A SURFACE ROUGHNESS PREDICTION MODEL FOR LASER BEAM CUTTING (LBC) ON ACRYLIC SHEETS

MOHD ARIF BIN MOKTI

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOV 2008

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 of Bachelor of Mechanical Engineering with Manufacturing.

Signature : ________________________

Name of Supervisor : DR KUMARAN A/L KADIRGAMA

Date :

Signature : ________________________

Name of Panel :

Date :

STUDENT'S DECLARATION

I hereby declare that this project report entitled "A Surface Roughness Prediction Model for Laser Beam Cutting (LBC) on Acrylic Sheets" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : ________________________
Name : MOHD ARIF BIN MOKTI
ID Number : ME05046
Date :

Special dedicated to my beloved Father, Mokti Bin Sukirman, Mother, Fauziah Binti Mokhtar, my brothers and also to Roslina Binti Razali

&

my supervisor, Dr Kumaran A/L Kadirgama

for their support and care.

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr Kumaran A/L Kadirgama for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct and his strong conviction for science. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision, his tolerance of my naive mistakes, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

I want to thank to all my members and to all the staff of the Mechanical Engineering Department, UMP, who helped me in many ways. Many special thanks go to members for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study

ABSTRACT

The present thesis discusses the development of the statistic model surface roughness for acrylic sheet on laser beam cutting and the effect of laser beam cutting (LBC) parameters towards acrylic sheet surface roughness. The model are developed by using the response surface methodology (RSM) to study the effect of cutting parameters (power, laser speed, gap distance and material thickness) on acrylic sheets surface roughness. The model of the experiment is performed with using Box-Behnken design which it will arrange all the cutting parameters with suitable combination that needed for experiments performance. The affect of input factors and the interaction between these factors are also investigated in this study. It was found that the interaction of these parameters (power, laser speed, gap distance and material thickness) with surface roughness was extremely strong. The predictive models in this study are believed to produce value of the surface roughness. The predicted model for first order and second order for this model is performed with using MINITAB software. MINITAB will able to give solution for many data analysis and then predicted model will come out after finish all the analysis steps.

ABSTRAK

Pembentangan tesis ini membincangkan tentang pembinaan ke atas model statistik kekasaran permukaan untuk kepingan acrylic melalui mesin laser dan kesan parameter-parameter pemotongan laser terhadap kekasaran permukaan kepingan acrylic. Model ini dibina menggunakan konsep reaksi permukaan untuk mengkaji kesan parameter-parameter pemotongan (kuasa, kelajuan laser, jarak ruang dan ketebalan bahan) ke atas kekasaran permukaan kepingan acrylic. Model untuk eksperimen ini adalah dijanakan menggunakan rekaan Box-Behnken di mana ia akan mengatur semua parameter-parameter pemotongan dengan kombinasi yang sesuai untuk kelancaran prestasi eksperimen. Kesan untuk faktor input dan saling tindakannya dengan faktor-faktor lain juga disiasat di dalam kajian ini. Didapati saling tindakan parameter ini (kuasa, kelajuan laser, jarak ruang dan ketebalan bahan) terhadap kekasaran permukaan sungguh kuat. Model ramalan dalam kajian ini adalah dipercayai boleh menghasilkan nilai-nilai untuk kekasaran permukaan. Model-model ramalan untuk turutan pertama dan turutan kedua untuk model ini adalah dijanakan menggunakan perisian komputer MINITAB. Perisian komputer MINITAB berkebolehan memberikan penyelesaian untuk analisa data yang banyak dan model ramalan akan terhasil sesudah selesai menjalani semua langkah-langkah analisa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF SYMBOLS

mm	Millimetre
µm	Micrometre
Ý	Surface roughness
X_1	Laser speed
X_2	Power
X_3	Gap distance
X_4	Material Thickness

LIST OF ABBREVIATIONS

LBC	Laser beam cutting
RSM	Response surface methodology
BBD	Box-Behnken design
CCD	Central composite design
ANOVA	Analysis of variance

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The present study considers the effect of simultaneous variations of laser beam cutting parameter (laser speed, power requirements, gap distance, and materials thickness) on the surface roughness prediction. For this purpose, the response surface methodology RSM is utilized. RSM is a group of mathematical and statistical techniques that are useful for modeling the relationship between the input (cutting conditions) and the output variables (surface roughness). [1]

RSM saves cost and time on conducting cutting material experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. [2-4]

1.1.1 Project Background

The first laser experimental implementation was operated by Theodore Mainman on 16 May 1960 at Hughes Research Laboratory in California, by shining a high-power flash lamp on a ruby rod with silver-coated surfaces. Laser Beam Cutting (LBC) is one of most important tool in technology, which is categorized by an outstanding future. The laser is an artificial energy source, discovered by physics which has become an important manufacturing tool especially in cutting process, engraving process and joining or welding process. A laser beam is an artificially generated electromagnetic radiation called laser light in visible wavelength range. Its theoretical physical description is attributed to Einstein in 1917, namely the principle of stimulated emission of radiation.

The introduction of laser and related devices has revolutionized the high technology and made a great deal of contribution to both basic and applied research in different areas. Although the present laser systems have not fulfilled all the preliminary expectations. Important advancements have been made by the advent of sophisticated laser systems in optical communications, medicine, industry and fields of interest. [5]

The growth of research and development of laser system for material processing has changed the technique of rapid prototyping (RP) or layer manufacturing from fabrication of prototypes to rapid tooling (RT) and rapid manufacturing (RM). Nowadays, many researchers successfully produced the direct fabrication of functional or structural end-use products, high strength alloys and high properties coating made by layer manufacturing techniques utilizing of laser system such as selective laser sintering (SLS), selective laser melting (SLM) and laser cladding on various kinds of metals, polymers and composite. [6-9]

The increase growth of laser application because of several advantages such as relatively low cost when mass production, reduction of production time, reduction of waste, precision cutting due to laser beam diameter can be focused to micrometer and up to nano level, laser beam can clean, coat and machine at complex shape and limited surface, able to produce functional parts with different materials and etc. [10-11]

For these reasons most developed countries have made huge investments in their laser research program and as a result have found many interesting results. This motivates more and more research in this field. [12]

According to Olaf Rehme, more than 130 different influence parameters affect on the laser material processing such as for cutting or melting. However, only approximately 13 of these parameters are crucial to produce quality parts. These parameters are divided into two categories, control parameter and disturbance variables. Control parameters consist of beam power, scan/cutting speed, hatch distance and layer thickness. Disturbance parameters are involves in type of materials and parts geometry. [13]

When any material involve in production or manufacturing process, the surface roughness is very important element that should be consider first. Surface roughness is an important factor when dealing with issues such as friction, lubrication and wear. It also has major impact on applications involving thermal or electrical resistance, fluid dynamics, noise and vibration control, dimensional tolerance and abrasive processes. Surface quality is one of most specified customer requirements where major indication of surface quality is surface roughness. Surface roughness is commonly a result of parameter process that has applied to the material during the process.

Surface roughness depends on what of the product function and uses. Some need higher level of surface roughness and some are not need that. From that, the conclusion is surface roughness is an important part for production and it depend on the product character and the application of the product.

1.2 PROBLEM STATEMENT

The surface roughness of the material is important to produce very fine finish product. Many manufactures are using trial and error method to find a suitable combination to get good quality of surface roughness. This method not only wastes time but increase the cost of the production. To overcome this problem, a prediction model will help the manufactures to predict the correct combination without wasting their production time.

1.3 RESEARCH OBJECTIVE

- To determine the effect of laser beam cutting (LBC) parameters towards acrylic sheet surface roughness.
- To develop a statistic model for surface roughness.

1.4 RESEARCH SCOPE

The research is limited to predict model for laser beam cutting on acrylic sheets, knowing the surface roughness, characteristic and to predict the surface roughness of acrylic sheets.

1.5 EXPECTED OUTCOME

A surface roughness prediction model, first order and second order prediction model for laser beam cutting (LBC) on acrylic sheets.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

For a long time, manufacturing engineers and researchers have been realizing that in order to optimize the economic performance of metal cutting operations, efficient quantitative and predictive models that establish the relationship between a big group of input independent parameters and output variables are required for the wide spectrum of manufacturing processes, cutting tools and engineering materials currently used in the industry. [14] Furthermore, it has been observed that the improvement in the output variables, such as tool life, cutting forces, surface roughness, etc. Through the optimization of input parameters, such as feed rate, cutting speed and depth of cut may in significant economical performance of machining operations. [15]

On the other hand, many other researches have followed purely experimental approaches to study the relationship between surface roughness and the independent variables conditions. This has reflected on the increased total cost of the study as a large number of cutting experiments is required. Furthermore, with this purely experimental approach, researchers have investigated the effect of cutting parameters on surface roughness using machining experiments based on a one-factor-at-a-time design, without having any idea about the behavior of surface roughness prediction when two or more variables are varied at the same time.

The present study considers the effect of simultaneous variations of cutting parameter (cutting speed, power requirements, gap distance, and materials thickness) on the surface roughness prediction. For this purpose, the response surface methodology RSM is utilized. RSM is a group of mathematical and statistical techniques that are useful for modeling the relationship between the input (cutting conditions) and the output variables (surface roughness). [16]

RSM saves cost and time on conducting cutting material experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. [17-19]

2.2 TYPE OF LASER

There have two type of lasers commonly use for cutting, gas and solid state laser using CO_2 and Nd; YAG. This two types of laser cutting are commonly use in industries. In industrial, the expansions of laser applications and relatively low cost of laser system with mass production, laser material processing has gained increased importance in variety of industries. Automotive, aerospace, defense, manufacturing, and many others sectors are widely adapting laser technology for welding, cutting, coating and hardening. Laser cutting greatly simplifies the design and manufacturing process because any pattern can do directly by computer. Laser cutting can easy to design complex parts that are difficult to make with conventional tools. The laser beam focused as small as .004” produces detail and very sharp corners. The process is non-contact, allowing delicate materials to be cut without damage. There are also no cutting tools that can wear or break. [20]

Figure 2.0(a): CO_2 laser cutting machine

Figure 2.0(b): Nd:YAG laser cutting machine

2.2.1 CO_2 Laser

For this project the CO_2 laser machine will be used to study the effects of these laser parameters toward acrylic sheets surface roughness. The CO_2 laser machine is more productive, reliable and easy to maintain. The CO_2 laser has a mixture of gasses, including carbon dioxide, which are excited either with electricity or radio waves. The light bulb gives off light in every direction.

