# RESISTANCE SPOT WELDING OF STAINLESS STEEL AND MILD STEEL

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# RESISTANCE SPOT WELDING OF STAINLESS STEEL AND MILD STEEL

WAN MUHAMMAD HAFIZI BIN WAN HASSAN

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Mechanical Engineering

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**UNIVERSITI MALAYSIA PAHANG**

**FACULTY OF MECHANICAL ENGINEERING**

I certify that the project entitled "Resistance Spot Welding of Stainless Steel and Mild Steel" is written by Wan Muhammad Hafizi bin Wan Hassan. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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I hereby declare that this report titled "Resistance Spot Welding of Stainless Steel and Mild Steel" is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 22 June 2012

**Dedicated, truthfully for supports, encouragements and always be there during hard times, to my beloved family**

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I hope this research project will be helpful for those who need reference in the field of metal casting process. Finally I would like to express my gratefulness to all of them who involved directly or indirectly in the completion of my final year project and thesis. Thank you.

## ABSTRACT

Resistance spot welding (RSW) is commonly used in manufacturing and automotive industry; because of their advantages such as high speed and high production, suitability for automation, easily to process and low cost. This project deals with the investigation of microstructure and mechanical properties of weld joint of Stainless Steel and Mild Steel. The main objective of this project is to investigate the weldability of stainless steel and steel weld. For design of experiment, Taguchi method was employed by using Minitab software, and total nine (9) sets experiment was conducted. The studies of mechanical properties, are consists by using three (3) tests; Tensile test, Charpy test, and microstructure to analyze and investigate the weldability of Stainless Steel and Mild Steel sheet. As a result, higher Tensile strength and Charpy toughness is due to increase in width and depth of weld nugget. Optimum specimen has higher width and depth than experimental specimen. Based on Taguchi analysis, the best combination of parameters is Current (5.0 kA), Weld Time (3.0 cycle) and Pressure (40 psi). The rank of parameter affected the resistance spot welding experiment is Current, Pressure and Weld Time respectively. Based on Regression analysis, the equation of Tensile strength and Charpy toughness were generated. As for recommendation, the other parameters such as diameters of electrode and hold time can be added in experiment. For conclusion, Taguchi analysis is verified with verification experiment.

## ABSTRAK

Kimpalan rintangan bintik biasanya digunakan dalam industri pembuatan dan automotif; kerana kelebihan kimpalan ini seperti kelajuan yang tinggi dan hasil pengeluaran yang tinggi, kesesuaian untuk automasi, mudah diproses dan berkos rendah. Projek ini berkait dengan pengkajian tentang mikrostruktur dan ciri-ciri mekanikal logam kimpalan yang menggabungkan “keluli tahan karat” dan “keluli lembut”. Objektif utama projek ini ialah untuk mengkaji kebolehan kimpalan diantara “keluli tahan karat” dan “keluli lembut”. Untuk prosedur eksperimen, kaedah Taguchi digunakan dengan menggunakan perisian Minitab dan sejumlah Sembilan (9) set eksperimen dijalankan. Menggunakan tiga (3) ujian; ujian ketegangan, ujian hempapan Charpy, dan mikrostruktur untuk menganalisis dan menyiasat kebolehan kimpalan di antara “keluli tahan karat” dan “keluli lembut”. Hasilnya, semakin tinggi kekuatan ketegangan dan keliatan Charpy, disebabkan peningkatan dalam lebar dan ketebalan nugget kimpalan. Spesimen optimum mempunyai lebar dan ketebalan nugget kimpalan lebih tinggi berbanding spesimen eksperimen. Berdasarkan analisis Taguchi, kombinasi terbaik untuk parameter ialah arus (5.0 kA), tempoh kimpalan (3.0 kitaran) and tekanan (40 psi). Kedudukan parameter yang mempengaruhi eksperimen kimpalan bintik ialah arus, tekanan dan tempoh kimpalan masing-masing. Berdasarkan kepada analisis regresi, persamaan kekuatan ketegangan dan keliatan Charpy telah dijana. Untuk cadangan penambahbaikan, parameter lain seperti diameter elektrod dan tempoh tahanan boleh ditambah dalam eksperimen. Kesimpulannya, analisis Taguchi disahkan dengan eksperimen pengesahan.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ANOVA | Analysis of Variance |
| BM | Base Metal |
| C | Carbon |
| Cr | Chromium |
| Cu | Copper |
| DOE | Design of Experiment |
| FKM | Fakulti Kejuruteraan Mekanikal |
| Fe | Ferrous |
| FZ | Fusion Zone |
| HAZ | Heat Affected Zone |
| IMC | Intermetallic Compounds Layer |
| Mn | Manganese |
| Ni | Nickel |
| OA | Orthogonal Arrays |
| RSW | Resistance Spot Welding |
| RWMA | Resistance Welding Manufacture's Association |
| Si | Silicon |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

