

CHARACTERIZATION OF LASER BEAM INTENSITY USED FOR
MACHINING

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ABSTRACT

In this report, a method of characterizing the laser beam intensity was introduced. The method that had been used is the experimental method by using the laser beam machine. The main objective is to determine the laser parameters that influence the laser beam intensity. Laser intensity was characterized based on the hypothesis that intensity would be directly influenced by the geometry and heat-affected zone generated by laser. Experiments were carried out using 2^k design of experiments generated in STATISTICA software. Two types of geometries: lines and spots were generated on acrylic sheet. The geometrical parameters and HAZ were measured under optical microscope and integrated image analyzer and taken as response in the STATISTICA analysis. Mathematical models were developed in STATISTICA and the most accurate models were chosen up for intensity characterization. The model show that the intensity will be characterized based on high and low term according to the laser machining parameters.

ABSTRAK

Dalam laporan ini, kaedah untuk menggambarkan penumpuan sinar laser diperkenalkan. Kaedah yang telah digunakan adalah kaedah percubaan dengan menggunakan mesin laser. Objektif utama adalah untuk menentukan parameter laser yang mempengaruhi penumpuan sinar laser. Penumpuan laser digambar berdasarkan pada hipotesis bahawa keamatan akan dipengaruhi secara langsung oleh geometri dan zon yang terkena haba yang dihasilkan oleh laser. Percubaan dilakukan dengan menggunakan rekaan eksperimen 2^k dihasilkan dalam perisian STATISTICA. Dua jenis geometri: garis dan titik-titik akan dihasilkan pada lembaran akrilik. Geometri zon yang terkena haba dan parameter akan diukur di bawah mikroskop optikal serta gambar analisa bersepadu dan dianggap sebagai respon dalam analisis STATISTICA. Model matematik akan dikembangkan di STATISTICA dan model yang paling tepat dipilih untuk menggambarkan perwatakan keamatan. Model menunjukkan bahawa keamatan akan ditanda berdasarkan istilah tinggi dan rendah bersesuaian dengan parameter mesin laser.

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LIST OF SYMBOLS

ϵ	Random error or disturbance
$\beta_{0,1,2..i}$	Unknown regression coefficient
d	Working distance
D	Diameter of hole generated
L	Generated line width
p	p – value
P	Laser power
t	Laser pulse duration
$t(5)$	t – test value
T	Exposure time
W	Heat-affected zone width
$x_{1,2..i}$	Random variable

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
DOE	Design of experiment
F	F distribution
FYP	Final Year Project
HAZ	Heat-affected zone
SS	Sum of squares
Std. Err.	Standard error
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Laser machining is an advanced machining process that had been widely used nowadays. Laser machining always be the first choice of machining since it is more flexible than other machining process. Laser machining in these days can be used to in many applications such as cutting, drilling, surface finish and even for milling operations. In addition, laser machining process is a process that very productive and it is very cost effective. Furthermore, laser machine had been used for many applications beside the machining process. As example, it had been used in medical application.

In laser machining, there is lots of parameter that one need to pay attention to. One of them is the laser beam intensity. Laser beam intensity play an important role in laser machining as it will affect the heat-affected zone (HAZ) during the machining process. The unwanted heat-affected zone will downgrades the quality of the cut surface which can affected the business since the result of the process is not perfect. For studying the laser beam intensity and the heat-affected zone, there are some parameters that needed to be considered while doing the experiment. Some of the parameters are the power supply to the laser machine, the height of the laser pointer to the material which is the working distance, the exposure time rate and the laser pulse duration which is the speed of the laser nozzle movement. These parameter need to be study and investigate since this parameters would affect the geometry generated and so for the heat affected zone.

Apart from the parameters alone, this project also applied the design of experiment. The design of experiment had been widely used nowadays for experimentation. Its usefulness in making experiment provide the experimenter with more option. The experimenter will not have to think about making the experiment in systematically order because the design of experiment had help in sorting the order. Design of experiment play an important role in making an experiment to avoid unnecessary error during the experimentation.

This project had been made in order to generate a mathematical model that can be used to explain the characteristic of the laser beam intensity. From the mathematical model, it can be used to calculate the required value to substitute the experimental value so researcher would not have to do another experiment in order to investigate the laser beam intensity or heat-affected zone. The model can be used to measure and estimate the value of heat-affected zone generated for each experiments without making any experiments. From that, the heat-affected zone can be analyzed so that the effect of the heat affected zone can be minimized.

1.2 PROBLEM STATEMENT

Laser beam has been used for machining of various materials. One of the problems with laser machining is unwanted heat-affected zone, which downgrades the quality of the cut surface. Such heat-affected zone occurs very often due to lack of information on the characteristic of the laser beam intensity.

1.3 PROJECT OBJECTIVE

- 1.3.1 To determine the parameters that influences the beam intensity
- 1.3.2 To obtain a relationship between beam intensity and machining parameters
- 1.3.3 To develop a model that explains the characteristic of the laser beam intensity

1.4 PROJECT SCOPE

- 1.4.1 The intensity of CO₂ laser beam will be characterized based on the interaction between the laser and acrylic material.
- 1.4.2 Laser parameters considered are pulse duration, laser power, the working distance and the exposure time.
- 1.4.3 Parameter set will be designed using STATISTICA experimental design.
- 1.4.4 The various spots and lines will be created according to the designed parameter sets.
- 1.4.5 Each spot and line will be investigated under optical or scanning electron microscope.
- 1.4.6 The intensity model will be developed in STATISTICA.

1.5 ORGANIZATION OF THESIS

This thesis consists of five chapters. Chapter 1 presents introduction. Chapter 2 highlights related literature regarding to the project title. Chapter 3 explained the methodology for the project. Chapter 4 shows the result from the experiment and the discussion regarding to the results. And Chapter 5 concluded the project and provide with recommendation for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the finding and previous study regarding to this project title will be told. Most of the finding is based on published journal from previous experimentation and study. From the finding, the general information about the project can be gathered before the experiment began. In section 2.2, the study and the finding of laser machining had been explained. The parameter that had been considered during the laser machining had been told in section 2.3. In section 2.4, the heat affected zone had been discuss. The design of experiment then will be explain in section 2.5 while the mathematical model regarding to the title had been explained in section 2.6.

2.2 LASER MACHINING

Laser machining has been widely used in the machining process nowadays and the laser beam from the laser machine can be use to cut various type of material. This is because many of the advanced machining process have their own limitation compare to the laser machining process. Laser beam is all about focusing onto the material in order to remove the unwanted material from the parent material by vaporizing and melting the unwanted material. (A. K. Dubey, May 2007). To cut a material into smaller pieces, the laser beam will be focus on the material in order to melt and burn the material beneath the laser beam, and the laser beam will then be move to cut the material according to the specific shape or design. For these past few years, many researchers had done lot of research in order to improve the performance of laser machining by investigating and studying the different factor that might affect the quality of the laser machining.

Laser processing can be classified into conventional laser processing and laser chemical processing. (D. Bäuerle, May 2003). Conventional laser processing are including cutting, welding and even drilling while laser chemical processing is a process that change the overall chemical composition of a material. Both processes had been used in different application as the conventional laser processing is widely used in heavier field compare to laser chemical processing that had been widely used in field that required precision in making small part and so on. Laser also had been used in surface machining process. Laser surface treatment is mostly used to apply corrosion and wear resistance layers, but also for repair of engine and machine parts. (J. Meijer, 2004). The laser application had been widely used in industry as the laser machining had been constantly optimize by the research that had been made for this past few years.

Characterization of laser beam intensity used for machining is an important subject to analyze in machining. This is because the laser intensity play an important role in machining since it will affected the heat-affected zone. And, there are many laser beam type that surely have different intensity such as carbon dioxide, CO₂ and neodymium:yttrium-aluminum-garnet, Nd:YAG lasers that are primarily used in materials processing. Laser has been widely used in machining nowadays since the introduction of the process in the 60's. But, to operate a laser machine needed a very skillful worker with several years of experience. (R.F de Graaf, 2001). This is a true fact, since the laser cutting is a complex process, an ordinary person who did not learn about the laser properties and type cannot manage to handle the laser machine. It might provoke a big error, if the operator who is without any experiences with laser operate such a complex setup in handling the laser machine.

By using the laser machining, the laser beam can cut a very hard or abrasive materials and the laser machining process is a very cost effective process with low operating and maintenance costs and maximum flexibility. (M. Radovanovic, May 2002). This is because, the laser machining process only needed a short period of time in making a part that needed. Laser machining inherent flexibility-including its fiber-optic beam delivery, simply fixturing, low setup times and the availability of multi-kW machines and two- and three-dimensional computer-controlled robotic laser-cutting systems-provide an attractive feature for the process. (S. Kalpakjian, 2006). This flexibility

of the process made it become a competitor to the traditional punching process that are widely use in many industry. The laser machining process nowadays had widely use in electronics and automotive industries and it had proven that the flexibility of the laser machining process is very useful in making a complicated part.

2.3 PARAMETER IN LASER MACHINING

Laser machining is a process influenced by a large number of parameters. (J. R. Duflou, 2001). With a large number of the parameter, there are higher risks for a process to have higher error. The error that occurred might disturbed the quality of a cutting process as well as the productivity of a process. With this problem in hand, lots of time, energy and cost required to overcome it. Even though there are problem in the process, the laser machining process still will become most demanding process for many company and factory because of the flexibility that it can provide.

In laser machining, the cut surfaces also should be aware of. The basic parameters in laser machining are cutting speed, kerf width, laser power, chemistry of gas, nozzle exit pressure, nozzle design, workpiece thickness and surface quality. (B T. Rao, October 2002). This parameters need to be set by selecting the appropriate operating window of cutting speed, gas pressure, laser power and stand-off distance.

Laser types also play an important role in machining as much as the laser intensity because we obviously need a correct laser type for the certain process. For example, CO₂ and Nd:YAG lasers is being used in machining, while, ultraviolet laser is being used in medical cutting application. (N. B. Dahotre, 2007). Each laser types can provide different application in machining. For melt transition process, the laser needed to use in the process is a laser emission characteristic that matched the material and machining dimensions. For surface vaporization process, laser with short pulses and higher power density may be used.

To achieve the optimum results in laser machining, by providing a gas assist, the result will become more accurate. Furthermore, the gas jet also provide help by generating additional thermal energy and to supply shear force for to the gas/liquid

boundary to eject the molten metal formed during the cutting process. (B T. Rao, October 2002). By using appropriate optimization techniques, it is possible to identify relatively large process windows, in which a good cut quality can be obtained. (J. R. Dufloy). There are many optimization techniques that can be apply by referring to the suitable factor according to the parameter that we have.

2.4 HEAT-AFFECTED ZONE

Unwanted effects such as distortion, surface cracking, embrittlement, decrease in weld ability, decrease in corrosion and fatigue resistance are often related with the heat affected zone. In order to minimize the heat affected zone, the laser cutting parameters set should be chosen carefully. Generally, by increasing the laser cutting speed would help in order to minimize the effect from the heat affected zone. (N. B. Dahotre, 2007). Such heat affected zone should always downgrade the quality of the cut surface after laser machining process. Heat affected zone is always giving the problem for laser machining because of the low quality cut surface. Not just for cut surface, the heat affected zone also giving bad impact on the metallurgical characteristics of laser machined work parts. (A. K. Dubey, May 2007). The longer the material exposed to the laser beam, the heat affected zone would gave high effects. With the high effects, not just the metallurgical and the cut surface would be affected. There would be more bad effect for the material.

2.5 DESIGN OF EXPERIMENT

To plan the experiment, collecting and analyzing the data in systematically and scientific way, the finer approach is by using the designed experiment because it can be done with limited use of available resource before the experiment. (A. K. Dubey, September 2006). By using the design of experiment, instead of making the data in systematically order, it also helped in reducing the error during the experiment. The relationship between the input and the output value can be expressed by using a mathematical model in terms of the mathematical equations. (A. K. Dubey, May 2007). From the model, the calculated value would be use to check the accuracy of the model. Furthermore, it also helped to further understand the complex process in laser machining process.