The CO_2 laser light waves are lined up, so the light waves will oscillating at the same plane and it will vibrate together. This polarization is call coherence where coherence makes this laser waves differ with the waves of the lamp light. The CO_2 laser cutting machine is operated in the infrared condition or range of the energy spectrum.

In the production industries, the laser cutting machines take the laser light from the resonator and bounce it to the several mirrors that called as the beam delivery system. This delivery system then will reflect the waves to the lens in the laser head. Then the lens will make the waves able to focus at the small spot and it able to cut the materials. Industrial laser cutting machine will able to cut a variety of materials including acrylic, steel, aluminum, plastic, thermoplastic and also titanium. The ability of laser to cut various types of materials make the laser cutting becomes mo famous and important tool in the future industries. [21]

2.2.2 Laser Working Principles

Lasers work as a result of resonant effects where the output of a laser is a coherent electromagnetic field which the waves have the same frequency and phase. In a basic laser, a chamber called a cavity is designed to internally reflect infrared (IR), visible-light, or ultraviolet (UV) waves so they reinforce each other. The cavity can contain gases, liquids, or solids. The choice of cavity material determines the wavelength of the output. At each end of the cavity, there is a mirror. One mirror is totally reflective, that will allowing none of the energy to pass through the other mirror, and only allowing 5 percent of the energy to pass through. Energy is introduced into the cavity from an external source this is called pumping.

As a result of pumping, an electromagnetic field appears inside the laser cavity at the resonant frequency of the atoms of the material that fills the cavity. The waves reflect back and forth between the mirrors. The length of the cavity is such that the reflected and re-reflected wave fronts reinforce each other in phase at the natural frequency of the cavity substance. Electromagnetic waves at this resonant frequency emerge from the end of the cavity having the partially-reflective mirror. The output may appear as a continuous beam, or as a series of brief, intense pulses. [22]

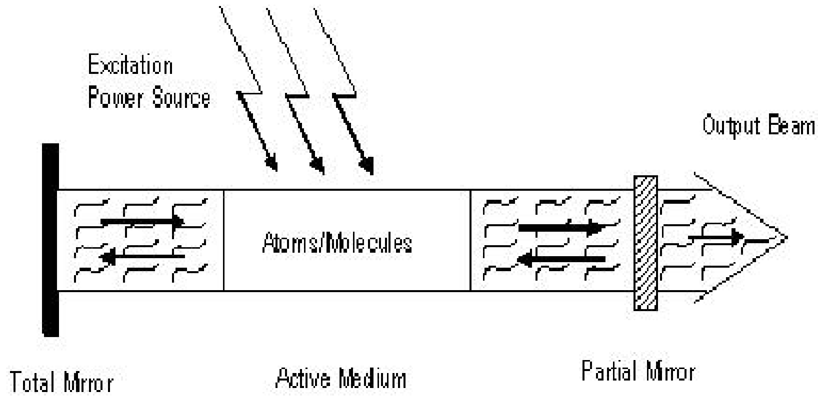

Figure 2.1(a): Basic components of laser

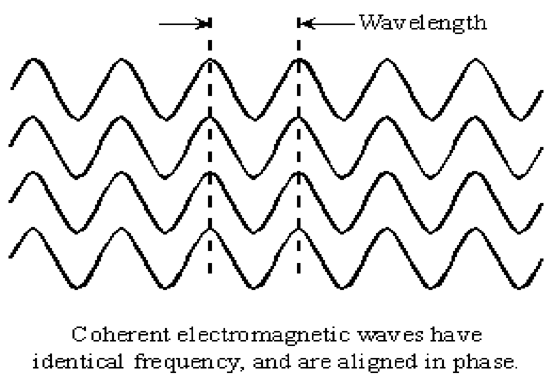

Figure 2.1(b): Electromagnetic waves

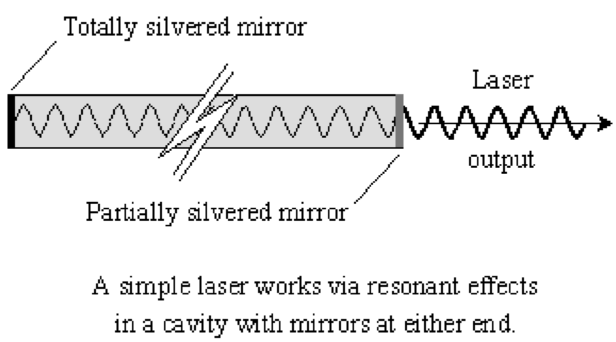

Figure 2.1(c): Pumping energy

2.3 RESPONSE SURFACE METHOD (RSM)

RSM can be defines as a statistical method that uses quantitative data from appropriate experiments to determine and simultaneously solve multivariate equations. Response surface methodology (RSM) quantifies relationships among one or more measured responses and a number of input factors. The options depend on the number of design factors, which can range from one to ten. Under RSM there are have the central composite design (CCD) and Box-Behnken design (BBD).
RSM are use;

- To determine the factor levels that will simultaneously satisfy a set of desired specifications.
- To determine the optimum combination of factors that yields a desired response and describes the response near optimum.
- To determine how a specific response is affected by changes in level of the factors over the specified levels of interest.
- To achieve a quantitative understanding of the system behavior over the region tested.
- To produce product properties throughout the region even at factor combinations not actually run.
- To find conditions for process stability.

Factor to consider:

- Critical factor are known.
- Region of interest, where factor levels influencing product is known.
- Factors vary continuously through out the experimental ranged tested.
- A mathematical function relates the factors to the measured response.
- The response defined by the function is a smooth curve

Limitations:

- Large variations in the factors can be misleading (error, bias, and no replication).
- Critical factors may not be correctly defined or specified.
- Range of levels of factors to narrow or to wide cannot be defined.
- Lack of use of good statistical principles.
- Over-reliance on computer.
- Polynomials with a small number of terms are most desirable.
- Most process outputs are some sort of smooth function of the inputs.
- Second-degree polynomials are generally adequate.

2.3.1 Box-Behnken Design (BBD)

Box-Behnken design requires only three levels, coded as −1, 0, and +1. Box and Behnken created this design by combining two-level factorial designs with incomplete block designs. This procedure creates designs with desirable statistical properties, but, most importantly, with only a fraction of the experiments needed for a full three-level factorial. These designs offer limited blocking options, except for the three-factor version. Design-Expert provides full factorial three-level designs for up to 4 factors. The number of experiments equals 3k plus some replicates of the center point. These designs will fit a quadratic model, but for more than two factors they require many more runs than needed to determine the coefficients in the model.

- The Box-behnken design fills out a polyhedron, approximating a sphere.
- For 3 factor (15 runs), the design consist of three four-run, two-level factorials in two factors, with the third factor at its mid-level and three center points, run in three blocks of 10 runs.
- Box-behnken design is subsets of the full three level factorial designs.
- Unreplicated responses surface designs can detect effects about 1-2 time experimental error.

2.3.2 Central Composite Design (CCD)

The central composite design (CCD) is a design widely used for estimating second order response surfaces. The central composite design (CCD) is the most frequently used RSM design. It is perhaps the most popular class of second order design. Introduce by Box and Wilson (1951) CCD has been studied and used by many researchers. A CCD can be broken down into three parts:

1. Two-level full or fractional designs (the core).
2. Axial points (outside the core).
3. Center points.

The two-level factorial part of the design consists of all possible combinations of the plus or minus one level of the factors. Axial points, often represented by stars, emanate from the center point, with all but one of the factors set to 0. The coded distance of the axial points is represented as a plus or minus alpha (α). For a two-factor problem, the axial points are: $(-\alpha, 0)$, $(+\alpha, 0)$, $(0, -\alpha)$ and $(0, +\alpha)$. For RSM experiments with five or more factors, Design-Expert offers one or more options to do Resolution V fractional cores for the CCD (A Resolution V fractional factorial allows estimates of all main effects and two-factor interactions, sufficient for a second order model.)

2.4 ACRYLIC SHEET

Acrylic is a useful, clear plastic that resembles glass, but has properties that make it superior to glass in many ways. Common brands of high grade acrylic include Polycast, Lucite and Plexiglass.

There are two basic types of acrylic, extruded and cell cast. Extruded or "continuous cast" acrylic is made by a less expensive process. It's softer, can scratch easier and may contain impurities. Cell cast acrylic is a higher quality acrylic and U.S domestic cell cast is good choice for applications that required the best. Imported cell cast acrylic is often manufactured to lesser standards.

Acrylic is used to make various products such as shower doors, bath enclosures, windows and skylights. It is many times stronger than glass, making it much more impact resistant and there for safer. Falling against an acrylic shower door will not likely break it. Acrylic also insulates better than glass, potential saving on heating bills.

A transparency rate of 93% makes acrylic is clearest material known. Very thick glass will have a green tint, while acrylic remains clear. This makes working with acrylic much easier. There are also no seams in acrylic structures, as chemical welding at the molecular levels actually melts seam into one piece of solid material, so welded and polished are invisible

.

