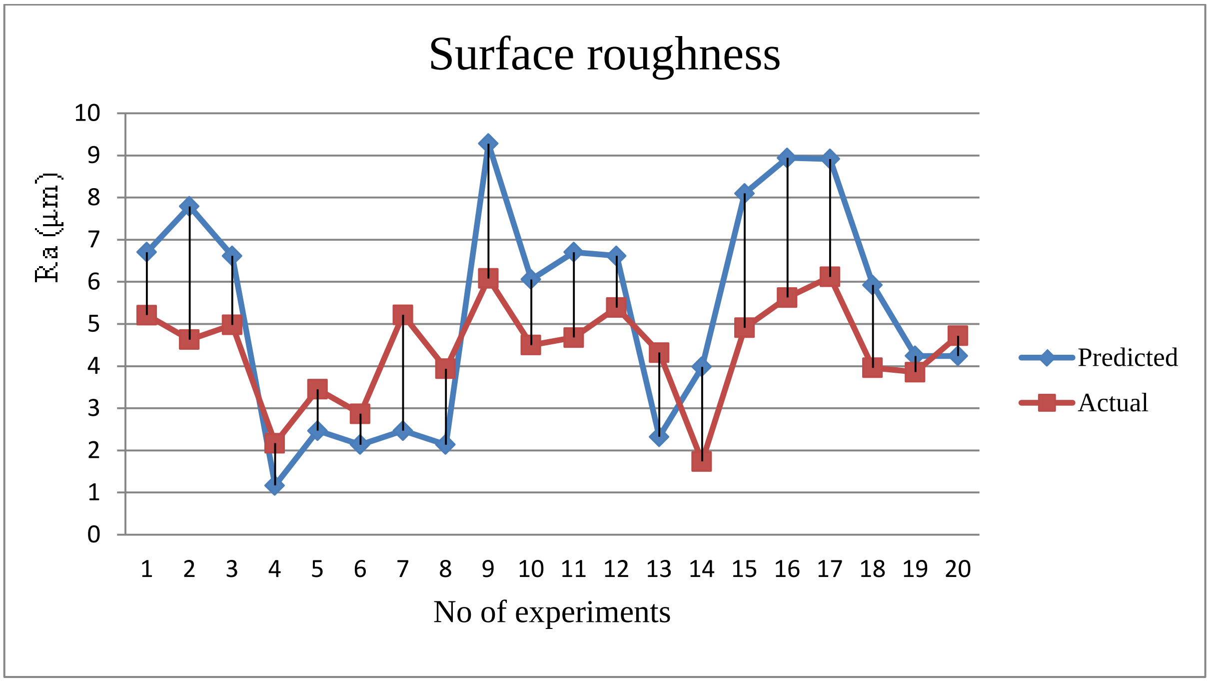


Figure 4.11: Graph of surface roughnessresult for predicted and actual

The actual result is tabulated from the data obtained from the surface roughness measurement. Where the predicted result is obtain from the regression equation of RSM analysis. Result of actual shows that there is slightly difference between the predicted results. This occurs because of the R^2tensile test is 86.44% which is high goodness fit of model. From the graph, we can observe that the highest surface roughness test for predicted is 9.1 µm and the lowest is 1.2 µm. For actual result, the highest is 6.12 µm and the lowest is 1.74 µm. The most factors contributed for low surface roughness is build orientation (B). It have been proved by the experiments that, increase of layer thickness with increase build orientation results on low surface roughness where air gap remain constants.

4.5 DISCUSSIONS

The tensile strength and surface roughness data of ABS sample with different level of process parameter are shown in Table 4.7. Figure 4.12 show the graph of tensile test and surface roughness result.