In experiment involving several factors where it need to study the joint effect of the factor on a response, factorial designs are frequently used. Though, there are several special cases involving the general factorial designs which important. This is because it can be use to form the basis of other designs that can be considerable practical value and they had been widely employed in research work. (D. C. Montgomery, 2003).

2^k factorial design is a complete replicate of design that require $2 \times 2 \times \dots \times 2 = 2^k$ observations. It is a design that is useful at the early stages of experimental work that required many factors to be investigated and examine. This model can be use to provide smaller number of runs when the experiment needed to be in many runs. And, since there are only two levels for each factor, the response should be assume approximately linear over the range of the factor levels chosen. (D. C. Montgomery, 2003).

2.6 MATHEMATICAL MODEL: REGRESSION MODEL

If there are more than one regressor variable, the regression analysis can be applied to analyze the situations. A multiple regression model need to be use when there are more than one regressor variable for a regression model. As example, the line width of a line geometry generated by the laser beam depends on the laser power, laser pulse duration and the working distance. The multiple regression model that can be use to describe the relationship between those parameter is

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \epsilon \quad (2.1)$$

Where Y represents the line width, x_1 represents the laser power, x_2 represents the laser pulse duration, x_3 represents the working distance and ϵ is a random error term. The equation called as the multiple linear regression models with three regressors. The Eq. (2.1) is a linear function for the unknown parameters which is the β_0 , β_1 , β_2 and β_3 and that is why the term linear used for the regression model.

The expected value of the error term, ϵ can be assumed zero. Partial regression sometimes can be use to represents β_1 and β_2 since the expected change for Y per unit change of x_1 when the x_2 are being held constant for measuring the β_1 , and the expected

change for Y per unit change of x_2 when the x_1 are being held constant for measuring the β_2 . (D. C. Montgomery, 2003).

For approximating a functions, the regression model that regularly be used is the multiple linear regression models. There is unknown relationship of true functional between Y and x_1 , x_2 and x_3 , but the linear regression model is an adequate approximation over certain range of the independent variables that will be investigated for a functions.

To find the interaction between the effect for a certain analysis, the multiple linear regression model also can be use to analyzed the effect. The interaction can be made by cross the product in the model, such as

$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{23} x_2 x_3 + \beta_{13} x_1 x_3 + \epsilon \quad (2.2)$$

Generally, not considering the shape of a surface plot that had been generated by the model, a linear regression model is a model that is linear in the parameters. Linear in parameters means that the β 's is linear. (D. C. Montgomery, 2003).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The main objective of this project is to find the relation of the laser parameter that can affect the laser beam intensity by doing the experiment of laser machining. In this section, it will tell about the experiment that had been done from the research up to the analysis to fulfill the objectives of the project. Before starting this project, reading needed to be done in order to understand the main point of the project. By making the literatures review, it helps in order to further understand the parameter and building up the flow of the project. For this project, the experiment made are based on the Design of Experiment (DOE) that had been made regarding to the variable and parameter needed to be considered in this experiment. By designing the experiment, major and minor error such as random error can be minimize and avoided. With this, the data and result that come out from the experiment is reliable and trusted. Figure 3.1 shows the overall methodology of this project.

3.2 METHODOLOGY FLOWCHART

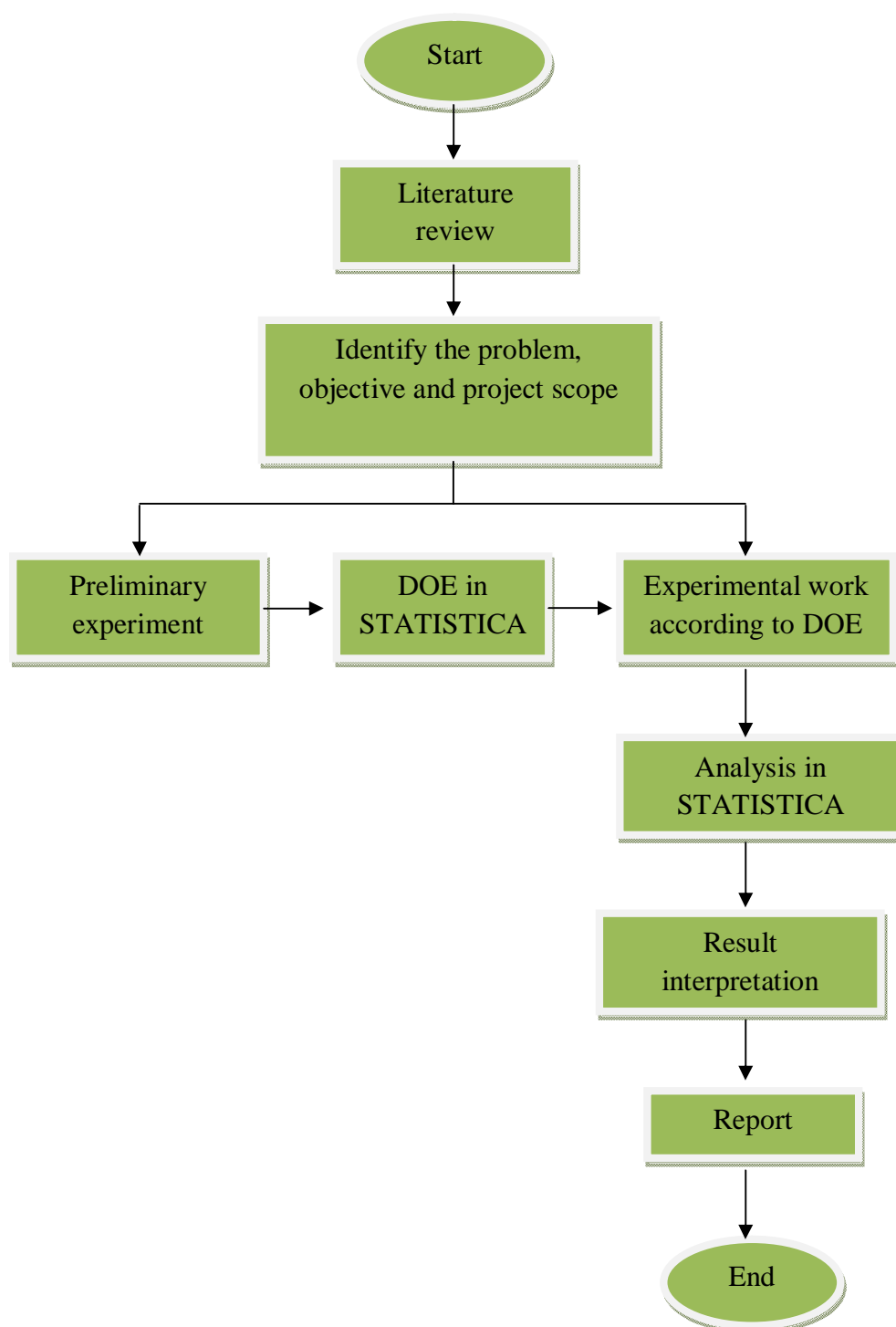


Figure 3.1: Flow chart of the methodology

3.3 THE WHOLE PROJECT FLOW

3.3.1 Literature Review

The project started after receiving the title. Then, the project need to be studied first by doing research for previous study from the published reports and published books. By doing the research, the general information regarding to the title can be gathered. It also helped in designing the suitable flow for this project.

3.3.2 Identifying the Objective, Problem and Project Scope

The objective of this project needed to be determined first by consulting the supervisor. From that, the problem statement and the project scope regarding with the title can be determined. With all the requirement of this project had been gathered, the project can be established.

3.3.3 Preliminary Experiment

This step needed to be done in order to determine the required parameter that will be used and be investigated for this experiment. From the preliminary experiment, it helped in further the understanding in making decision to choose the parameters required.

3.3.4 Designing the Experiment

To design this experiment, STATISTICA had been use and the result from the experiment had been interpreted using this software. First of all, the independent and dependent variable should be determined base on the title of the project. In this project, the independent variables are laser power, working distance, laser pulse duration and the exposure time. Laser pulse duration used in the moving laser experiment while the exposure time used in static laser experiment. Laser pulse duration is the time duration for the laser pointer at the laser machine to complete it process in one cycle. Exposure time is the time of the material expose under the laser beam. The dependent variable for

each experiment is difference. For line geometry experiment, the dependent variable is the width of line generated and the heat-affected zone (HAZ) generated by the laser beam. For spot geometry experiment, the dependent variable is the diameter of hole generated and the heat-affected zone generated by the laser beam. This variable is important to the experiment as it can be used to determine and measure the intensity of the laser beam.

3.3.5 Running the Experiment

To run the experiment, the table of the parameter that needed to be investigated during the experiment should be complete. The table can be get from STATISTICA after the parameter had been keyed in the software. The experiment need to be run in order that the STATISTICA had produced since this software had been used to reduce the number or error that might occur during the experiment. Before starting the experiment, the laser pointer should be check and clean from any single debris and dirt. Make sure that the lens in the laser pointer is clean enough because the lens played an important part in focusing the laser beam. The unwanted material will give unwanted effect to the laser beam and it will automatically affect the result.

3.3.6 Analysis in STATISTICA

Analysis in STATISTICA will be done after the required data had been gathered from the experiment. The data first need to be filled in the STATISTICA design of experiment table so that it can be use for analysis. From that, proceed with the analysis and come out with the require information for the model. Develop the ANOVA table, Effect Estimate table, Regression Coefficient table, Normal Probability plot, Observed against Predicted value plot and the Surface plot.

3.3.7 Result Interpretation

The data that had been gathered after the analysis then needed to be interpreted. This main objective of this process is to check the validity the accuracy of the result.

After that, the model will be developed based on the information gathered from the analysis.

3.3.8 Report Writing

After all the data and model had been gathered, the report then can be write to record all the flow, the main information and the finding in this project.

3.4 SPECIFICATION OF THE EXPERIMENT OF LINE GEOMETRY EXPERIMENT

3.4.1 Material Information

This experiment will be done by using the acrylic plate. The acrylic plate will then be cut into three pieces with suitable dimension for the experiment. Acrylic material will be use in the experiment because acrylic material are widely use in industry nowadays. In addition, since the acrylic material is a clear plastic material, it will make the observation to examine the line and spot generated easier. In this experiment, CO₂ laser will be use to generate the line needed in order to investigate the intensity of the laser beam. Furthermore, the CO₂ laser has maximum power up to 30 Watt. Meanwhile, the laser speed of movement which is the laser pulse duration, there are no maximum or minimum values. This means that from the computer, the speed of the movement can be set freely upon desired value required by any experiment. The laser beam will be assisted by gas to optimize the laser processing and the gas is generated by using a compressor. Figure 3.2 and 3.3 show the material and apparatus that had been used in this experiment.



Figure 3.2: Laser machine

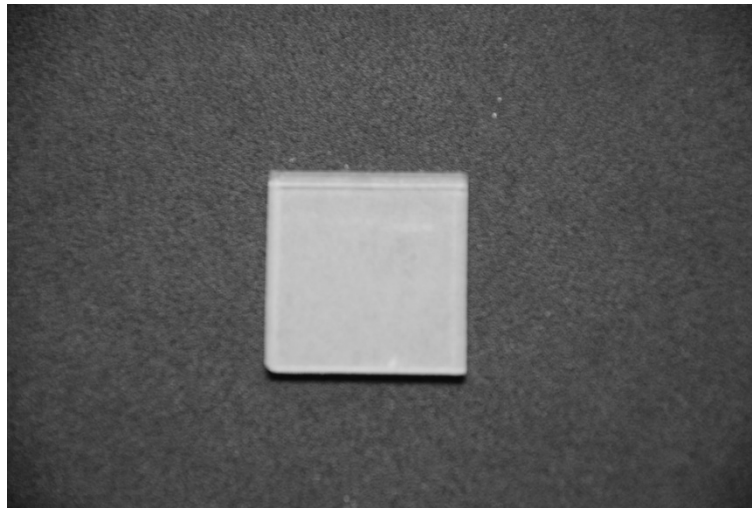


Figure 3.3: Acrylic specimen

3.4.2 Preparing the Material

In order to find the suitable dimension for the specimen, a few test experiments had been made. It needed since the laser beam might pass through material if the thickness of the material is not thick enough. If the laser beam pass through during moving laser experiment it will cut the specimen into a smaller pieces. Therefore, the

acrylic plate that had been use in this experiment has the thickest among other acrylic plate provided which is 10mm thick.