Acrylic particles are inherently non-conductive, some of the acrylic particles were made conductive by application of a conductive coating. The laser apparatus has several features which create difficulties when cutting particles. Acrylic particles have a greater mass than paper particles of the same dimensions. [23]

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Laser beam cutting (LBC) are commonly use for cut materials with various shape such as straight cut, sphere, or rectangular. Laser beam cutting is usually used in industrial manufacturing to produce product because it easy to handle and better product can be produce. If look the product that have produce by using laser beam cutting (LBC), the surface of the product more smooth than using the others machine. This is because laser beam cutting (LBC) is controlling by computer.

The laser cutters usually work like a milling machine, laser enters through the side of the sheet and then cuts it through the axis of the beam. The cutting process will conduct and control by computer. Enter the required data in the system common and then computer will runs this cutting process. For that, one worker is enough to handle laser machine. That why laser commonly used in industrial manufacturing, not only can produce better product but it also can reduce the cost to hiring more workers. But, this is not important in this case.

The important is, firstly should know the function of laser beam cutting and the ability of this machine. Usually laser is used to cut materials for example acrylic sheet but people don’t know the effect of the laser on the surface roughness of the material after the laser cutting process. For that, the important thing is to know which factor will affect the surface roughness of the acrylic sheet before continues the cutting process.

When consider the entire factor, first thing is should know the part of the laser beam cutting (LBC) and know how this laser has been function. This knowledge will help and give more easily to handling the laser machine and to get the better product especially the surface roughness of the product.

In developing laser system, controlling the control parameters is very importance. Moreover, the ability of the system to control these parameters accurately will improve its performances. In addition, the performance of this laser system is based on the advances of controller it’s used.

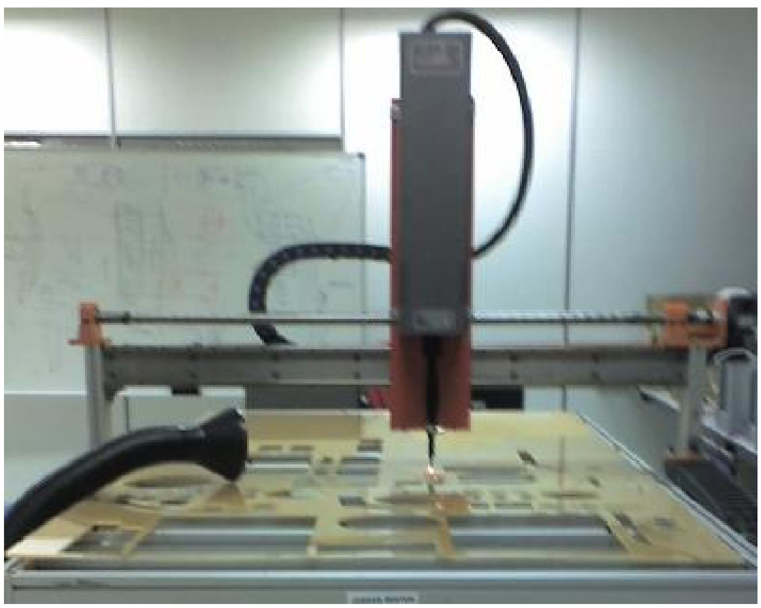

Figure 3.0(a)

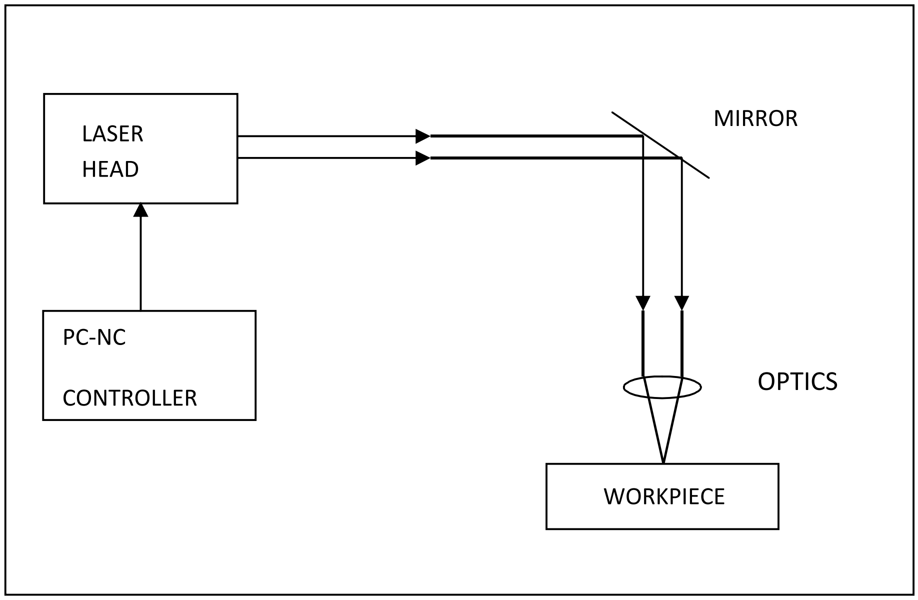

Figure 3.0(b)

Figure 3.0(a) and 3.0(b): Schematic illustration of laser system for cutting process.

3.2 EXPERIMENT DETAILS

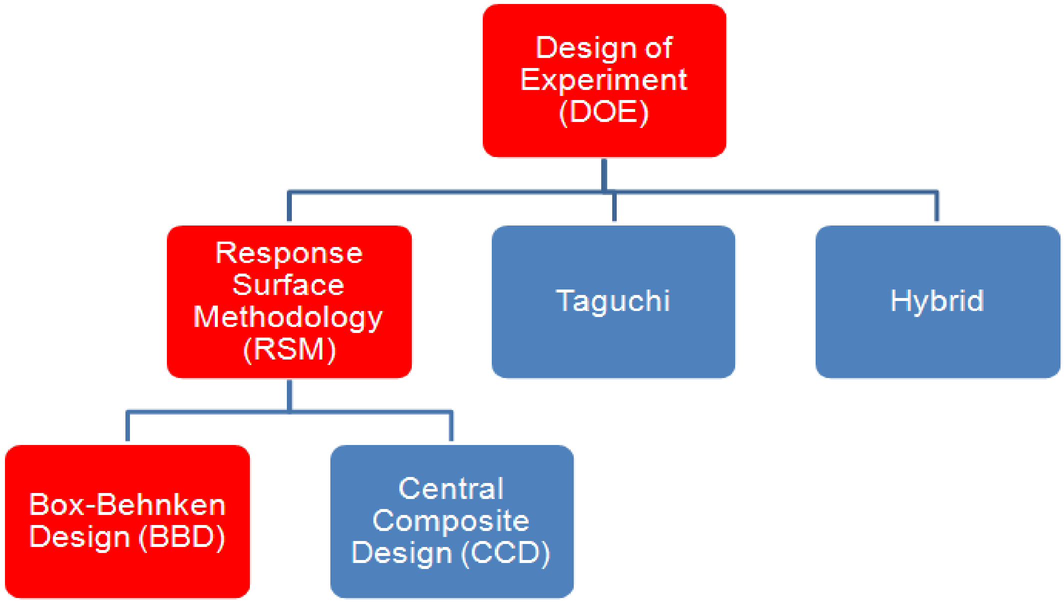

Figure 3.1: Experiment details

The Response Surface Method is used to find the effect of laser cutting parameters (power requirement, laser speed, gap distance and material thickness) on surface roughness when machining Acrylic sheets. This simulation gain more understanding of the surface roughness distribution in laser cutting. Response Surface Method (RSM) has been used to minimize the number of experiments. The contour plot from the RSM shows the relationship between variables (beam power, laser speed, gap distance and material thickness) and response (surface roughness). It was found that surface roughness is affected significantly by the laser speed followed by the power requirement, hatch distance and then by the layer/material thickness. Generally, the increase in beam power, layer/material thickness, hatch distance and decrease in laser speed will cause surface roughness to become larger.

After obtaining and analyzing the results of the Box-Behnken experimental design, a three-level factorial experiment was designed for investigation. The Box-Behnken analysis is more suitable for experiments with a larger number of variables, whereas this analysis is simpler and easier to use. In this design, the power use is between 90-95 %, with laser speed (700, 1850, 3000 pulse/s), gap distance (8, 10 and 12 mm), and the material thickness is (3, 6 and 9 mm). The levels of the four input independent variables are given in Table 3.0.

By using Box-Behnken analysis, the low, middle, and the high values for all factors combination can be shown in Table 3.1. The objective is to increase the interaction between all factors with the laser cutting. 27 experiments were performed in a random manner on PCNC Laser machine and using room temperature. Each experiment will stopped after finish cut the part of the acrylic sheet and then repeated with other conditions until 27 conditions of the experiments.

Table 3.0: Levels of independent variables

No.	Factors	Symbol	Level 1	Level 2	Level 3
Control Factors					
1	Power requirements (%)	A	90	92	95
2	Laser speed (pulse/s)	B	700	1850	3000
3	Gap distance (mm)	C	8	10	12
4	Materials thickness (mm)	D	3	6	9

Table 3.1: Conditions of the cutting experiments according to Box-Behnken design

Exp.No	Power (%)	Laser Speed (pulse/s)	Gap Distance (mm)	Thickness (mm)
1	92.5	1850	12	9
2	92.5	1850	10	6
3	90	1850	10	9
4	92.5	3000	12	6
5	90	700	10	6
6	92.5	1850	10	6
7	95	1850	12	6
8	92.5	3000	10	3
9	95	1850	10	3
10	90	1850	10	3
11	92.5	700	10	3
12	95	1850	10	9
13	92.5	1850	12	3
14	90	1850	12	6
15	92.5	3000	8	6
16	92.5	3000	10	9
17	95	1850	8	6
18	92.5	1850	8	3
19	92.5	700	12	6
20	92.5	1850	8	9
21	92.5	1850	10	6
22	92.5	700	8	6
23	95	700	10	6
24	95	3000	10	6
25	92.5	700	10	9
26	90	1850	8	6
27	90	3000	10	6

3.3 ADVANTAGES OF BOX-BEHNKEN DESIGN

In machining research, there are found that the Box-Behnken design has a broad application compared to other experiment designs used for RSM. The Box-Behnken design is based on the combination of the factorial with incomplete block designs. It does not required a large number of tests, it considers only three levels (-1, 0, 1) of each combination of cutting parameters. The Box-Behnken design is normally used for non-sequential experimentation when a test is conducted only once. It allows an efficient evaluation of the cutting parameters in the first and second order models.