Recently, joining between low carbon steel and stainless steel has hit the spots of the process and construction industries. Low carbon steel for example is mild steel, commonly known have durable and relatively hard materials. For stainless steel, because of high chromium content, it has good corrosion resistance. It also has high strength and ductility, which means an ability to form a desire shape.

The industry out there is constantly seeking construction of equipment and production optimization. For example, in oil and gas industry, resistance spot welding (RSW) is a key technology because the process is fast and can easily weld many different material combinations that are difficult or even impossible to join by other welding techniques. Besides that, many materials can be joined by using RSW, for example stainless steel, aluminum, nickel, copper and titanium. Recently, copper alloys are spot welded commercially to fulfill industries needs.

The project title is “Resistance Spot Welding of Stainless Steel and Mild Steel”. The project researched to see the good result of joining and to analyze the design of experiment for optimization parameters in RSW.

## 1.2 PROBLEM STATEMENTS

The common problems that happen in dissimilar metal joining is the joint not strong, because of Intermetallic Compounds Layer (IMC) occurs. IMC happens because of different chemical composition of materials that have been joining. In order to get rid or reduce IMC, controlling RSW parameters is becoming primary, and by using the DOE for predicting optimize parameter. Controlling RSW parameters need more attention to avoid defects and to produce good weld quality.

## 1.3 PROJECT OBJECTIVES

a) To investigate Taguchi methods to predict optimizes parameter (welding current, weld time, squeeze time and pressure).
b) To investigate the weldability of stainless steel and mild steel joint (Tensile and Charpy test)

## 1.4 PROJECT SCOPES

a) Resistance spot welding parameters (Current, Weld Time, Squeeze Time and Pressure)
b) Choosing and preparing the materials (Stainless Steel and Mild Steel)
c) Analyze and investigate the joining results and optimization of parameters by using Taguchi Method.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Welding is a process in which materials of the same fundamental type or class are brought together and caused to join and become one, through the formation of primary (and, occasionally, secondary) chemical bonds under the combined action of heat and pressure (Messler, 1993).

From *The American Heritage Dictionary*, welding function is to join (metals) by applying heat, sometimes with pressure and sometimes with an intermediate or filler metal having a high melting point.

## 2.2 DISSIMILAR METAL WELDING PROCESS

Commonly, dissimilar metal welding refers to the joining of the metals that has difference on chemical composition, physical and mechanical properties, microstructure, melting point, thermal coefficient and thermal conductivity. In the last few years, new processes have been utilized for dissimilar metal welding such as friction stir welding and laser welding process to join dissimilar metals (Gedney, 2005).

For dissimilar metal welding, a common problem is an intermetallic compound (IMC) is always generated. When a joining process is used, IMC will form in the weld at the joint, and caused to decreased strength and give defects such as cracks (Imaizumi, 1984). A characteristic of IMC formed must be analyzed and investigated in order to minimize their formation, ductility, crack sensitivity and susceptibility to corrosion.

## 2.3 RESISTANCE SPOT WELDING PROCESSES

From the Resistance spot welding (RSW), this joining method has high efficiency in terms of production method. This is importance to the industries, which can fulfill the needs of automation lines and mass production in industries. Because of the RSW method is flexible, their process is easy to control and not mention their equipment is simple, it efficiently fits for small batch production (Suolaklvenkatu, 2009).

RSW is process, which generate heat through the resistance and to the flow of the electric current in parts being welded. By increasing the contact resistance, the RSW can work properly. The RSW equipment is included with pairs of water-cooled electrodes. This electrodes usually made from copper alloyed, because to increase erosion resistance. This electrode also helps in the process by allow current to the joint and apply pressure to the workpiece (Messler, 1999).

In order to obtain best results in RSW, control the welding parameter become more important. Figure 2.1 below shows the schematic of RSW process.