3.4.3 Preparing the Laser Machine

Before running the experiment, a few tests should be made to make sure that the machine is in good condition. From the test, the problem that may occur can be detected earlier before the experiment and it can be corrected. This step might look like a small thing to do. But, this step might be the most important step as it will affect the result from the experiment. This step also will make optimized the laser machine and then optimized the result that will be getting from the experiment.

3.4.4 Step by Step Procedure

1. Prepare all the material and suitable measurement apparatus for the experiment which is ruler.
2. Put the acrylic plate under the nozzle of the laser machine and set the working distance or the height of the nozzle according to the first value in the STATISTICA table.
3. Then, set the laser power that will be use from the laser controller device by referring to the value in STATISTICA table.
4. Next, change the value of laser pulse duration in the coding in C++ to change the time for a process to complete one cycle.
5. Label the line generated according to the order provide from STATISTICA table.
6. Repeat the step 2 until 4 until all the desired result had been collect.
7. Take the material with the spot generated and put the material under optical microscope.
8. Examine and measure the line width and heat-affected zone for all the line generated.
9. Finally, put the data into the STATISTICA table to be analyzed.

3.5 SPECIFICATION OF THE EXPERIMENT OF SPOT GEOMETRY EXPERIMENT

3.5.1 Material Information

As in section 3.4.1, this experiment also will be done by using the acrylic plate. The acrylic plate will then be cut to one piece with suitable dimension for the experiment. Note that for this experiment, the laser beam will be focused on only one acrylic specimen for all the ten runs. Acrylic material will be use in the experiment because acrylic material are widely use in industry nowadays. In addition, since the acrylic material is a clear plastic material, it will make the observation to examine the line and spot generated easier. For this experiment too, the CO₂ laser will be use to generate the spot needed in order to investigate the intensity of the laser beam. Furthermore, the CO₂ laser has maximum power up to 30 Watt. Meanwhile, the laser speed of movement which is the laser pulse duration, there are no maximum or minimum values. This means that from the computer, the speed of the movement can be set freely upon desired value required by any experiment. The laser beam will be assisted by gas to optimize the laser processing and the gas is generated by using a compressor. For the figure of the material and apparatus that had been used, please refer to Figure 3.2 and Figure 3.3 in section 3.4.1.

3.5.2 Preparing the Material

In order to find the suitable dimension for the specimen, a few test experiments had been made. It needed since the laser beam might pass through material if the thickness of the material is not thick enough. If the laser beam pass through the specimen during the spot geometry experiment, the effect on the specimen would be hard to examine under the optical microscope. Therefore, the acrylic plate that had been use in this experiment has the thickest among other acrylic plate provided which is 10mm thick.

3.5.3 Preparing the Laser Machine

Before running the experiment, a few tests should be made to make sure that the machine is in good condition. From the test, the problem that may occur can be detected earlier before the experiment and it can be corrected. This step might look like a small thing to do. But, this step might be the most important step as it will affect the result from the experiment. This step also will make optimized the laser machine and then optimized the result that will be got from the experiment.

3.5.4 Step by Step Procedure

1. Prepare all the material and suitable measurement apparatus for the experiment such as ruler and stopwatch.
2. Put the acrylic plate under the nozzle of the laser machine and set the working distance or the height of the nozzle according to the first value in the STATISTICA table.
3. Then, set the laser power that will be use from the laser controller device by referring to the value in STATISTICA table.
4. Turn ON the laser and set the time. Turn OFF after the time duration needed had been reached.
5. Label the spot generated according to the order provided from STATISTICA table.
6. Repeat the step 2 until 5 until all the desired result had been collect.
7. Take the material with the spot generated and put the material under optical microscope.
8. Examine and measure the diameter and heat-affected zone for all the spot generated.
9. Finally, put the data into the STATISTICA table to be analyzed.

3.6 STATISTICA ANALYSIS

From the software, there are lot results that can be gathered. In this project, the investigation or the analysis is focusing on the relation between the independent variable and the dependent variable which is the relation between machining parameter and the geometry generated from the experiment. Therefore, from the STATISTICA software, choose Industrial Six Sigma to analyze it. From there, choose Effect Estimate Table and a table will appear after that. In the table, there are result and value that show the relation between independent and dependent variable. After that, get the Normal Probability Plot graph to put it in the Results and Discussions section for the discussion. This information will assist this analysis and experiment in order to find the suitable and appropriate mathematical model to represent the laser beam intensity characteristics.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the result and the analysis for the experiment from the beginning until the end of the experiment will be present. All the data and the analysis will be use to explain the characteristic of the laser beam intensity. The data and the analysis also will be use to determine the parameter that influence the laser beam intensity in the machining process. In this chapter too, the model that are needed for this project will be produced and discussed for the availability of the model and the accuracy of the model. This chapter also will explained and showed on what based the model had been choose to explain the characteristic of the laser beam intensity. Furthermore, this chapter will discuss about the reliability of the data that had been gathered during the experiment. The reliability and the repeatability of the machine also will be discussed in this chapter.

4.2 HYPOTHESIS

The intensity of a laser beam used for machining cannot be measure directly. In other words, the equipment to characterize the laser beam intensity is not available to date. That is why the parameter of the laser machining should be considered. In common sense too, the intensity of the laser beam are related to the geometry generated and the heat affected zone from the laser beam. In this project, the laser beam intensity is represented by the geometry generated and the heat affected zone. A mathematical model that relates these parameters and laser machining parameters is used to characterize laser intensity. It should be note that the interaction between the geometry would not be investigated in this project according to the project objective.

4.3 LINE GEOMETRY EXPERIMENT RESULTS

4.3.1 Line Geometry Experiment Data

As mentioned in the methodology section, the moving experiment or line geometry experiment is been made by making various line on the acrylic material. The specimen picture after the experiment is shown in Figure 4.1 below.

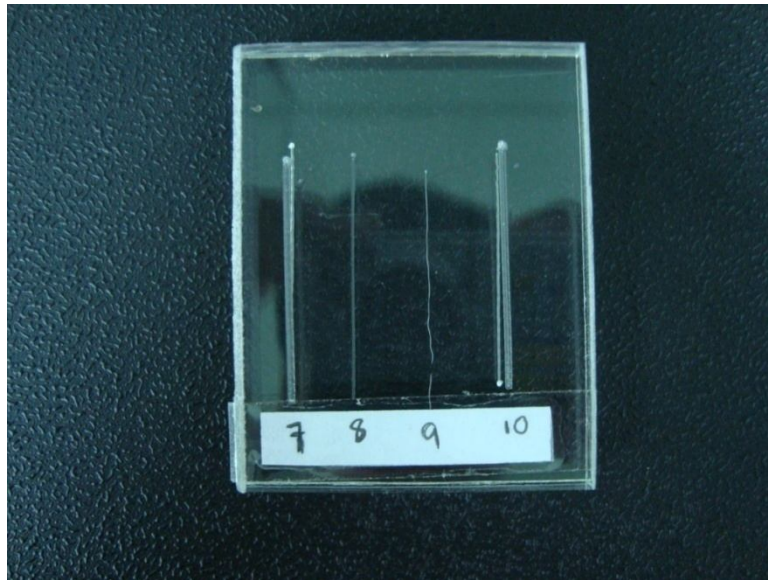


Figure 4.1: Specimen picture after the line geometry experiment

From the figure, it can be see that there are numbering below the line generated. The numbering showed the number of run according to the design of the experiment. After that, the specimen will then be put under optical microscope to measure the width of the line generated and the width of the heat-affected zone. Figure 4.2 show the specimen picture under the optical microscope.

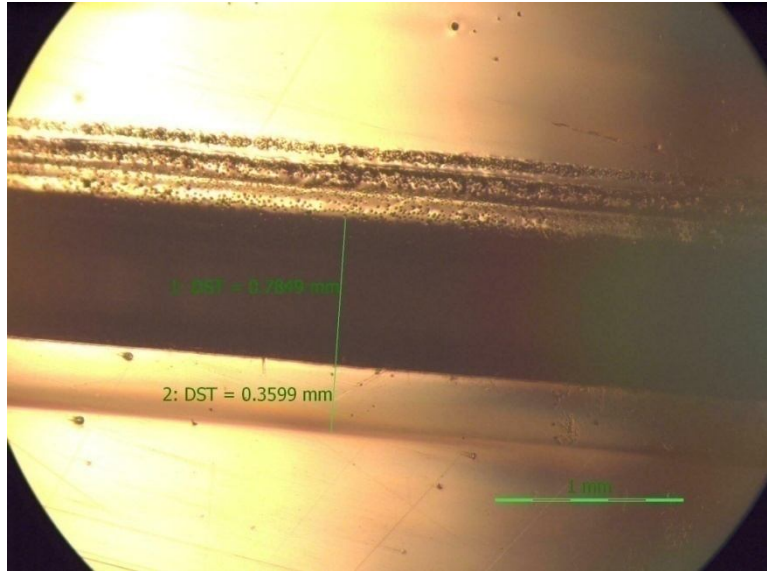


Figure 4.2: Specimen picture under optical microscope

The line width and the HAZ will be measure by making a datum line. From the datum line, compare it with the scale that had been generated for measurement. After the width for both line width and heat-affected zone width had been measured, the value then will be keyed in the table for STATISTICA analysis. The result from the experiment is shown as in Table 4.1 below.

Table 4.1: Table of result from line geometry experiment

Factor/Order of Run	Laser Power, P(W)	Laser Pulse Duration, t(s)	Working Distance, d(cm)	Generated Line Width, D(mm)	Width of
					Heat Affected Zone, W(mm)
1	28.00000	500.00000	10.00000	0.7849	0.3599
2	28.00000	50.00000	15.00000	0.7248	0.5832
3	1.50000	50.00000	10.00000	0.1238	0.0885

Table 4.1: Continued

Factor/Order of Run	Laser Power, P(W)	Laser Pulse Duration, t(s)	Working Distance, d(cm)	Generated Line Width, D(mm)	Width of Heat Affected Zone, W(mm)
4	28.00000	50.00000	15.00000	0.6654	0.5123
5	28.00000	500.00000	10.00000	1.1020	0.3067
6	1.50000	500.00000	15.00000	0.3714	0.4184
7	14.75000	275.00000	12.50000	0.7421	0.1650
8	1.50000	500.00000	15.00000	0.3486	0.4426
9	1.50000	50.00000	10.00000	0.0949	0.0949
10	14.75000	275.00000	12.50000	0.7614	0.1541

After the data had been put into the STATISICA analysis table, the data will then be analyzed.

4.3.2 Laser Power, Laser Pulse Duration, Working Distance against Generated Line Width

Before continuing with other analysis, the data need to be check first whether it is valid or not. The observed against predicted value need to be generate first to check the validity of the data gathered. STATISTICA will be use to generated observed against predicted value plot. The Figure 4.3 showed the plot.