3.4 EXPERIMENT SETUP

Different thickness of acrylic will be used to investigate the effectiveness of cutting processes using this system. The acrylic thickness that have been used are 3mm, 6mm and 9mm. The acrylic sheets with different size that will be used can be shown in Figure 3.2(a), 3.2(b) and 3.2(c). Furthemore, surface roughness will be analyse and will produce the prediction model. The laser power that have been used are 90%, 92% and 95% from the power of the laser mahine. The laser machine power is 30W, so the laser power that have been used are 27W, 27.6W and 28.5W. The laser speed for this machine is considered the speed of the laser head move to complete the cutting process. The laser speed is measured in pulse per second. The laser speed used are 700,1850, and 3000 pulse per second. That mean higher number of the laser speed will present higher speed of laser movement. The gap distance for this cutting condition is measured from the surface of the acrylic sheets to the tip of laser.

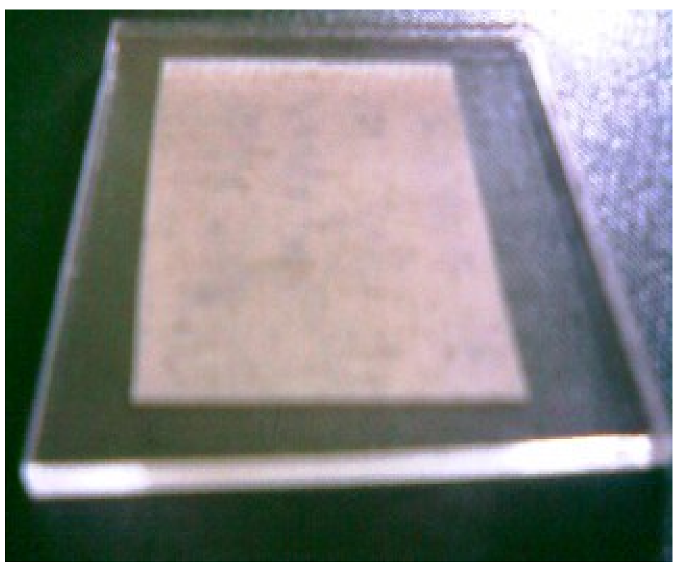

Figure 3.2(a): Acrylic with thickness 3mm

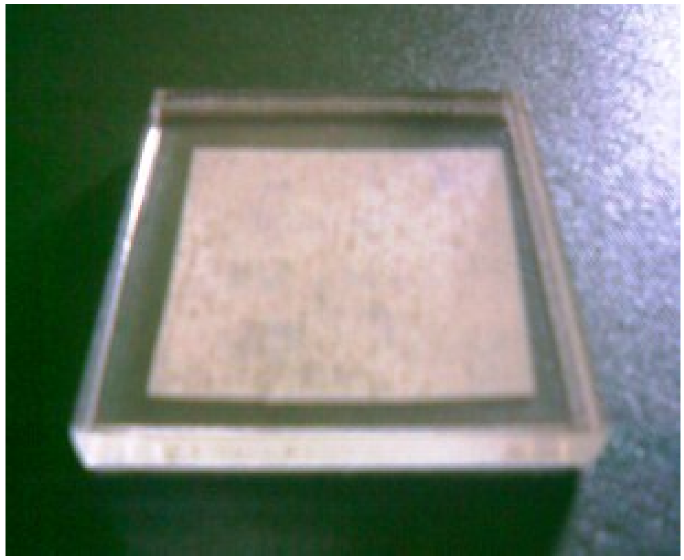

Figure 3.2(b): Acrylic with thickness 6mm

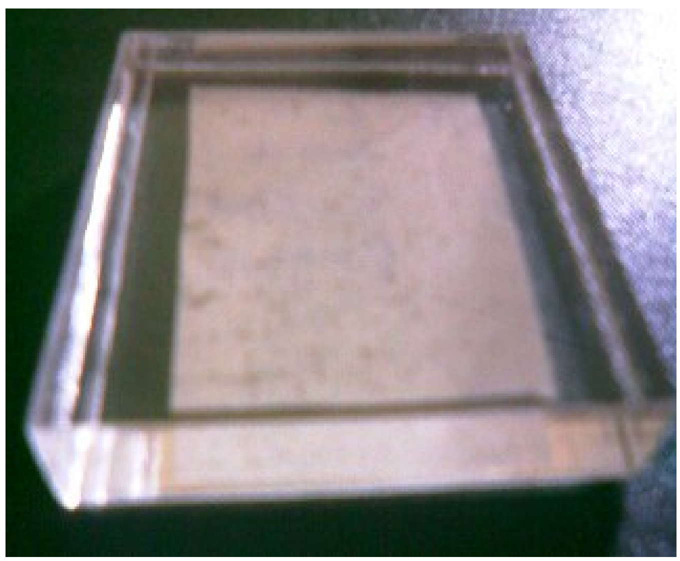

Figure 3.2(c): Acrylic with thickness 9mm

3.5 DATA COLLECTION AND ANALYSIS

The surface roughness values readings will be take until 4 measurements for each experiment and then the average of the surface roughness will be calculated. Perthometer is a device that used to measure the surface roughness for the acrylic sheets. After that, the values of the surface roughness will be analyzed by using MINITAB software. By using MINITAB software, first and second order prediction models will be generated and the effects of the parameters that have been used will be known. The first and second order prediction models that have generated will be able to produce the accurate of predicted values for surface roughness.

3.5.1 Surface Roughness

Surface roughness values will be measured using Perthometer as shown in Figure 3.3(a) and the image for the acrylic surface is taken by using image analyzer device as shown in Figure 3.3(b). These devices are very important to define the surface roughness values for acrylic sheets after laser cutting process.

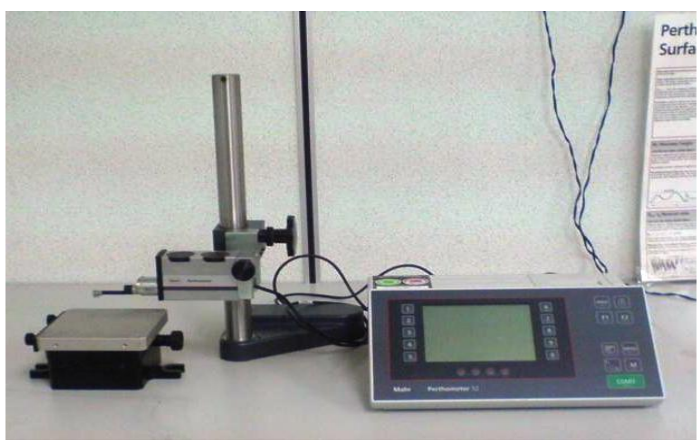

Figure 3.3(a): Perthometer

Figure 3.3(b): Image Analyzer

For each experiment, four reading values for surface roughness will be taken and then the average values of surface roughness for each experiment will be calculated. The Figure 3.3(c) shows the four sides of acrylic that the readings have been taken. The objective here is to make sure the accurate reading of surface roughness can be achieved.

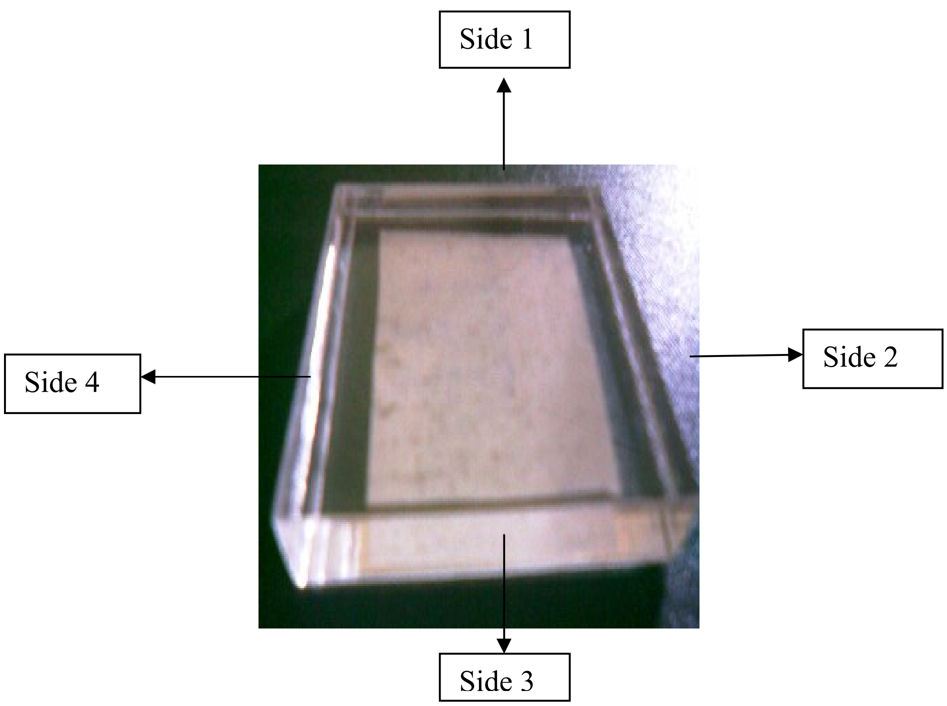

Figure 3.3(c): Sides for readings taken

CHAPTER 4

RESULTS AND DISCUSSION

4.1 EXPERIMENTAL RESULTS

After finish run the 27 experiments, the surface roughness values is measured by using Perthometer and all of the experiments data are write down in the Table 4.0. Different combination of cutting parameters will give different values of surface roughness. The surface roughness values are measured in unit µm where this is for standard measurement of surface roughness. The Table 4.0 below show the average values of surface roughness for each experiment. There have 27 experiments number that successfully run according to Box-Behnken design.