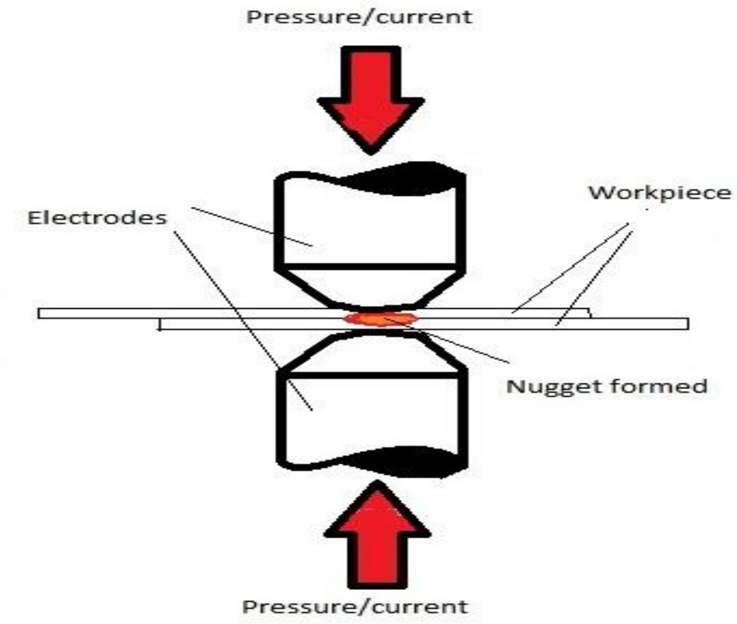


**Figure 2.1:** Schematic of the Resistance Spot Welding process

### 2.3.1 PARAMETERS IN RESISTANCE SPOT WELDING

#### 2.3.1.1 Welding Current

Normally, welding current is important parameter in the welding process. Also in RSW, welding current is important in order to determine the heat generation from the process. Usually measured in kilo amperes (kA) and based on *Resistance Welding Manufacture's Association (RWMA)*, the typical amount of current needed to weld carbon steel is about 10 kilo Ampere (kA).

When welding current is increase, the weld formed also increase in diameter. Therefore the strength of the weld also rapidly increases. (Suolaklvenkatu, 2009).

### 2.3.1.2 Weld Time

In the welding process, the size of welds will increase when the weld time increase. Because of this relation, the heat generation is directly proportional to the welding time. From the process, the heat transfer from the current to the workpiece, usually start from the weld zone. Once the weld forms, the heat transfer to the base metals and surroundings of workpiece.

Welding current and weld time must be controlled efficiently, because if weld time is high enough and weld time is prolonged, expulsion will occur in welds. This accident also can cause the electrodes stick to the workpieces.

### 2.3.1.3 Electrodes force/ electrodes pressure

Electrodes guide the force or pressure and also weld current to the desired location, which located in interfaces of workpieces. From the force or pressure, it effect on the contact between both of workpieces, which means interfaces of workpieces, region formation of welds occur. If the force or pressure is little, the interfaces required contact between workpieces, and causes the sparking, splashing and rapid wear of electrodes (Suolaklvenkatu, 2009).

### 2.3.1.4 Squeeze Time

Squeeze time is a time between pressure application and weld to occur. This parameter does not affect the technical properties of the weld. For the process, the squeeze time must be properly adjusted to allow the electrode pressing pressure to the workpiece. After that, welding current is entered and form the welds (Suolaklvenkatu, 2009).

#### 2.3.1.5 Hold Time

Hold time is a time that pressure is maintained after the weld is made. The hold time must be properly adjusted to give time for the molten metal to solidify. Therefore, it stated that the more thick of workpiece, the longer requires for hold time (Suolaklvenkatu, 2009).

## 2.4 SHEET METAL

Sheet metal is a metal formed into thin and flat pieces. Usually sheet metal will be cut, rolled, bent and other into variety of different shapes. There are many type of metals can be made into sheet metal, such as brass, copper, aluminum, steel and stainless steel. Sheet metal has many applications in industries, such as body car making, aerospace for wing plane and building structure.

## 2.5 WELDING DEFECTS

Based on American Society of Mechanical Society (ASME), welding defect is any flaw that compromises the usefulness of the finished weldment. Welding defects can be divided into the five factors as shown in Figure 2.2.