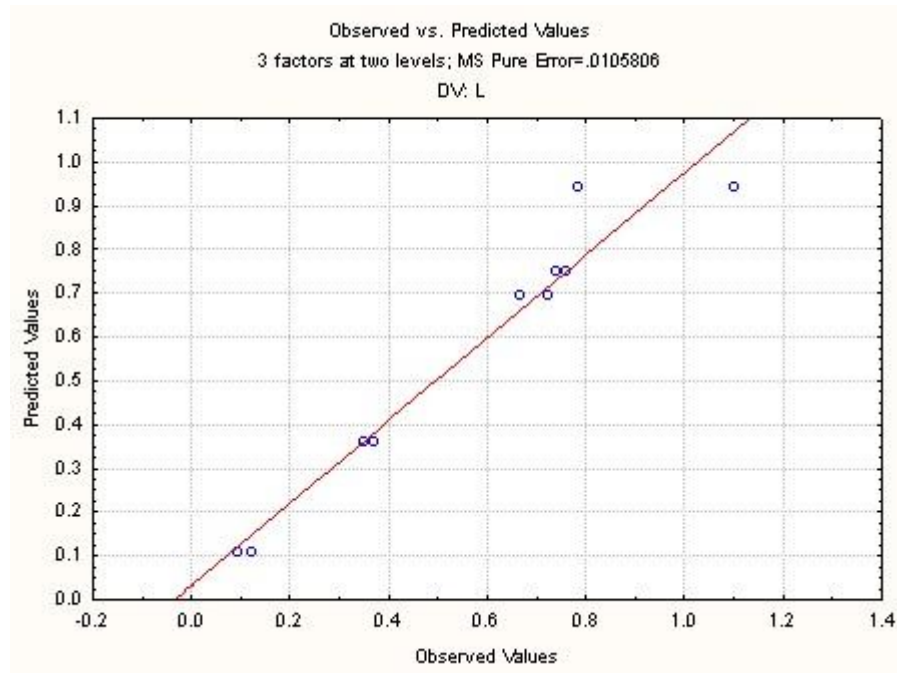


Figure 4.3: Observed against predicted value plot for generated line width

Note that the predicted value are generate from the design of the experiment that had been done before doing the experiment. This figure will be use to determine whether the data that had been gathered can be use or not in this analysis. In this case, the plot of observed value is lies near to the predicted value line. This shows that the data can be use for the analysis. After the data had been examined, the data will be use for other analysis. The table below shows the result of effect estimates for the generated line width against all the independent variables that had been generated using STATISTICA software.

Table 4.2: Effect estimate table of generated line width

Factor	Effect	Std. Err.	t(5)	p
Mean/Interaction	0.526980	0.036367	14.49052	0.000028
Laser Power	0.584590	0.072734	8.03732	0.000482
Laser Pulse Duration	0.249490	0.072734	3.43015	0.018633
Working Distance	0.001140	0.072734	0.01567	0.988101

From the table, it can be seen that the highlighted columns which are laser power and laser pulse duration, gave the significant effect to the generated line width. The other variable which is the working distance did not give a significant effect to the generated line width. From STATISTICA, the surface plot for the dependent variable can be generated. Figure 4.4 and Figure 4.5 show the surface plot for laser power, laser pulse duration and working distance against the generated line width.

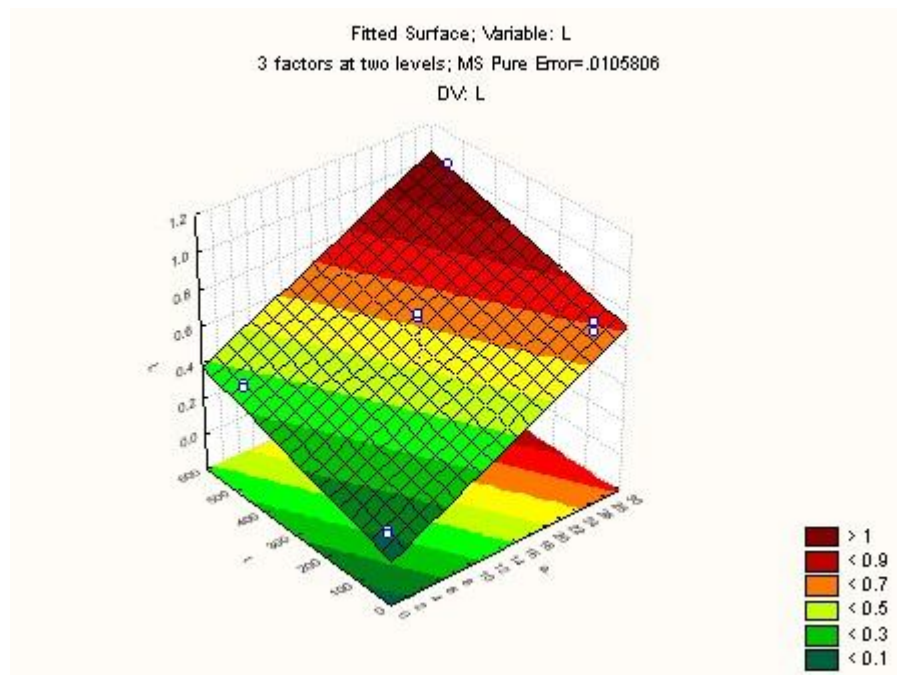


Figure 4.4: Surface plot of laser power and laser pulse duration against generated line width

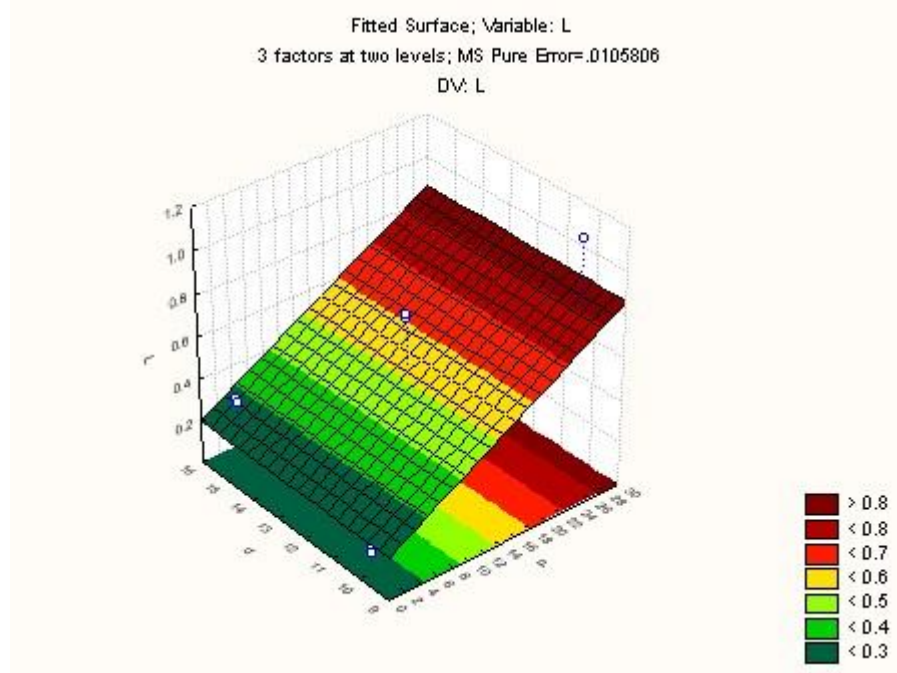


Figure 4.5: Surface plot of laser power and working distance against generated line width

By referring to the both figures, one can be know the relation between the independent variables and the dependent variable in this experiment. Meanwhile, table below show the regression coefficient for the generated line width.

Table 4.3: Regression coefficient table of generated line width

Factor	Regression Coefficient	Std. Err.	t(5)	p
Mean/Interaction	0.046279	0.194940	0.237401	0.821767
Laser Power	0.022060	0.002745	8.037319	0.000482
Laser Pulse Duration	0.000554	0.000162	3.430149	0.018633
Working Distance	0.000228	0.014547	0.015673	0.988101

By referring to the general model Eq. (2.1) for 2^k factorial design,

$$Y = B_0 + B_1x_1 + B_2x_2 + B_3x_3 + \epsilon$$

and substitute the value of the regression coefficient into the model. In this case, x_1 is the laser power, x_2 is the laser pulse duration and x_3 is the working distance. The model after the substitution is,

$$L = 0.046279 + 0.022060P + 0.000554t + 0.000228d \quad (4.1)$$

where L is the generated line width, P is the laser power supply, t is the laser pulse duration, d is the working distance and ϵ is the random disturbance or error.

4.3.3 Laser Power, Laser Pulse Duration, Working Distance against Heat-Affected Zone Width

As in the analysis before, the data for heat-affected zone need to be check too. Once the data had been checked, then the analysis will then be continued. STATISTICA will be use to generate the figure shown below.

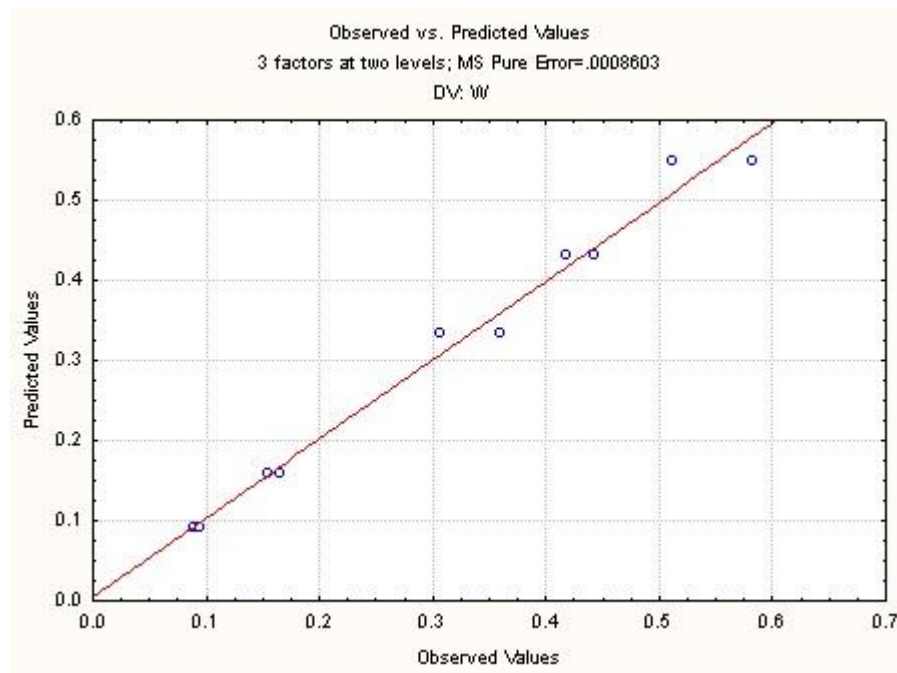


Figure 4.6: Observed against predicted value plot for heat-affected zone width

From the figure, it can be concluded that the data can be used for other analysis because the observed value plot are lies near to the predicted value line. Note that the predicted value is generated from STATISTICA earlier during designing the experiment. The analysis process then continued by generating the effect estimate table. The table below shows the result from the analysis in STATISTICA for effect estimates from the heat-affected zone width against all the independent variables.

Table 4.4: Effect estimate table of heat-affected zone width

Factor	Effect	Std. Err.	t(5)	p
Mean/Interaction	0.350819	0.010370	33.83037	0.000000
Laser Power	0.179413	0.020740	8.65061	0.000341
Laser Pulse Duration	0.062163	0.020740	2.99725	0.030195
Working Distance	0.276613	0.020740	13.33723	0.000042

From the table, it can be see that all rows and columns are highlighted, which mean that all independent variables gave significant effect to the heat-affected zone. Then, continue the analysis by generating the surface plot for the laser power, laser pulse duration and the working distance against the heat-affected zone width. Figure 4.7 and Figure 4.8 show the generated surface plot for the analysis.