The experimental results are very important here to produce the correct equation for prediction models on acrylic sheets surface roughness. Then the prediction models either first order model or second order model will able to predict the accurate values of surface roughness. These two equations of prediction model only suitable and will give the accurate values for the range that has used for run the experiments.

The limited ranges here are power (90% until 95%), laser speed (700 pulses per second until 3000 pulses per second), gap distance (8 mm until 10 mm) and material thickness (3mm until 9 mm). If the experiments are run in this ranges, the accurate values will be achieve according to the prediction model equation. For the next experiments if the others parameters or the values of the parameters does not in the ranges, the prediction model not valid and there will have an error.

Table 4.0: Experiment reading of surface roughness

Experiment Number	Laser speed (pulse/s)	Power (%)	Gap distance (mm)	Thickness (mm)	Surface Roughness (µm)
1	1850	92.5	12	9	0.4625
2	1850	92.5	10	6	0.4685
3	1850	90	10	9	0.4353
4	3000	92.5	12	6	0.5293
5	700	90	10	6	0.4546
6	1850	92.5	10	6	0.4601
7	1850	95	12	6	0.4855
8	3000	92.5	10	3	0.5333
9	1850	95	10	3	0.5155
10	1850	90	10	3	0.5253
11	700	92.5	10	3	0.4898
12	1850	95	10	9	0.4212
13	1850	92.5	12	3	0.533
14	1850	90	12	6	0.5125
15	3000	92.5	8	6	0.4388
16	3000	92.5	10	9	0.4495
17	1850	95	8	6	0.43
18	1850	92.5	8	3	0.4593
19	700	92.5	12	6	0.4721
20	1850	92.5	8	9	0.3875
21	1850	92.5	10	6	0.4621
22	700	92.5	8	6	0.4197
23	700	95	10	6	0.4334
24	3000	95	10	6	0.4643
25	700	92.5	10	9	0.4125
26	1850	90	8	6	0.4345
27	3000	90	10	6	0.4805

4.2 DEVELOPMENT OF FIRST ORDER EQUATION MODEL

After conducting the 27 experiments, the surface roughness readings values are used to find the parameters appearing in the postulated first order model (Eq. (1)). To do the calculation of these parameters, the method of least squares is used with the aid of MINITAB. The first order linear equation for predicting the surface roughness is expressed as:

$$\acute{Y} = 0.627 + 1.55\times10^{-5} X_1 - 0.00309X_2 + 0.0178X_3 - 0.0135X_4 \quad \textbf{(Eq. 1)}$$

$\acute{Y}$ = Surface roughness

X_1 = Laser speed

X_2 = Power

X_3 = Gap distance

X_4 = Material Thickness

From this linear equation, one can easily noticed that the response $\acute{Y}$ (surface roughness) is affected by the laser speed (X_1), power (X_2), gap distance (X_3) and lastly by the material thickness (X_4). Generally, increasing in the laser speed, power, gap distance and material thickness will cause the surface roughness value to become larger. On other hand, the decreasing in laser speed will slightly cause a reduction in surface roughness value.

Table 4.1 shows the surface roughness values obtained by experimentation and the surface roughness values predicted by the first order model. It is clear that the predicted values for the surface roughness are very close to the experimental readings values. This indicated that the obtained linear model is able to provide accurate values of the surface roughness.

Table 4.1: Experimental and first order predicted results

Exp. No	Laser speed (pulse/s)	Power (%)	Gap distance (mm)	Thickness (mm)	Exp. Results (µm)	Pre. Results (µm)	Error (%)
1	1850	92.5	12	9	0.4625	0.460	0.4625
2	1850	92.5	10	6	0.4685	0.466	0.6237
3	1850	90	10	9	0.4353	0.433	0.6043
4	3000	92.5	12	6	0.5293	0.519	1.9832
5	700	90	10	6	0.4546	0.456	-0.2004
6	1850	92.5	10	6	0.4601	0.466	-1.1906
7	1850	95	12	6	0.4855	0.493	-1.6003
8	3000	92.5	10	3	0.5333	0.524	1.7402
9	1850	95	10	3	0.5155	0.498	3.3005
10	1850	90	10	3	0.5253	0.514	2.1601
11	700	92.5	10	3	0.4898	0.488	0.2819
12	1850	95	10	9	0.4212	0.417	0.9490
13	1850	92.5	12	3	0.533	0.542	-1.6218
14	1850	90	12	6	0.5125	0.509	0.7344
15	3000	92.5	8	6	0.4388	0.448	-2.0859
16	3000	92.5	10	9	0.4495	0.443	1.5048
17	1850	95	8	6	0.43	0.422	1.7629
18	1850	92.5	8	3	0.4593	0.471	-2.5026
19	700	92.5	12	6	0.4721	0.483	-2.3518
20	1850	92.5	8	9	0.3875	0.390	-0.5190
21	1850	92.5	10	6	0.4621	0.466	-0.7526
22	700	92.5	8	6	0.4197	0.412	1.7506
23	700	95	10	6	0.4334	0.440	-1.5331
24	3000	95	10	6	0.4643	0.476	-2.4433
25	700	92.5	10	9	0.4125	0.407	1.3003
26	1850	90	8	6	0.4345	0.438	-0.7793
27	3000	90	10	6	0.4805	0.491	-2.2083

4.2.1 Analysis of Variance for First Order Prediction

The adequacy of the first order model was verified by using the analysis of variance (ANOVA). At a level of confidence 95% standard level that used by the other researcher, the model was checked for its adequacy. Table 4.1.1(a) and 4.1.1(b) shows the analysis of variance (ANOVA) and it shown that the lack-of-fit F-value of 4.24 is not significant with relative to the pure error and it prove that the model could fit and adequate.

Table 4.1.1(b) shows the significant parameters as the p-values are less than 0.05 and it shows which parameters have influence on surface roughness values. Parameters that have been used (laser speed, power, gap distance and material thickness) shows that all of this parameters bring effects on surface roughness values. For the first order prediction, conclusion can be make is all the parameters used are significant and have effects on surface roughness values.

Table 4.1.1(a): Analysis of variance ANOVA for first order equation (from Minitab)

Source	Degree of Freedom	Sequential Sum of Square	Adjusted Mean square	F	P
Regression	4	0.0394	0.00985	129.7	0
Linear	4	0.0394	0.00985	129.7	0
Residual Error	22	0.001671	0.000076		
Lack-of-fit	20	0.001632	0.000082	4.24	0.208
Pure Error	2	0.000039	0.000019		
Total	26	0.041071			

Table 4.1.1(b): Significant values for first order coefficient

Term	Coef	Standard error Coef	T	P-value	
Constant	0.465578	0.001677	277.607	0	***Significant***
Laser speed	0.0178	0.002516	7.076	0	***Significant***
Power	-0.007733	0.002516	-3.074	0.006	***Significant***
Gap distance	0.035425	0.002516	14.082	0	***Significant***
Thickness	-0.040642	0.002516	-16.155	0	***Significant***

4.2.2 Contours Plot for First Order Model

The first order linear equation from (Eq 1) was used to plot contours of the surface roughness at different values of the gap distance and thickness. Figure 4.0(a), 4.0(b) and 4.0(c) shows the surface roughness at three different combinations of the gap distance and thickness (lowest, middle and highest values). From the contours plot, it shows that the reduction in laser speed and increasing in power used will cause the surface roughness values less than 0.444 µm. If laser speed is increase and then the power of the laser is decrease, the higher values of surface roughness will be produce. By referring this contours plot, one easily can determine the output of the surface roughness that will come out.

For the fixed gap distance and material thickness used, the parameters factor should be considered only power and laser speed. Adjustment in power and laser speed will bring big effects on surface roughness values. In production industries, contours plot can be referred to make the production time become more faster. One only need to refer the contours plot which factor will make the surface roughness become smaller or higher. So, it can reduce the wasted time in production and production will become more faster then before.