Table 4.7: Six sample taken from RSM analysis for tensile test and surface roughness

Run order	Factor			Tensile strength (N/mm^2)	Surface roughness (μm)	Strain Extension (mm)
	Layer thickness	Build orientation	Air gap			
3	-1	1	-1	10.04	4.98	1.3
4	1	1	1	13.69	2.17	0.9
5	-1	-1	-1	14.29	3.45	1.4
14	2	2	0	16.10	1.74	1.3
17	0	0	-2	15.60	6.12	1.1

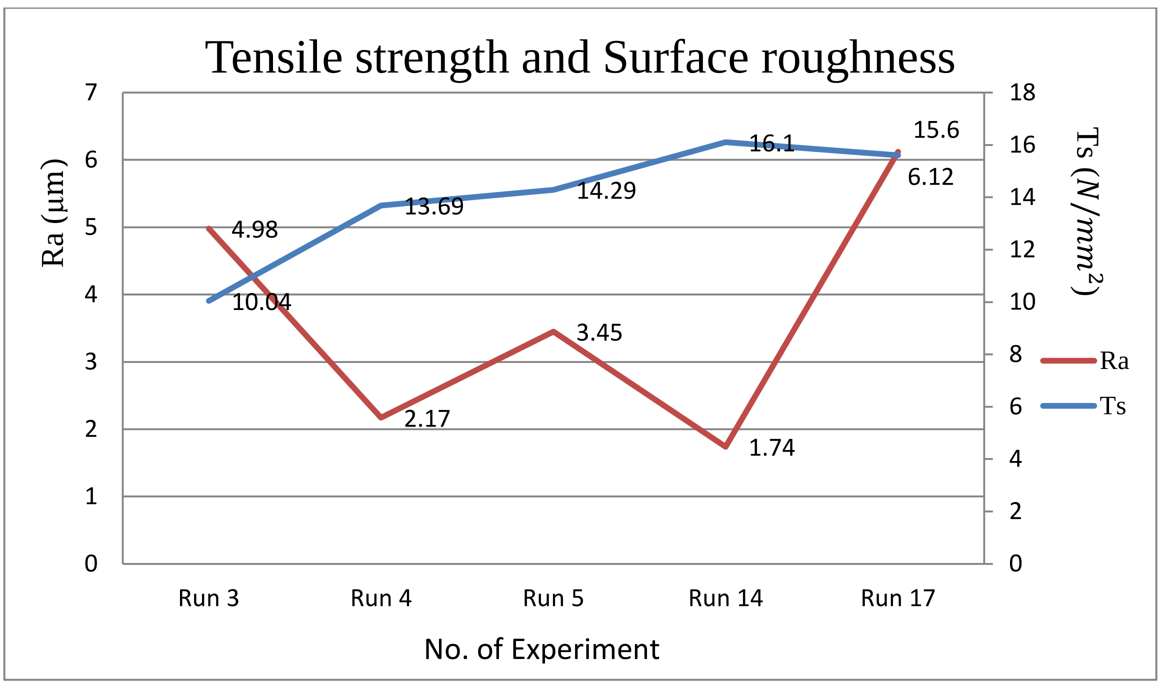


Figure 4.12: Graph of Tensile test and surface roughness

Based on the results from tensile test and surface roughness test, it can be conclude that run order 14 is the best for the manufacturing. Surface roughness for run order 14 is the highest tensile test result and low surface roughness to be carried out for manufacturing. It means we should balance the value of the test. It seems that, run order 14 will be the best choice to manufacturing coffee maker part.

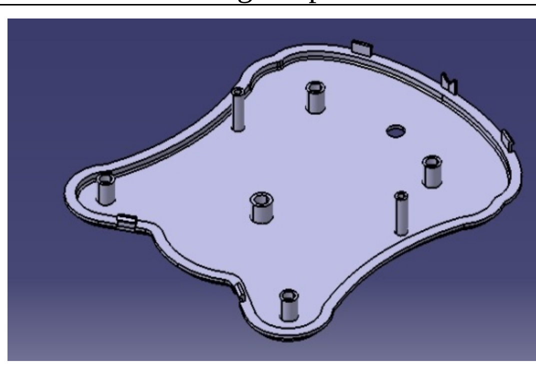
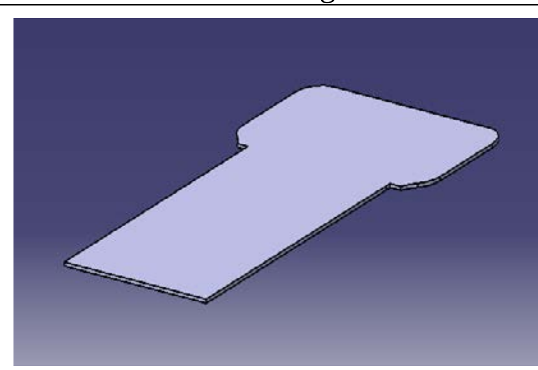
4.6 COFFEE MAKER PART MANUFACTURING AND ASSEMBLY