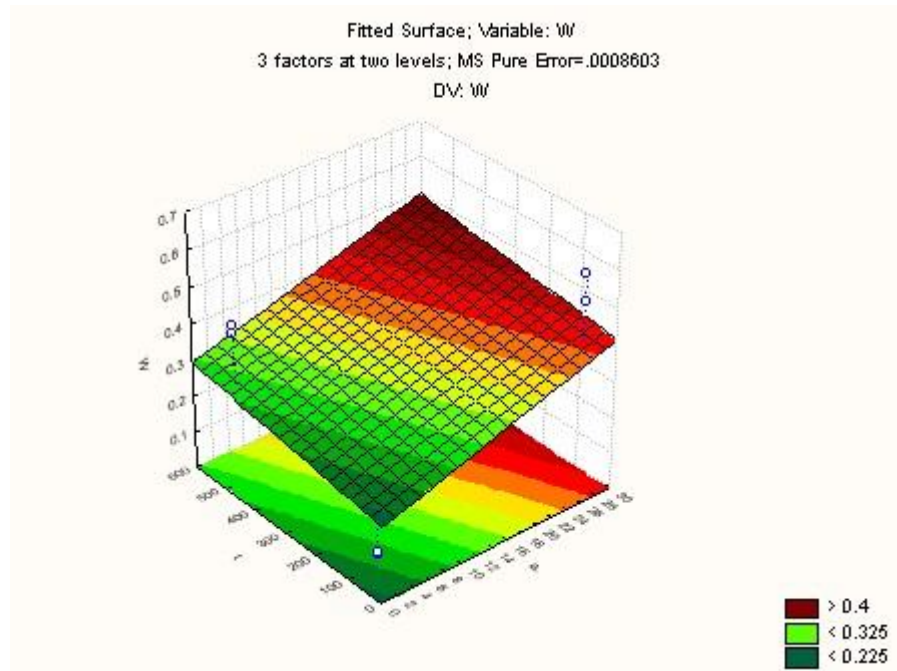


Figure 4.7: Surface plot of laser power and laser pulse duration against generated head-affected zone width

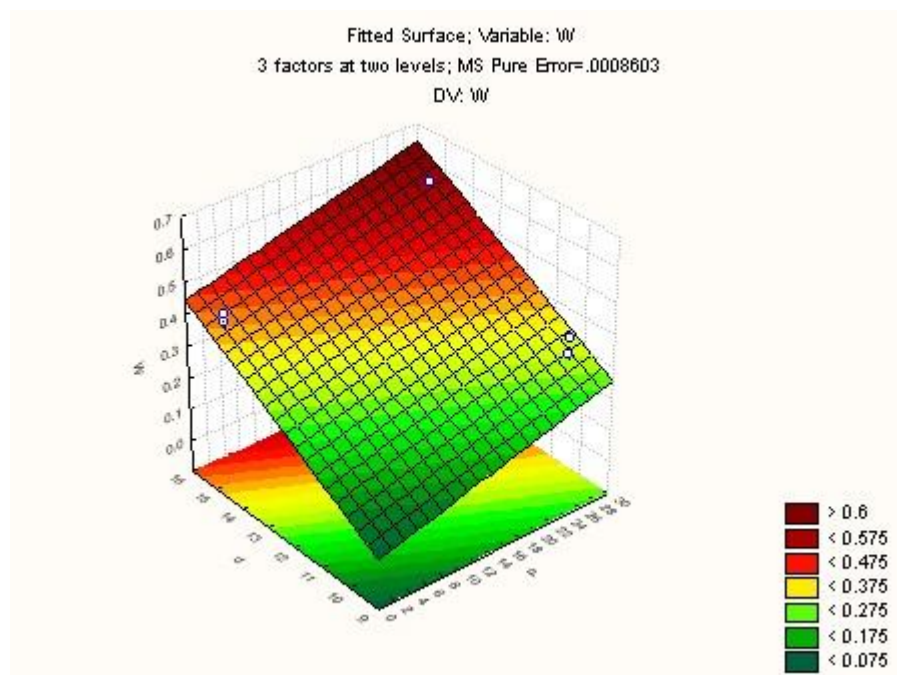


Figure 4.8: Surface plot of laser power and working distance against generated heat affected-zone width

By referring to the both figures, one can be know the relation between the independent variables and the dependent variable in this experiment. Meanwhile, table below show the regression coefficient for the generated heat-affected zone width.

Table 4.5: Regression coefficient table of heat-affected zone width

Factor	Regression Coefficient	Std. Err.	t(5)	p
Mean/Interaction	-0.478562	0.055586	-8.60937	0.000349
Laser Power	0.006770	0.000783	8.65061	0.000341
Laser Pulse Duration	0.000138	0.000046	2.99725	0.030195
Working Distance	0.055322	0.004148	13.33723	0.000042

By referring to the general model Eq. (2.1) for 2^k factorial design,

$$Y = B_o + B_1x_1 + B_2x_2 + B_3x_3 + \epsilon$$

and substitute the value of the regression coefficient into the model. In this case, x_1 is the laser power, x_2 is the laser pulse duration and x_3 is the working distance. The model after the substitution is,

$$W = -0.478562 + 0.006770P + 0.000138t + 0.055322d \quad (4.2)$$

where W is the heat-affected zone width, P is the laser power supply, t is the laser pulse duration, d is the working distance and ϵ is the random disturbance or error

4.4 SPOT GEOMETRY EXPERIMENT RESULTS

4.4.1 Spot Geometry Experiment Data

The static experiment or spot geometry experiment is made by focusing the laser beam onto the specimen as it will generate hole that can be examine. The specimen picture for the static experiment is shown in Figure 4.9 below.

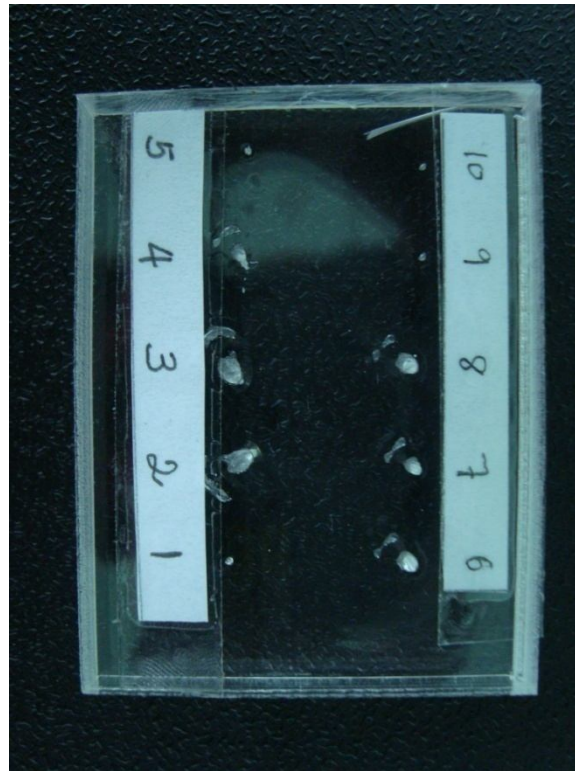


Figure 4.9: Specimen picture after the spot geometry experiment

As in previous experiment for moving, the numbering is referring to the number of run and the order of the run according to the design of the experiment. Next, the specimen will then be put under the optical microscope to measure the diameter of the hole generated and the width of the heat-affected zone. Figure 4.10 show the specimen picture under the optical microscope.

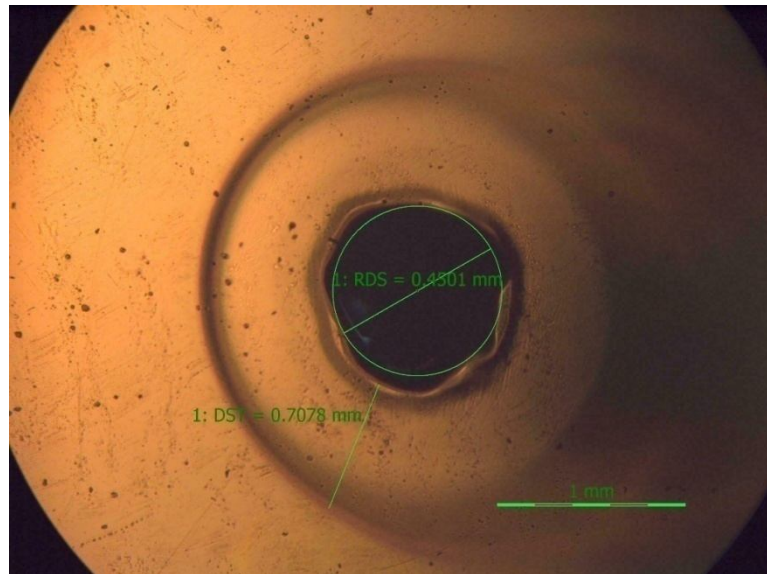


Figure 4.10: Specimen picture under the optical microscope

To measure the diameter and the HAZ width, the best diameter and width are measure by making diameter in the hole and line for the HAZ width. From that, the measurement will be compare with the scale provided. After all of the value for the diameter and the heat-affected zone width had been gathered, the data will then be put into the table for analysis in STATISTICA. The result from the experiment is shown as in table below.

Table 4.6: Table of result from spot geometry experiment

Factor/Order of Run	Laser Power, P(W)	Exposure Time, T(s)	Working Distance, d(cm)	Diameter of Hole Generated, D(mm)	Width of Heat Affected Zone, W(mm)
1	1.50000	10.000000	10.00000	1.0090	0.6794
2	28.00000	10.000000	15.00000	2.4960	1.0510
3	28.00000	10.000000	15.00000	2.5540	1.0860
4	28.00000	2.000000	10.00000	2.0610	0.5288
5	1.50000	10.000000	10.00000	1.0320	0.9597

Table 4.6: Continued

Factor/Order of Run	Laser Power, P(W)	Exposure Time, T(s)	Working Distance, d(cm)	Diameter of Hole Generated, D(mm)	Width of Heat Affected Zone, W(mm)
6	14.75000	6.000000	12.50000	2.5810	0.8230
7	28.00000	2.000000	10.00000	2.0100	0.6359
8	14.75000	6.000000	12.50000	2.5130	0.8660
9	1.50000	2.000000	15.00000	0.9992	0.5013
10	1.50000	2.000000	15.00000	0.9742	0.4782

After the data had been put into the STATISICA analysis table, the data will then be analyzed.

4.4.2 Laser Power, Exposure Time, Working Distance against Diameter of Hole Generated

Before starting the analysis, the data from the experiment need to be checked the validity. The data need to be analyzed in STATISTICA and observed against predicted value plot need to be generated from it first. The Figure 4.11 showed the plot for the predicted and observed value of holes diameter.

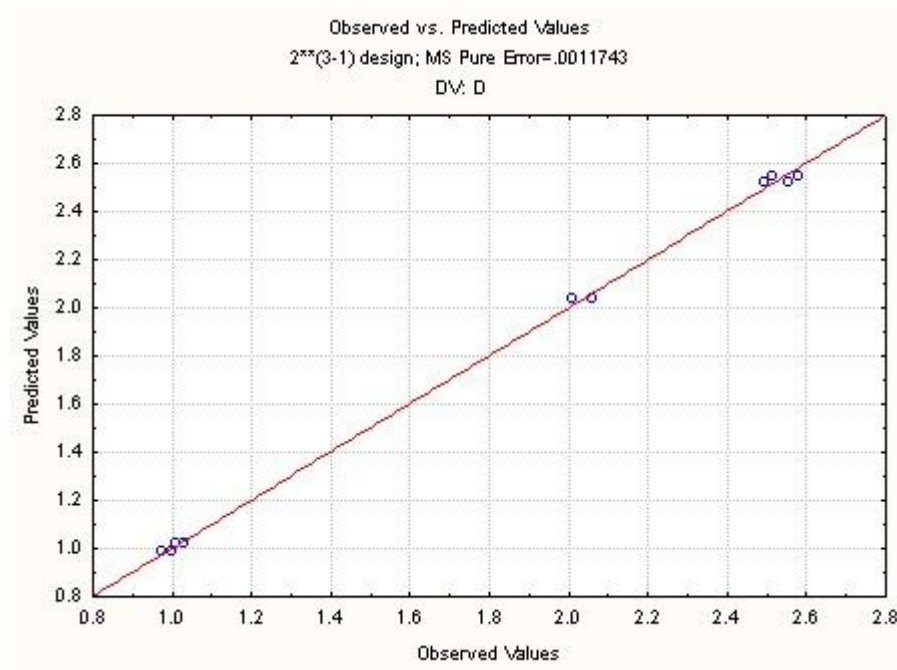


Figure 4.11: Observed against predicted value plot for diameter of hole generated

From the figure, it shows that the observed value plot lies near to the predicted value line. From that, one can know that the data from the experiment can be use for the next analysis in this case. The data then will be use to generated effect estimate table and the table below shows the result from the analysis in STATISTICA for effect estimates from the generated all the independent variable against diameter of hole generated.