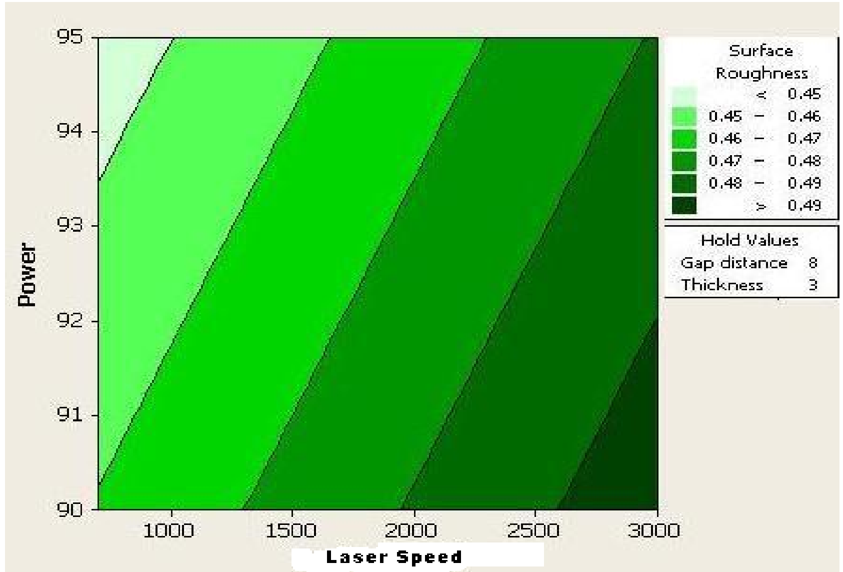

Figure 4.0(a): Laser speed and power contour line with gap distance=8 mm and thickness=3mm

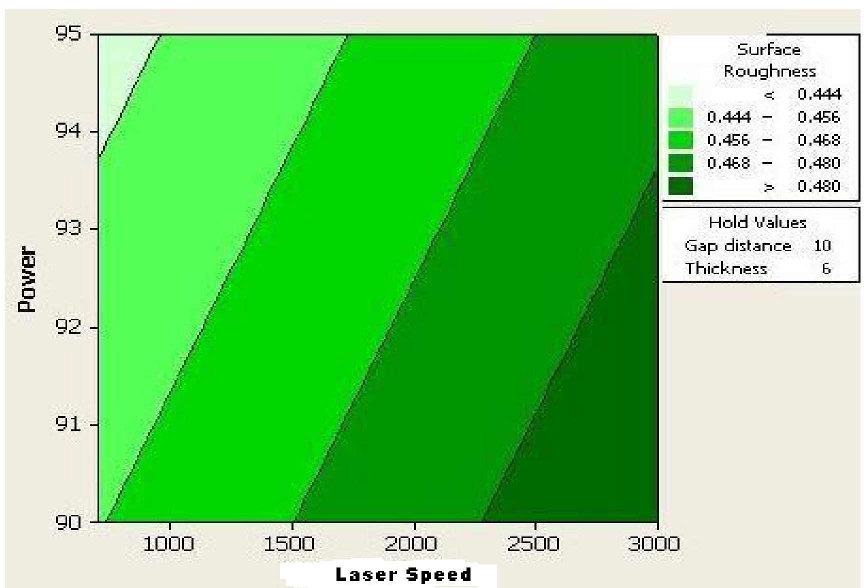

Figure 4.0(b): Laser speed and power contour line with gap distance=10 mm and thickness=6mm

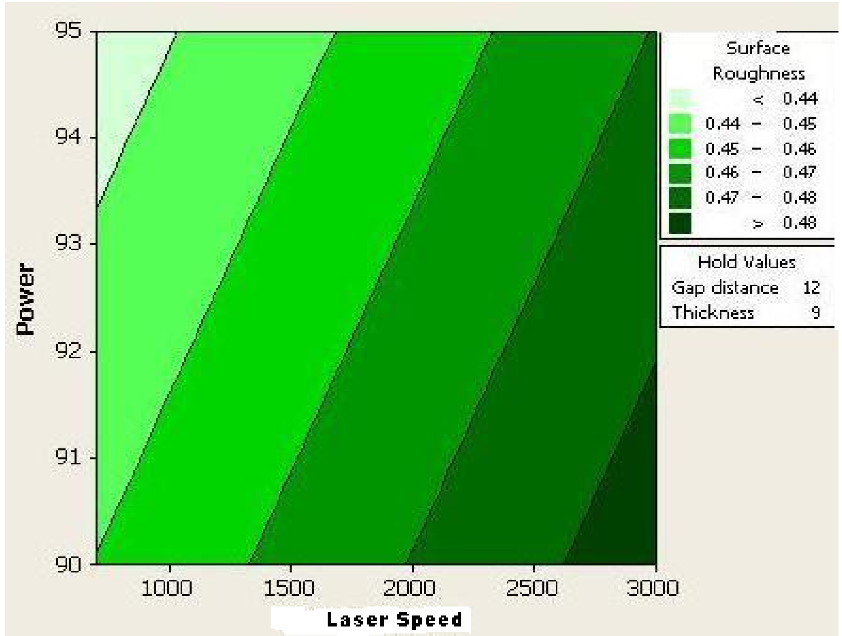

Figure 4.0(c): Laser speed and power contour line with gap distance=12 mm and thickness=9mm

4.3 DEVELOPMENT OF SECOND ORDER EQUATION MODEL

The second order equation was established to describe the effect of the four cutting conditions investigated on the surface roughness. The equation is given by:

$\acute{Y}" = 1.627 – 6.22x10^{-5}X_1 – 0.0351X_2 + 0.124X_3 – 0.00726X4 + 4.14x10^{-6}X_1X_3$ **(Eq 2)**

$\acute{Y}"$ = Surface roughness

X1 = Laser speed

X2 = Power

X3 = Gap distance

X4 = Material Thickness

The second order equation shows that the surface roughness is increase with increasing the laser speed and power. In other hand its mean that the surface roughness also will reduce with reducing the laser speed and power. Same as in first order model case but for second order model there will have another significant parameter that have highly influence in the response. For the second order model, laser speed and gap distance have influence in surface roughness prediction model. It noticed that the interaction between laser speed and gap distance has the most dominant effect on the surface roughness.

The surface roughness readings values for experimental and predicted values for this second order equation shown in table 4.2. From the equation 2, the values that have predicted are close to the experimental values.

Table 4.2: Experimental and second order predicted results.

Exp. No	Laser speed (pulse/s)	Power (%)	Gap distance (mm)	Thickness (mm)	Exp. Results (µm)	Pre. Results (µm)	Error (%)
1	1850	92.5	12	9	0.4625	0.462	0.0811
2	1850	92.5	10	6	0.4685	0.464	1.0530
3	1850	90	10	9	0.4353	0.439	-0.7744
4	3000	92.5	12	6	0.5293	0.524	1.0194
5	700	90	10	6	0.4546	0.456	-0.2695
6	1850	92.5	10	6	0.4601	0.464	-0.7535
7	1850	95	12	6	0.4855	0.485	0.0884
8	3000	92.5	10	3	0.5333	0.529	0.8586
9	1850	95	10	3	0.5155	0.504	2.1363
10	1850	90	10	3	0.5253	0.518	1.4270
11	700	92.5	10	3	0.4898	0.490	-0.0145
12	1850	95	10	9	0.4212	0.421	0.0346
13	1850	92.5	12	3	0.533	0.543	-1.8308
14	1850	90	12	6	0.5125	0.512	0.1390
15	3000	92.5	8	6	0.4388	0.434	1.0929
16	3000	92.5	10	9	0.4495	0.444	1.1819
17	1850	95	8	6	0.43	0.425	1.0533
18	1850	92.5	8	3	0.4593	0.473	-2.8866
19	700	92.5	12	6	0.4721	0.469	0.6028
20	1850	92.5	8	9	0.3875	0.391	-0.8065
21	1850	92.5	10	6	0.4621	0.464	-0.3174
22	700	92.5	8	6	0.4197	0.417	0.5351
23	700	95	10	6	0.4334	0.438	-1.0287
24	3000	95	10	6	0.4643	0.476	-2.5109
25	700	92.5	10	9	0.4125	0.412	0.1606
26	1850	90	8	6	0.4345	0.430	1.1076
27	3000	90	10	6	0.4805	0.489	-1.7534

4.3.1 Analysis of Variance for Second Order Prediction

The analysis of variance shown in table 4.2.1(a) and 4.2.1(b) give the meaning that the model is adequate as the p-values of the lack-of-fit is not significant. The adequacy of the second order model was verified by using the analysis of variance (ANOVA) at a level of confidence 95%.

For second order prediction model, the analysis of variance is used to shows the significant parameters and also to shows the interaction between the parameters with the surface roughness values. Table 4.2.1(b) shows the interaction between parameters and it is significant for the p-values are less than 0.05.

Table 4.2.1(a): Analysis of variance ANOVA for second order equation (from Minitab)

Source	DF	Seq SS	Adj MS	F	P
Regression	14	0.040175	0.00287	38.44	0
Linear	4	0.0394	0.00985	131.95	0
Square	4	0.000264	0.000066	0.88	0.503
Interaction	6	0.000511	0.000085	1.14	0.396
Residual Error	12	0.000896	0.000075		
Lack-of-Fit	10	0.000857	0.000086	4.45	0.197
Pure Error	2	0.000039	0.000019		
Total	26	0.041071			

Table 4.2.1(b): Significant values for second order coefficient

Term	Coef	SE Coef	T	P	
Constant	0.463567	0.004988	92.93	0	
Laser speed	0.0178	0.002494	7.137	0	***Significant***
Power	-0.007733	0.002494	-3.101	0.009	***Significant***
Gap distance	0.035425	0.002494	14.203	0	***Significant***
Thickness	-0.040642	0.002494	-16.295	0	***Significant***
Laser speed*Laser speed	-0.000387	0.003741	-0.104	0.919	
Power*Power	0.001462	0.003741	0.391	0.703	
Gap distance*Gap distance	-0.002025	0.003741	-0.541	0.598	
Laser speed*Power	0.00125	0.00432	0.289	0.777	
Laser speed*Gap distance	0.009525	0.00432	2.205	0.048	***Significant***
Laser speed*Thickness	-0.001625	0.00432	-0.376	0.713	
Power*Gap distance	-0.005625	0.00432	-1.302	0.217	
Power*Thickness	-0.001075	0.00432	-0.249	0.808	
Gap distance*Thickness	0.000325	0.00432	0.075	0.941	

4.3.2 Contours Plot for Second Order Model

The second order linear equation from (Eq 2) was used to plot contours of the surface roughness at different values of the gap distance and thickness. Figure 4.1(a), 4.1(b) and 4.1(c) shows the surface roughness at three different combinations of the gap distance and thickness (lowest, middle and highest values). From the contours plot, it shows that the reduction in laser speed and increasing in power used will cause the surface roughness values less than 0.444μm.