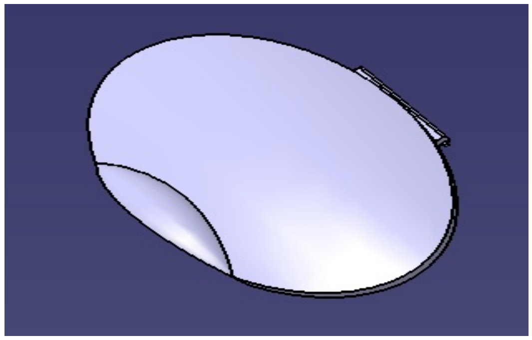
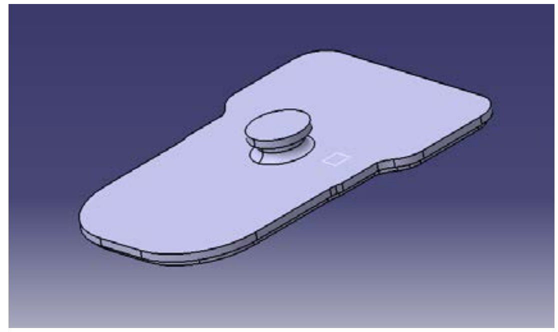
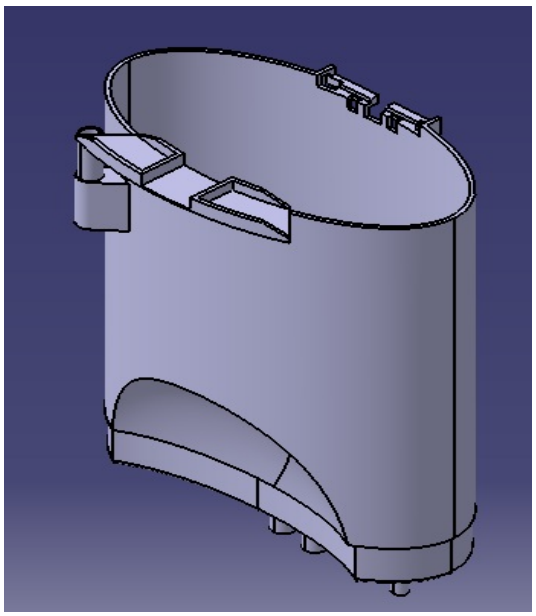
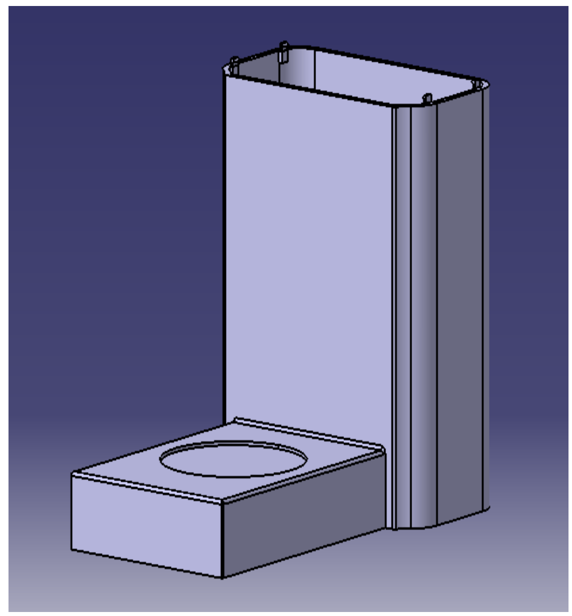
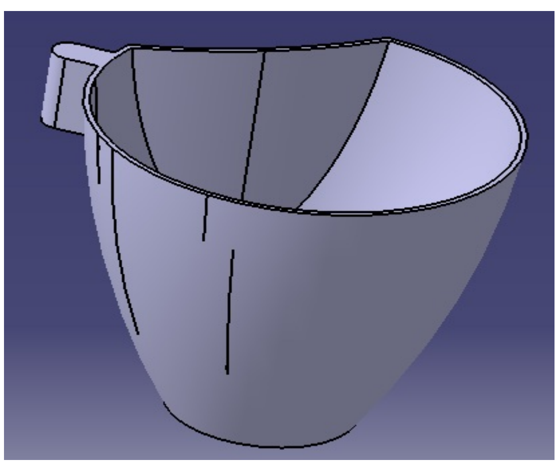
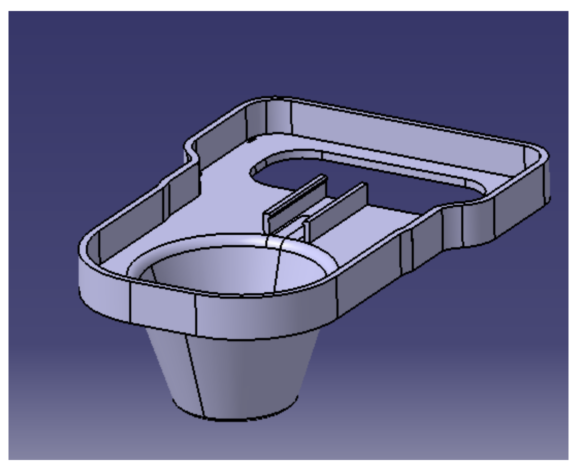
Based on the analysis of RSM for tensile and surface roughness test, coffee maker part were manufacturing using FKP rapid prototyping Fortus 360mc machine based on fused deposition modeling mechanism. The coffee maker part was manufacturing using ABS material. The parameter that is control is layer thickness, build orientation and air gap. Table 4.8 show the optimum parameter used in this coffee maker manufacturing. Table 4.9 shows coffee maker parts has been manufactured.