Table 4.7: Effect estimate table of diameter of hole generated

Factor	Effect	Std. Err.	t(5)	p
Mean/Interaction	1.641925	0.012116	135.5217	0.000000
Laser Power	1.276650	0.024231	52.6863	0.00000
Exposure Time	0.261650	0.024231	10.7981	0.000118
Working Distance	0.227850	0.024231	9.4032	0.000229

From the table, it can be seen that all rows and columns are highlighted, which means that all of the independent variables gave significant effect to the diameter of hole generated. Next, the surface plot for the case can be generated. Figure 4.12 and Figure 4.13 show the surface plot for the diameter of hole generated.

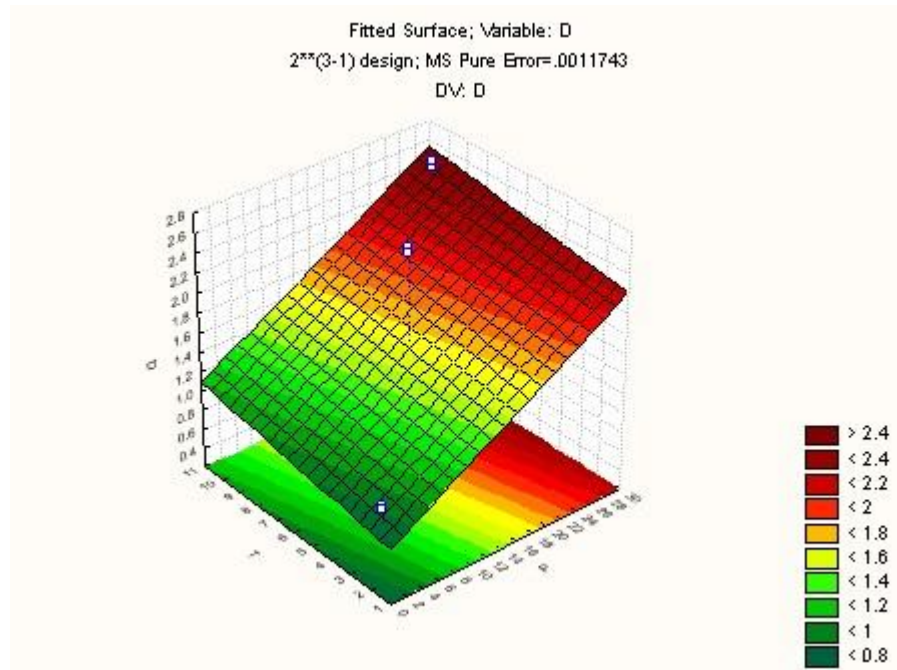


Figure 4.12: Surface plot of laser power and exposure time against the diameter of hole generated

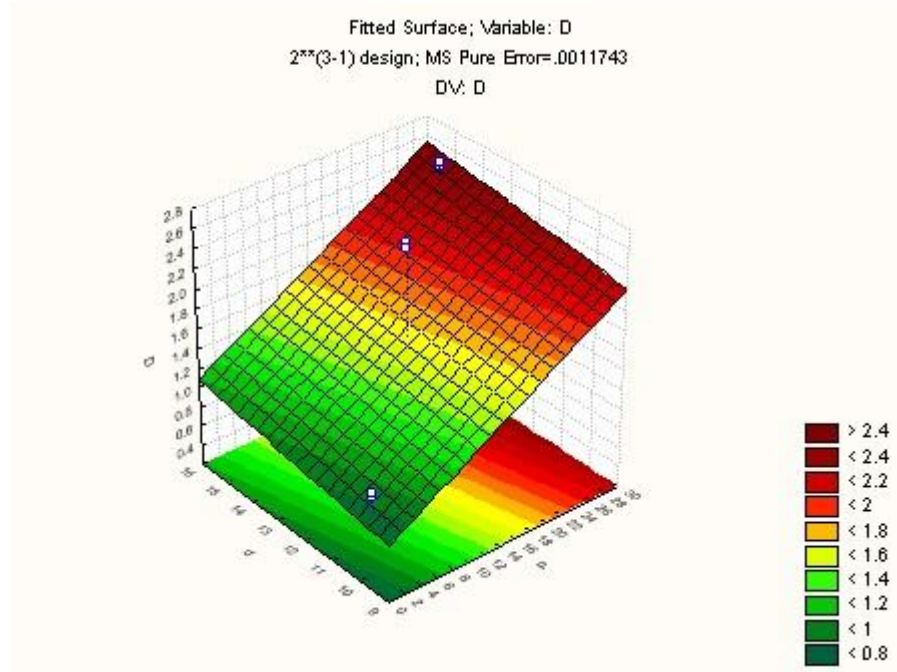


Figure 4.13: Surface plot of laser power and working distance against the diameter of hole generated

From both of the figure, the relation between the independent variables and the dependent variable can be examined. Meanwhile, table below show the regression coefficient for the generated line width.

Table 4.8: Regression coefficient table of generated line width

Factor	Regression Coefficient	Std. Err.	t(5)	p
Mean/Interaction	0.165474	0.065792	2.51509	0.053494
Laser Power	0.048175	0.000914	52.68625	0.000000
Exposure Time	0.032706	0.003029	10.79807	0.000118
Working Distance	0.045570	0.004846	9.40317	0.000229

By referring to the general model Eq. (2.1) for 2^k factorial design,

$$Y = B_0 + B_1x_1 + B_2x_2 + B_3x_3 + \epsilon$$

and substitute the value of the regression coefficient into the model. In this case, x_1 is the laser power, x_2 is the time duration and x_3 is the working distance. The model after the substitution is,

$$D = 0.165474 + 0.048175P + 0.032706T + 0.045570d \quad (4.3)$$

where D is the diameter of hole generated, P is the laser power supply, T is the exposure time, d is the working distance and ϵ is the random disturbance or error.

4.4.3 Laser Power, Exposure Time, Working Distance against Heat-Affected Zone Width

As in the previous analysis, the data for the heat affected zone width also need to be examined first. An observed against predicted value plot need to be generated first as in previous analysis to check the validity of the data. Figure 4.14 show the observed against predicted value plot for the heat-affected zone.

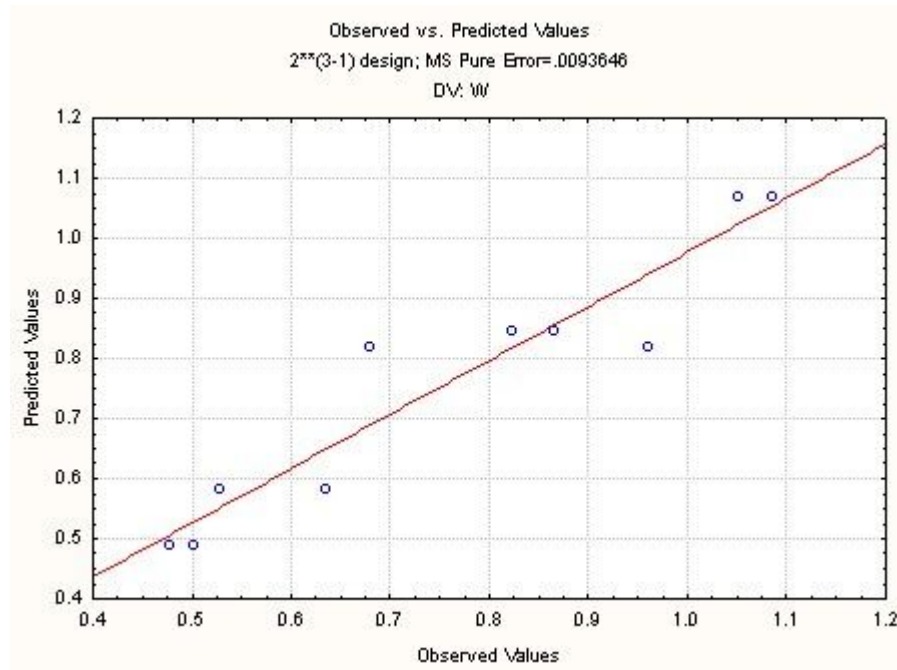


Figure 4.14: Observed against predicted value plot of heat-affected zone width

From the figure, it showed that the data are not quite good as the previous data. But, it still can be use as most of the value is near to each other. Furthermore, most of the observed value is lies near to the predicted value line. By using the data, an effect estimate table had been generated. The Table 4.9 show the result from the analysis in STATISTICA for effect estimates from the all the independent variables against heat-affected zone width.

Table 4.9: Effect estimate table of heat-affected zone width

Factor	Effect	Std. Err.	t(5)	p
Mean/Interaction	0.740038	0.034214	21.62987	0.000004
Laser Power	0.170775	0.068427	2.49571	0.054777
Exposure Time	0.407975	0.068427	5.96216	0.001899
Working Distance	0.078175	0.068427	1.14245	0.305005

From the table, it can be see there is only one row from the independent variables that had been highlighted which is the exposure time row. Since it is been highlighted, it shows that the exposure time gave a significant effect compare to the other two independent variables. In addition, Figure 4.15 and Figure 4.16 show the surface plot for heat-affected zone data against the independent variables.

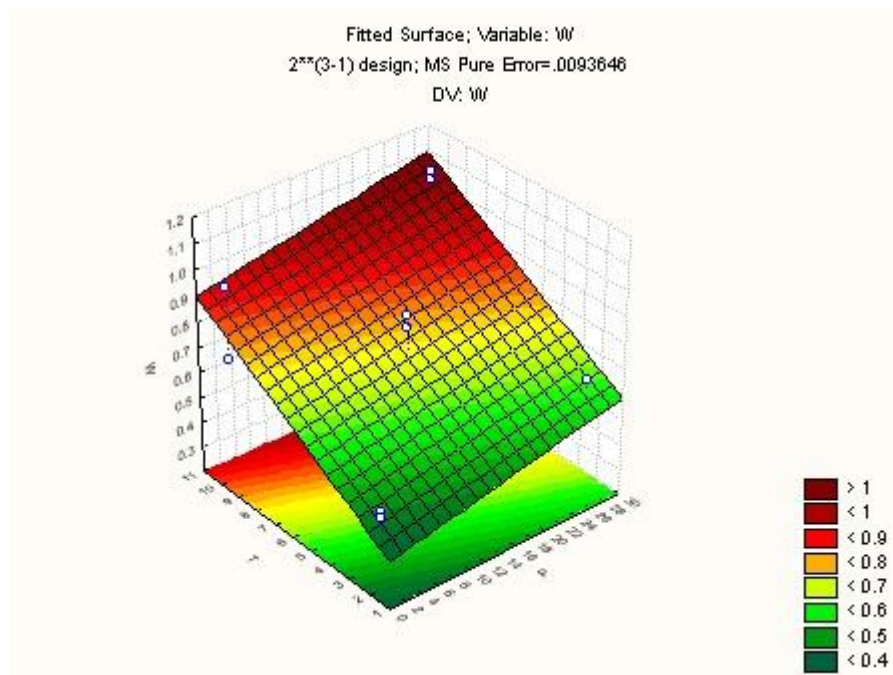


Figure 4.15: Surface plot of laser power and exposure time against heat-affected zone width