The function of the second order contours plot also same as first order contours plot to predict the output of the surface roughness values. But the second order contours plot will give more accurate view of output. The output here is the surface roughness predicted values. In the second order contours plot there have curve line, the curve line is show the strongly effect of the cutting parameters. In this case, reducing the laser speed and increasing the power of the laser in the certain values not will make the surface roughness also will become smaller. This is because the second order prediction will give more accurate values then the first order prediction model.

For the second order prediction model, it not only show the interaction between parameters used with the surface roughness values, it also can show the interaction between one parameter with the others parameters used. That why this second order prediction model can give more accurate values for the surface roughness predicted values.

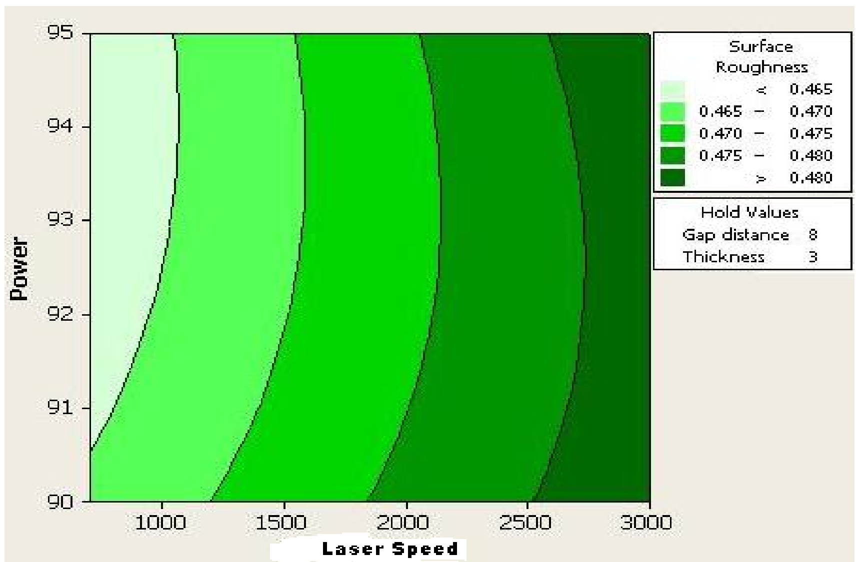

Figure 4.1(a): Laser speed and power contour line with gap distance=8mm and thickness=3mm

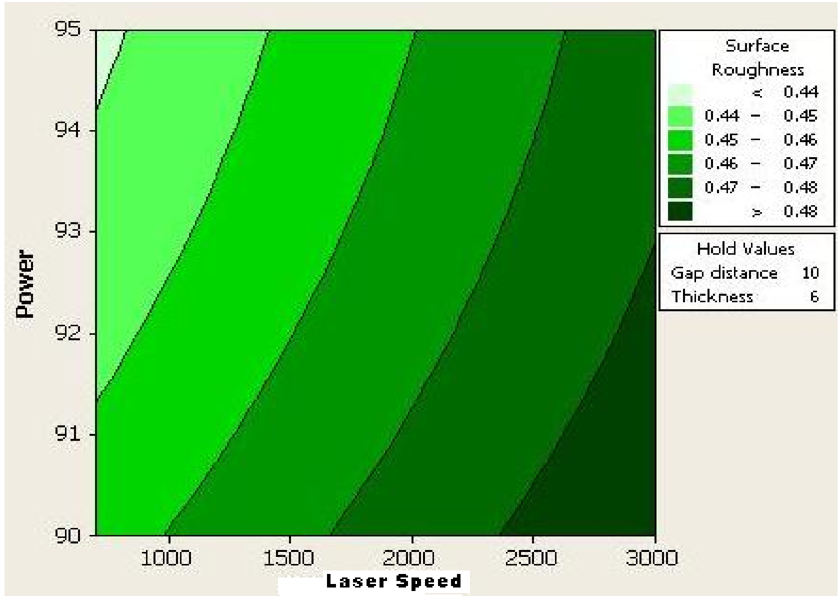

Figure 4.1(b): Laser speed and power contour line with gap distance=10 mm and thickness=6mm

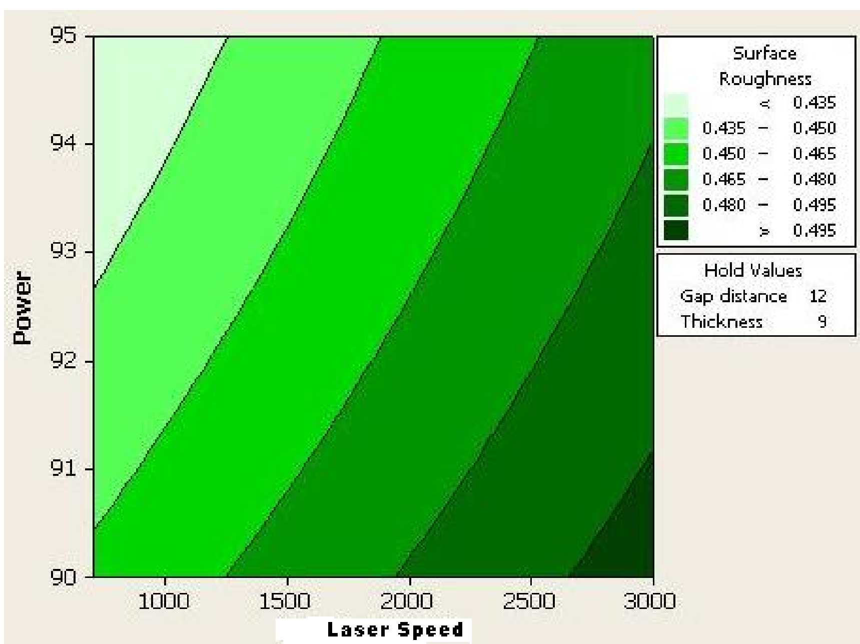

Figure 4.1(c): Laser speed and power contour line with gap distance=12 mm and thickness=9mm

4.4 COMPARISION RESULTS

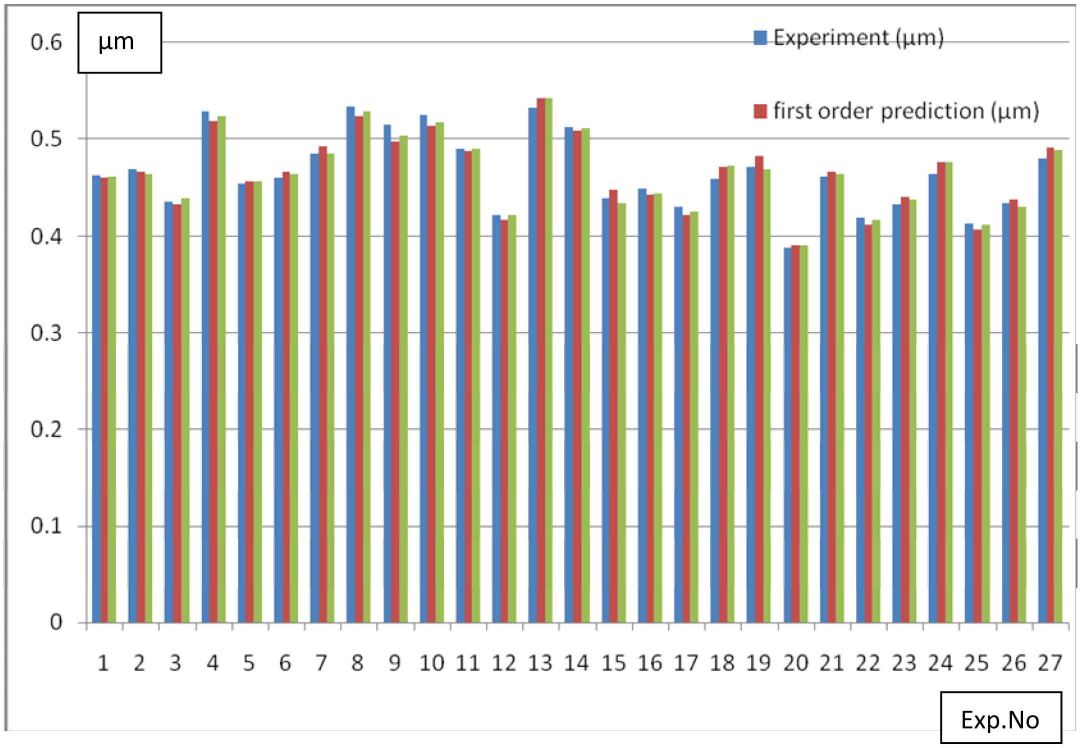

Figure 4.2(a): Experiment, 1st order prediction and 2nd order prediction values.

Figure 4.2(a) shows the comparison between experimental, first order prediction and second order prediction. The values for first order and second order predicted closed to experimental values. There also can see the range of predicted values still in the range of experimental values. So the prediction models either first order prediction or second order prediction can be used because it able to give the accurate predicted values for surface roughness.