Table 4.8: Optimum parameter value

Parameter	Optimum value
Layer thickness	0.254mm
Build orientation	60 degree
Air gap	0.002

Table 4.9: Drawing oforiginal part and redesign part

Part	Original part	Redesign
Base		

Part	Original part	Redesign
Top cover		
Main body		
Pivot		

When the coffee maker part is done manufacture, each part needs to be assembly.Table 4.10 shows redesign part that is done manufactured.Table 4.11 shows the assembly part of original design and redesign product.

Table 4.10: Redesign Coffee maker part

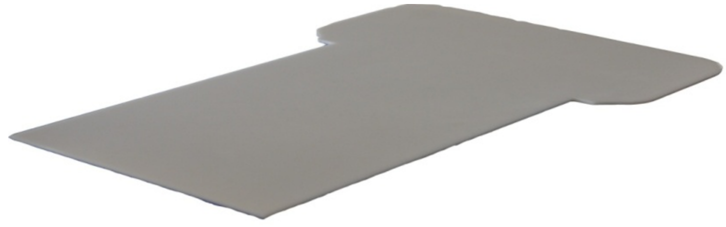
Part name	Part manufactured
Top cover	
Pivoted	
Body base	
Bottom cover	

Table 4.11: Assembly part of original design and redesign product

Original Coffee Maker	
Redesign Coffee maker	

4.7 ASSEMBLY TIME ANALYSIS

To make an analysis of the Coffee maker the method had been used is a Boothroyd-Dewhurst DFA analysis. Based on previous study, the assembly efficiency for manual assembly of the original design is 5.1%. The assembly efficiency for manual assembly of the redesign is 6.5%. From the both result, design efficiency will changes with the new design will produce higher assembly efficiency with 6.5% rather than current design which is 5.1%. A design efficiency index is used in the previous study to evaluate the improvement in design in a quantitative number. Table 4.12 shows a complete conclusion table for assembly time of original and redesign product.

Table 4.12: Comparison of assembly time between original and redesign Coffee maker

	Original product	Redesign product (predicted)	Redesign product (actual)
Assembly time	117.49s	92.59s	85s
Design efficiency	5.1%	6.5%	7.1%
DFA Index	5.0	6.3	7.1

4.8 SUMMARY

For this experiment, all part was fit well and easily to assembly. Few part of coffee maker manufacture needed to be assembly with the existing part such as valve, pivoted bridge, wire connector, pot and most importantly the wire and switch to turn on the coffee maker. Each existing part was assembly with part manufacture, and it’s all fit well.The response surface methodology (RSM) is a robust process for optimization of the single response as well as multiple responses. In present work, optimization of two FDM responses is considered are tensile and surface roughness. Response surface methodology can be used as an analysis tool in any process when parameters affecting the responses are identified through experimental and theoretical validation. Response surface methodology is very ideal method to analyses three level data.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In Chapter 1, the problem statement has been developed and the scope of study also been developing in order to achieve the objective. The aim of this project is to find optimum parameter for rapid prototyping to manufacture coffee maker part using response surface methodology and to test the tensile strength, surface roughness and function ability of the redesign coffee maker.