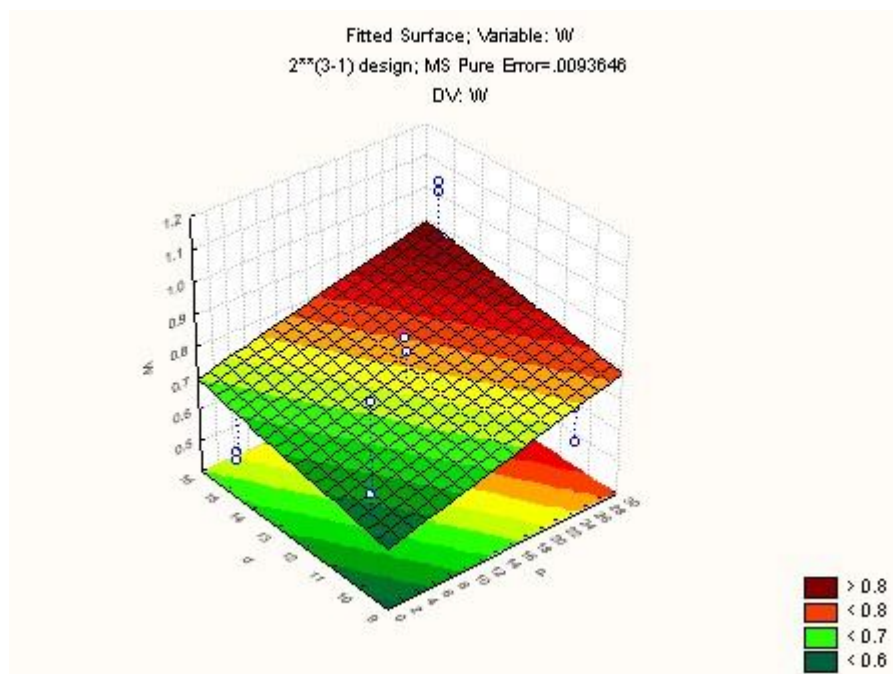


Figure 4.16: Surface plot of laser power and working distance against heat-affected zone width

From both figures, the relation between heat affected zone and all the independent variable can be examine. Meanwhile, table below show the regression coefficient for the heat-affected zone.

Table 4.10: Regression coefficient table of heat-affected zone width

Factor	Regression Coefficient	Std. Err.	t(5)	p
Mean/Interaction	0.143565	0.185794	0.772709	0.474618
Laser Power	0.006444	0.002582	2.495712	0.054777
Exposure Time	0.050997	0.008553	5.962161	0.001899
Working Distance	0.015635	0.013685	1.142452	0.305005

By referring to the general model Eq. (2.1) for 2^k factorial design,

$$Y = B_o + B_1x_1 + B_2x_2 + B_3x_3 + \epsilon$$

and substitute the value of the regression coefficient into the model. In this case, x_1 is the laser power, x_2 is the exposure time and x_3 is the working distance. The model after the substitution is,

$$W = 0.143565 + 0.006444P + 0.050997T + 0.015635d \quad (4.4)$$

where W is the heat-affected zone width, P is the laser power supply, T is the exposure time, d is the working distance and ϵ is the random disturbance or error.

4.5 DISCUSSION

The data that had been gathered are based on the experiment. And, even with all the precaution had been taken before starting the experiment, there is always a chance for an error occurs. Since this experiment is using the STATISTICA software to design the experiment, it had reduced the number and percentage of an error occurs. In addition, STATISTICA also had been used in designing the experiment because it helped in making the experiment is in systematically order. But, it is only for the general error regarding to the flow of the experiment. By using a machine for this experiment, it is a must to check the reliability and the repeatability of the machine. So, the data from the experiment need to be use to analyze whether the machine is reliable or not. From the ANOVA table generated by the STATISTICA software, it can be use to determine the machine reliability. Table 4.11, Table 4.12, Table 4.13 and Table 4.14 showed the ANOVA table for the dependent variables in the experiment.

Table 4.11: ANOVA table of line width for line geometry experiment

Factor	SS	F	p
(1)P	0.683491	64.59850	0.000482
(2)t	0.124491	11.76592	0.018633
(3)d	0.000003	0.00025	0.988101
Pure Error	0.052903		
Total SS	0.941722		

Table 4.12: ANOVA table of heat-affected zone width for line geometry experiment

Factor	SS	F	p
(1)P	0.064378	74.8330	0.000341
(2)t	0.007728	8.9835	0.030195
(3)d	0.153029	177.8818	0.000042
Pure Error	0.004301		
Total SS	0.287970		

Table 4.13: ANOVA table of holes diameter for spot geometry experiment

Factor	SS	F	p
(1)P	3.259670	2775.841	0.000000
(2)T	0.136921	116.598	0.000118
(3)d	0.103831	88.420	0.000229
Pure Error	0.005872		
Total SS	4.816952		

Table 4.14: ANOVA table of heat-affected zone width for spot geometry experiment

Factor	SS	F	p
(1)P	0.058328	6.22858	0.054777
(2)T	0.332887	35.54736	0.001899
(3)d	0.012223	1.30520	0.305005
Pure Error	0.046823		
Total SS	0.467721		

By referring to the tables, notice that there are row of Pure Error and the value for the Pure Error. The value of the Pure Error can be use to determine the reliability of a machine that had been use for each experiment. The par number for the Pure Error is 1 for every machine. And, from the table, it show that all of the values in Pure Error are less than 1(<1). Therefore, it can be said that the machine is reliable for this experiment. To justify the normal distribution assumption, the Normal Probability plot can be use and the graph can be generated from the STATISTICA software. Normal distribution is acceptable as the normal values are scattered nearby to the solid line. Figure 4.17, Figure 4.18, Figure 4.19 and Figure 4.20 showed the Normal Probability plot for the dependent variables in the experiment.

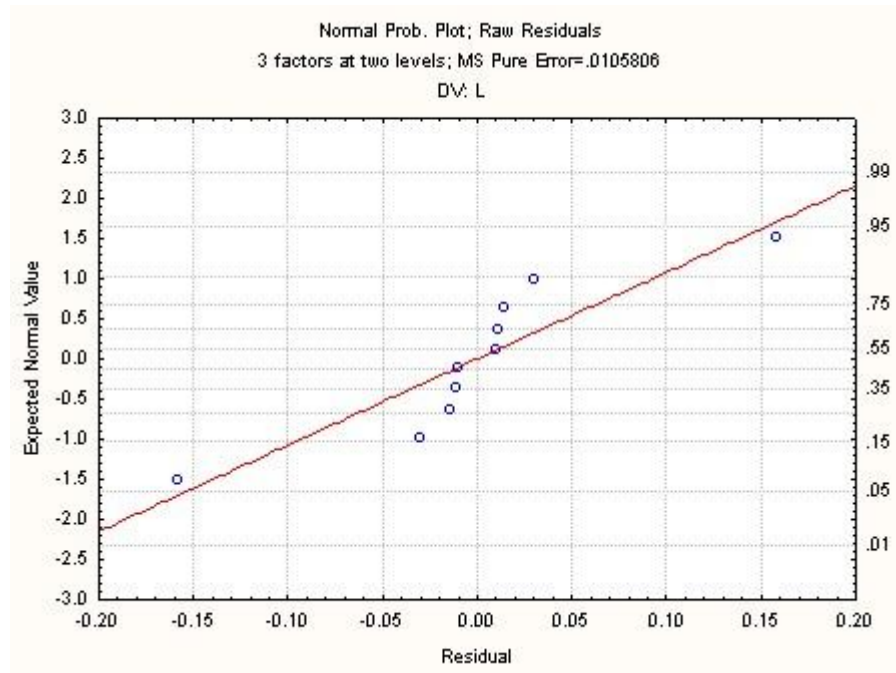


Figure 4.17: Normal probability plot for line width in line geometry experiment

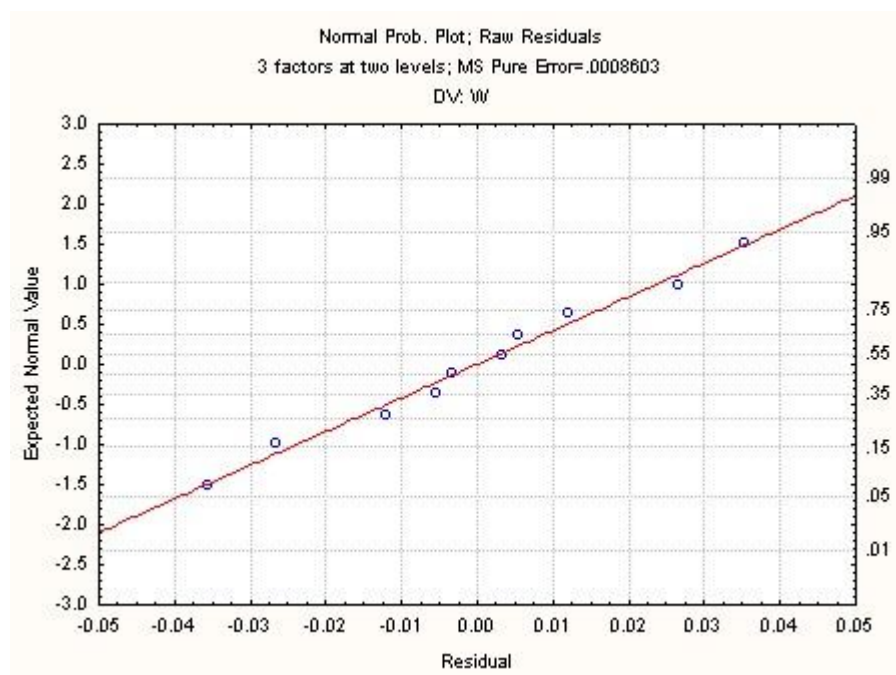


Figure 4.18: Normal probability plot for heat-affected zone in line geometry experiment

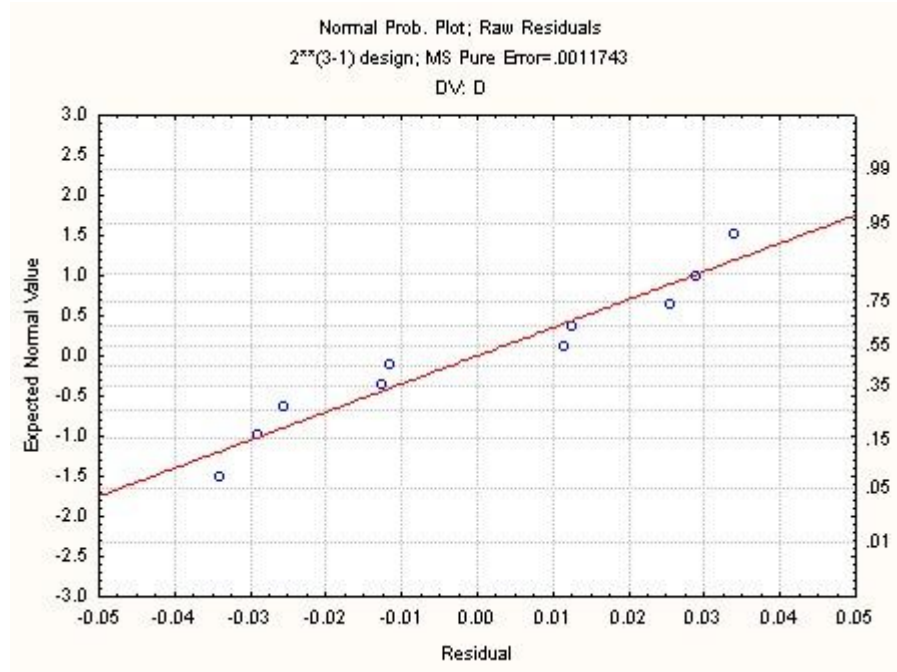


Figure 4.19: Normal probability plot for holes diameter in spot geometry experiment