4.5 ERRORS FOR FIRST ORDER AND SECOND ORDER PREDICTION

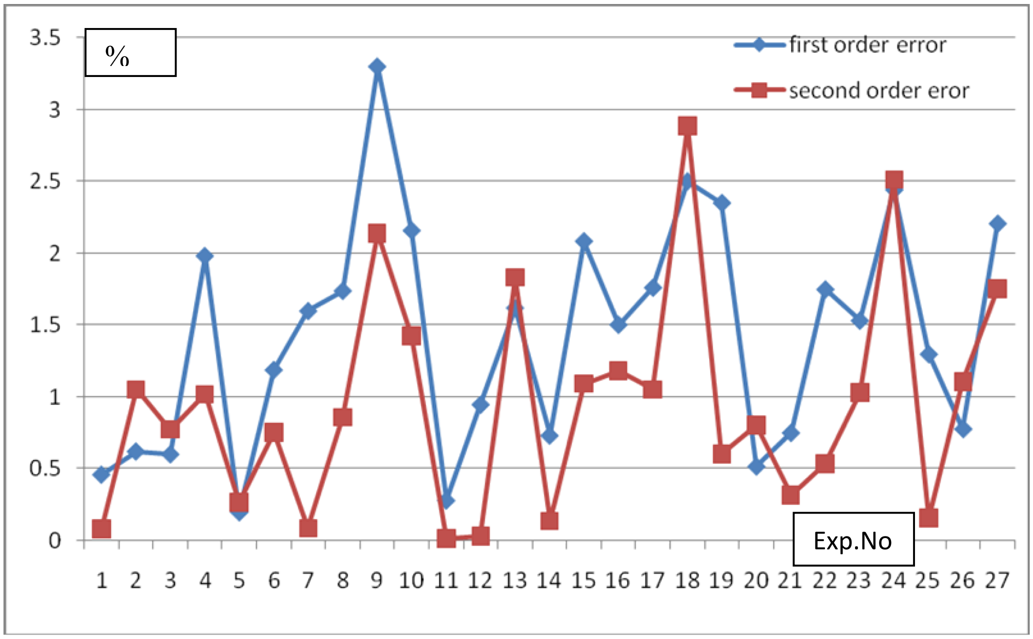

Figure 4.2(b): Error for 1st order and 2nd order prediction.

Figure 4.2(b) show the errors of first order and second order predicted values. There only have small errors between first and second order prediction model. There also can see that the second order model will give more accurate predicted values then first order model prediction and it more closed to the experiment values. However, this two prediction model either first order prediction model or second order prediction model still able to produce the accurate values and closed to the experimental reading values.

4.6 IMAGE ANALYZER

The effect of laser cutting parameters can be shown in figure 4.3(a) and 4.3(b). Figure 4.3(a) is the image analyzer for the surface roughness 0.5125µm and 4.3(b) is the image analyzer for the surface roughness 0.4125µm. With different values of parameters used, the figure 4.3(b) show better surface roughness compare with the figure 4.3(a). This happen because the cutting parameters (laser speed, power, gap distance and thickness) have strongly effect on surface roughness. The different combination will give different values of surface roughness. These parameters are significant for surface roughness effect and that was proved by the first and second order equation.

This observation can noticed that by using higher laser speed and power as in figure 4.3(a) the structure of the acrylic not melted with fine. That why the surface roughness for figure 4.3(a) become more rough if compare to the figure 4.3(b). But using lower laser speed and power, the surface structure will be better and shown by figure 4.3(b).

From this figure also show that small different in reading values of surface roughness will bring big effect on the surface structure of material. Surface roughness is depends on product uses, higher or smaller values of surface roughness does not mean this surface roughness is bad or good. But in this case, figure 4.3(b) show better surface finish than figure 4.3(a). The range of surface roughness for figure 4.3(b) is below 0.5µm and it more smooth compare to figure 4.3(a) which surface roughness reading is above 0.5µm.

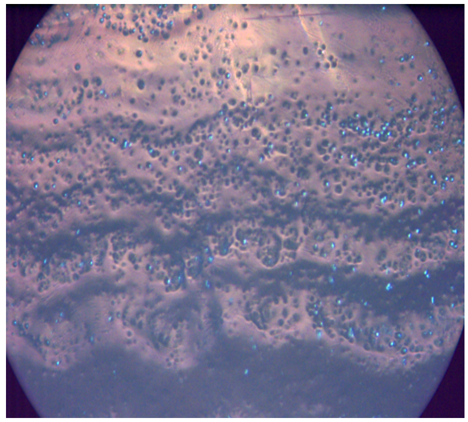

Figure 4.3(a): Laser speed=1850 pulse/s, power=90%, gap distance=12mm, thickness=6mm

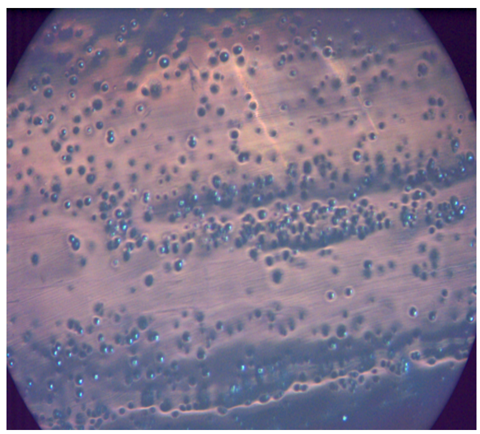

Figure 4.3(b): Laser speed= 700 pulse/s, power= 92.5%, gap distance= 10mm, thickness= 9mm

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the analysis that have done, the following conclusion can be withdrawn from this study are, response surface methodology (RSM) can be used and successfully proved the surface roughness prediction model for laser beam cutting (LBC) on acrylic sheets. The first order and second order equation developed by RSM using MINITAB are able to provide accurately predicted values of surface roughness close to those values that have get from experiments. The two equation of these prediction, first oder and second order prediction indicate that the laser speed was the dominant cutting condition on the surface roughness, followed by the power, gap distance and then the material thickness. The better surface roughness can be get by increasing the power and then reduces the laser speed and gap distance. The second order model proves the existence of a very strong interaction of the laser speed and gap distance. That mean this two parameters should be give more attention during setting the condition of laser cutting because this two parameters bring big effect on surface roughness values. The surface condition can be shown by using image analyzer device to view the surface structure after laser cutting process. Prediction model will able to get the surface roughness values needed. It also can reduce the labor cost and production time if comparing with try and error methods.

5.2 RECOMMENDATION

From the study that have done using different laser speed, power, gap distance and thickness the image analyzer show the different structure image for the different surface roughness that mean all of this parameters bring effect to the surface roghness condition. All of this parameters normally also will bring another effects to the acrylic such as kerf width. So for the next project, one may continue this study by using same parameters and then study the effect on HAZ, Kerf Width and also taper.

REFERENCES;

[1] D.C. Montgomer, Design, Analysis of Experiments, 5th ed, John Wiley & Sons, 2001, pp.427-500.

[2] R. Mead, D.J. Pike, A review of response surface methodology from a biometric viewpoint, Biometrics 31 (1975) 803-851.

[3] W.J. Hill, W.G. Hunter, A review of response surface methodology; a literature survey, Technometrics 8 (1966) 571-590.

[4] C.R. Hicks, fundamental Concepts in the design of experiments, 4th ed, Saunders College.

[5] Senior JM. Optical fiber communications. New York: Prentice- Hall; 1992.

[6] Edson Costa Santos, Masanari Shiomi, Kozo Osakada, Tahar Laoui. Rapid manufacturing of metal components by laser forming. International Journal of Machine Tools & Manufacture 2005 1-9.

[7] A. Almeida, F. Carvalho, P.A Carvalho, R. Vilar. Laser developed Al-Mo surface alloys: Microstructure, mechanical and wear behavior. Surface & coating Technology 200, 2006, 4782-4790.

[8] P.L Blackwell, A. Wisbey. Laser aided manufacturing technologies; their application to near net shape forming of high-strength titanium alloys, Journal of Materials Processing Technology 170 (2005) 268-276

[9] S.P Edwards, G Dearden, P. French, K.G Watkins, Laser forming of metal laminate composite materials, 22nd International Congress on Application of Lasers & Electro-optics (ICALEO2003), Jacksonville No. 595, Vol. 95, 2003

[10] Ehsan Toyserkani, Amir Khajepour, Stephen Corbin, Laser Cladding, CRC Press 2005, 3-8.

[11] Noriah Bidin, Teknologi laser, UTM 2002 pg 3-4

[12] H.Golnabi, MH Mahdieh. Trend of laser research developments in global level. Optics & laser technology 38 (2006) 122-131.

[13] Olaf Rehme, Claus Emmelmenn. Reproducibility for properties of selective laser melting, Proceeding of the Third International WLT-Conference on Lasers in manufacturing 2005 Munich June 2005, pg 1-6.

[14] E.J.A. Armarego, R.H. Brown, The Machining of Metals, Prentice-Hall, New Jersey, 1969.

[15] E.J.A. Armarego, Machining performance prediction for modern manufacturing, in: Proceeding of the Seventh International Conference on Production and Precision Engineering and Fourth International Conference on High Technology, Chiba, Japan, 1994, p. k52

[16] D.C. Montgomer, Design, Analysis of Experiments, 5th ed, John Wiley & Sons, 2001, pp.427-500.

[17] R. Mead, D.J. Pike, A review of response surface methodology from a biometric viewpoint, Biometrics 31 (1975) 803-851.

[18] W.J. Hill, W.G. Hunter, A review of response surface methodology; a literature survey, Technometrics 8 (1966) 571-590.

[19] C.R. Hicks, fundamental Concepts in the design of experiments, 4th ed, Saunders College Publishing, Holt, 1993.

[20] http://www.repairfaq.org/sam/laserco2.htm

[21] http://en.wikipedia.org/wiki/carbon_dioxide_laser

[22] M. Kumar and A K Nath, "Optimization Study of an Ultraviolet Preionized TEA CO2 Laser", Opt. Engg, 33, 1885, 1994

[23] Heinrich M. Jaeger, Sidney, Nagel, Robert P. Behringer, "The Physics of Granular Materials", Physics Today, 32-38, (April 1996)