In Chapter 2, literature review was crucial because it is necessary to get the exposure and information about the project scope and objective. At first and the most important things in conducting this project is to understand about parameter of rapid prototyping that affect on tensile strength and surface roughness of the part. Second is to understand about response surface methodology. In order to create design of experiment for response surface methodology using MINITAB 15, knowledge and capability using MINITAB 15 software is necessary. This information important when analyzing stage took place in chapter 4.

In Chapter 3, the scope of study is to manufacture coffee maker part using response surface methodology. The aim is to find method uses to manufacture coffee maker part with high tensile strength and low surface roughness. Rapid prototyping with mechanism of fused deposition modeling is used to manufacture coffee maker part. Response surface methodology used to create a design of experiment for this project.

Response surface methodology is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes.

In Chapter 4, the main focus is to manufacture coffee maker part using rapid prototyping using response surface methodology. The most challenging part is to analyze the parameter using MINITAB 15 to find optimum parameter which is high tensile strength and low surface roughness. Based on CCD run using response surface methodology, it's been fix that 20 run of experiment would be done with different value of parameter. Analysis for tensile strength and surface roughness were done. After the coffee maker parts were done manufactured, it's undergoing assembly process. Dimensions and accuracy of each part is the most for assembly. From the previous study, assembly time for each part was completely reduced and the design efficiency is increase. What more important things are systematically analyze the response to find the most optimum parameter. From analysis of experiment, it can be conclude that most factors contributed for tensile strength is layer thickness where increase in layer thickness result on high tensile strength. For surface roughness test, most factor contributed is build orientation where increase in build orientation and layer thickness, result on low surface roughness finish.

5.2 LIMITATIONS AND RECOMMENDATION

Rapid Prototyping have few limitations. In FDM, heat is dissipated by conduction and forced convection and the reduction in temperature caused by these processes forces the material to quickly solidify onto the surrounding filaments. Bonding between the filaments is caused by local re-melting of previously solidified material and diffusion. This results in uneven heating and cooling of material and develops non uniform temperature gradients. As a result, uniform stress will not be developed in the deposited material and it may not regain its original dimension completely.

Speed at which nozzle is depositing the material may alter the heating and cooling cycle and results in different degree of thermal gradient and thus also affects the part accuracy.At lower slice thickness, nozzle deposition speed is slower as compared to higher slice thickness. Also during deposition, nozzle stops depositing material in random manner (in between depositing a layer and after completely depositing a layer) and return to service location for tip cleaning. While depositing the material at the turns near the boundary of part, nozzle speed has to be decreased and then increase to uniform speed. If deposition path length is small, this will result in non uniform stress to build up especially near the part boundary.

The pattern used to deposit a material in a layer has a significant effect on the resulting stresses and deformation. Higher stresses will be found along the long axis of deposition line. Therefore, short raster length is preferred along the long axis of part to reduce the stresses.

The response surface methodology (RSM) is a robust process for optimization of the single response as well as multiple responses. In present work, optimization of FDM responses is considered are tensile strength and surface roughness. Due to time constraints, we optimized only two responses, although flexural and impact strength, hardness test, may be carried out in future. Response surface methodology can be used as an analysis tool in any process when parameters affecting the responses are identified through experimental and theoretical validation.

As illustrated in benchmark tests and the industrial design application, the response surface methodology (RSM) can converge to a global design optimum with a modest number of function evaluations. Further work may improve its efficiency and ability to handle large-scale engineering design problems.

For further improvement, Coffee Maker should be carried on using injection molding where injection molding is the most effective way to manufacture plastic product. Otherwise injection molding parts are assumed as established and fixed. One of the main goals in injection molding is the improvement of quality of molded parts besides the reduction of cycle time, and lower production cost.

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