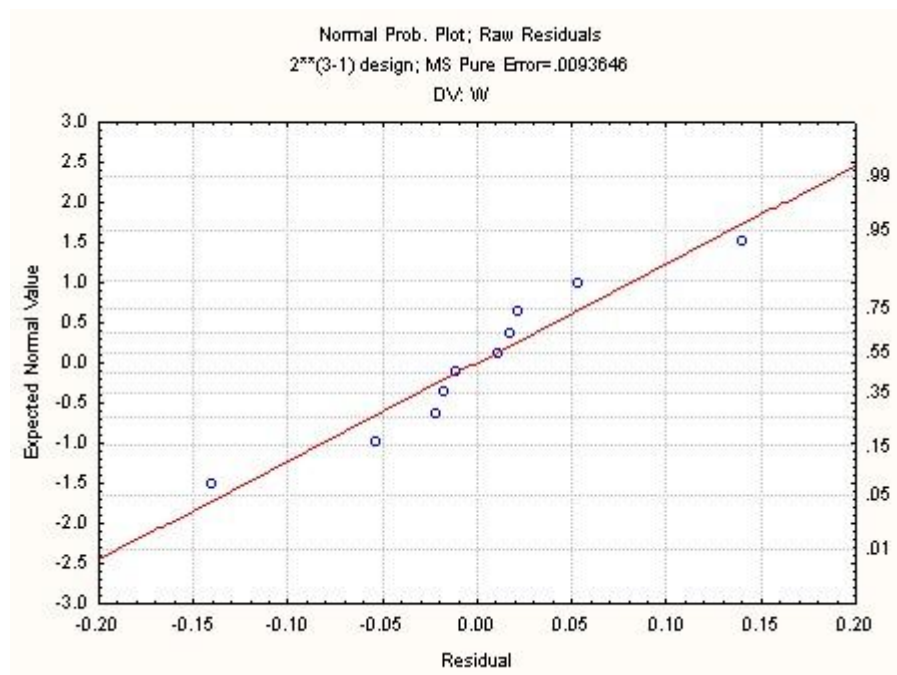


Figure 4.20: Normal probability plot for heat-affected zone in spot geometry experiment

Since there are four mathematical models that had been develop for this experiment, the appropriate model that can explained the laser beam intensity need to be choose. For line geometry experiment, substitute the value of laser power, laser pulse duration and the working distance into Model (4.1). From the calculated value, use it to compare with the experimental value. As for the heat-affected zone in line geometry experiment, use Model (4.2) to determine the calculated value before comparing it with the experimental value. For spot geometry experiment, substitute the value of laser power, exposure time and the working distance into Model (4.3). Same goes for the heat-affected zone for spot geometry. But, instead of using Model (4.3), use Model (4.4) to get the calculated value for heat-affected zone. With the calculated value known, compared the value with the experimental value. From the comparison, choose the model that is highly accurate as the most appropriate model. It can be said that the appropriate model are chosen based on the model accuracy.

As for the measurement, supposed that the width and the diameter of the geometry generated by the laser should be the best measurement. As for the line geometry experiment, the width of the heat-affected zone that had been generated at the side of the line geometry is not the same on both side of the line.

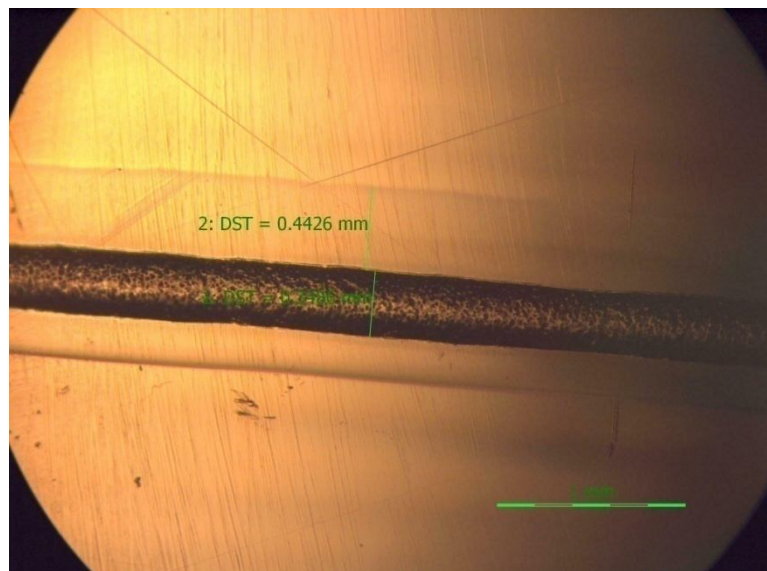


Figure 4.21: Specimen picture for line geometry experiment

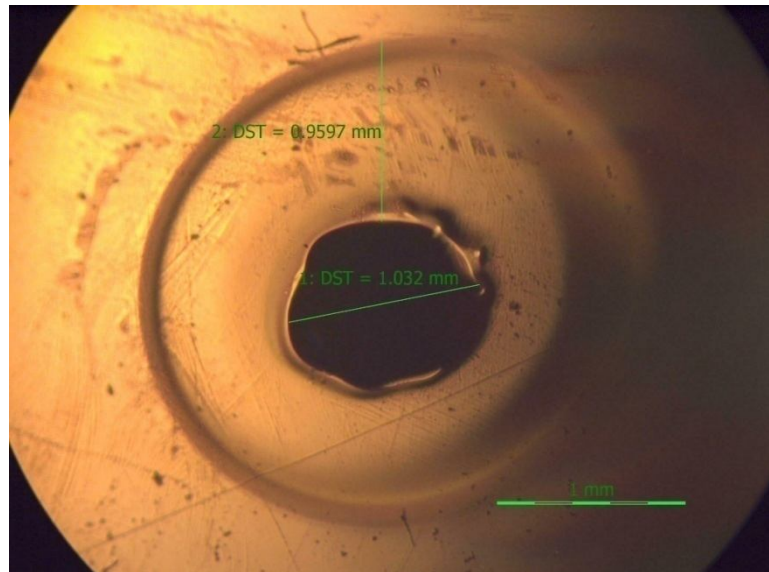


Figure 4.22: Specimen picture for spot geometry experiment

As been showed in the Figure 4.21 above, noticed that the heat-affected zone on the both side are not same in size. The best width for the heat-affected zone should be taken for the analysis. The same goes with the heat-affected zone for spot geometry experiment. From Figure 4.22 above, it showed that the heat-affected zone is not actually in circle shape. That is why the best width should be taken for the analysis. This problem should affect the accuracy of the data and the model. But, the data had been proved for the usage in this analysis. So, the model is valid and can be used to measure and predict the geometry generated as well as the heat-affected zone.

From the model, there is ϵ which is the random disturbance or error. For calculation, the random disturbance can be neglect since the data that has been design tor the experiment had been in random. The STATISTICA software already made the data in systematically order after the randomization process had been completed. The experiment need to be run according to the given order from STATISTICA software so that the random disturbance or error can be avoided.

4.5.1 LASER INTENSITY CHARACTERIZATION

From the result, the mathematical model that was chosen is the Model (4.2) and Model (4.3). This mathematical model was chosen based on the accuracy of the calculated value by comparing it with the experimental value. The intensity would be characterizes based on high and low term. For this experiment, the intensity of the laser beam is related to the laser machining parameters. For Model (4.2) which is,

$$W = -0.478562 + 0.006770P + 0.000138t + 0.055322d$$

the working distance, d gave more significant effect to the laser beam intensity compare to the other two parameters which is the laser power, P and laser pulse duration, t . This is because the regression coefficient value for the working distance is higher compare to the other two parameters. It can be said that when the working distance value are higher, the laser beam intensity would be higher. This result also might influence from the focusing of the laser beam. Since the working distance is different, the focusing of the laser beam would also be different. For Model (4.3) which is,

$$D = 0.165474 + 0.048175P + 0.032706T + 0.045570d$$

the laser power, P gave more significant effect to the laser beam intensity compare to the exposure time, T and the working distance, d . The reason are same as before which is the regression coefficient value for laser power are higher compare to the other two parameters. Thus, it can be said that the higher the laser power supply the higher the laser beam intensity is. In general, the increasing of all the machining parameter would also influence the laser beam intensity. The higher all of the laser machining parameters value, the higher the laser beam intensity would be. However, the uniformity of the intensity cannot be explained by using this mathematical model.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter, the conclusion of the project will be told according based on the project objective and the project scope. The recommendation also will be in this chapter as the recommendation will provide the information to improve the experiment in the future. This recommendation also will help other researcher to enhance the data and the result for this experiment.

5.2 CONCLUSION

Based on the experimental result, it can be concluded that the laser power, laser pulse duration, exposure time and the working distance affected the laser beam intensity used for machining. It is prove by the p-value from the effect estimate and ANOVA table. Based on the observation during the experiment too, it also showed that the parameter gave the significant effect to the geometry generated. For example, if the laser power supply to produce the laser beam is low, the geometry that had been generated should be small in size. If the laser pulse duration used is small, the geometry generated also will become small. Based on that, it can be said that all of the parameter used in this experiment are affecting the laser beam intensity. In common sense, if the power supply is high, the intensity of the beam would be high too.

For this experiment, the most appropriate mathematical model is Model (4.2) and Model (4.3). By substituting the value of the parameter into the model, the calculated value can be created. From the calculated value, and comparing it with the experimental value, the accuracy of a model can be check. Based on the comparison, the

most appropriate mathematical model can be chose. The most appropriate mathematical model is chosen based on the accuracy of the calculated value. The mathematical model with high accuracy is chosen to be the most appropriate model to characterize the laser beam intensity. From the calculated value, the characteristic of a laser beam can be predicted.

From the experiment, it is found that the geometry generated by the laser beam also influence by the intensity of the laser beam. And, from the geometry generated, it also can be use to predict the characteristic of the laser beam intensity. With high value of the width and the diameter generated, the laser beam intensity used for this experiment also would be high.

5.3 RECOMMENDATIONS

From the experiment and the analysis, there should be more addition to improve the experiment result and make the model developed become more reliable. Firstly, for the experiment, the number of the experiment and parameter range should be expanded for more valid conclusion. With the higher number of experiment, the experimental data would become more accurate approaching the predicted value. From that, the experimental data that will be used will increase the accuracy of the mathematical model that had been developed for the experiment. Furthermore, the mathematical model with high accuracy would become more reliable to calculate the experimental value for the parameters that should be investigate without conducting the experiment.

Secondly, different material should be consider into this experiment as the acrylic material cannot be use to determine the laser beam intensity used for machining other materials. By adding different material type, the characteristic of the laser beam intensity can be clearly shown. Since every material has different properties, there might be a chance that the parameter that can influence the laser beam intensity will be changing according to the material type.

The interaction between both of the dependent variable which is the value that had been measure after the experiment should be took into consideration. This would be

the third recommendation for this project since the interaction between the dependent variable had not been investigated in this project. With the interaction, the analysis would provide different result from the result that is in this report. The interaction between independent variables also should be consider to get more valid data and result to generate more reliable model to demonstrate the characteristic of the laser beam intensity.

With the number of experiment should be expand, the mathematical model should be confirm with the additional experiment. This is because different number of experiment will affect the mathematical model. So, the new mathematical model should be confirmed with the new parameter number and so on.

Furthermore, the investigation of the focusing for the laser beam also can be considered in this project for more valid conclusion. This is because the focusing of the laser beam gave indirect effect to the laser beam intensity. With this addition, further information regarding to the intensity would be useful in characterizing the laser beam intensity.

APPENDIX A1

Gantt Chart FYP1

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Title conformation														
Literature Review														
Introduction Problem Statement, Objectives, Project Scopes														
Develop experiment model in STATISTICA														
Laser machine learning														
Proposal Writing														
Presentation Preparation														
Presentation														

Figure 6.1: Gantt chart for FYP 1

APPENDIX A2

Gantt Chart FYP2

TASK	WEEK														
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Experiment Setup															
Laser beam intensity experiment															
Result analysis under the microscope															
Result analysis in STATISTICA															
Develop mathematical formula															
Report writing															
Presentation															

Figure 6.2: Gantt chart for FYP 2