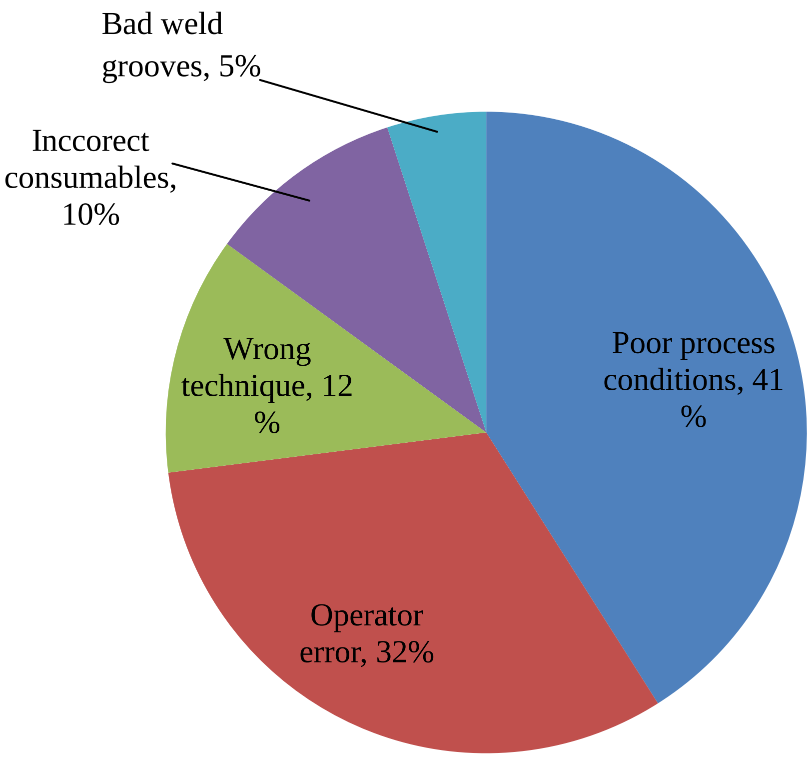


**Figure 2.2:** Percentage Defects from ASME

Source: Matthews and Clifford (2001)

In the welding process, defects can give bad effect for the weld performance and weld strength when the joints were tested by destructive tests. There are examples for welding defects; porosity, crack, undercut and overlap.

1. Porosity

Basically, porosity is occurring when cavities or pores formed in the welds. Porosity in the welds formed because of the gas and non-metallic material entrapment in molten metal during solidification. In general, poor welding technique cause this defect to happen in the welds. Figure 2.3 shows the porosity defect on the weldment.

The study shows that porosity can be controlled in many ways, for example before start the welding process, proper selection of electrodes, filler materials and selecting welding parameters (B. Leigh and V. Grant. 2009).

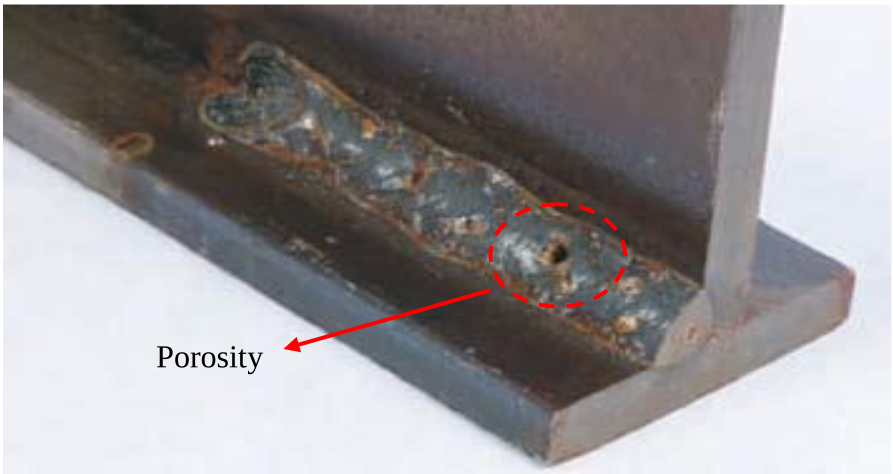


**Figure 2.3:** Welding defects- Porosity

Source: B. Leigh and V. Grant. (2009)

2. Crack

Cracks that may occur in welded materials are caused generally by many factors and may be classified by shape and position, cracks are classed as planar. This defect is can be classified into several types: longitudinal, transverse, branched and chevron.

After the welding process, the crack must be removed by grinding back. Welders also can repair the welding by welding back (B. Leigh and V. Grant. 2009).

3. Undercut

Undercut can be seen as irregular groove at the welds. Usually, the poor welding technique and selecting parameter cause the undercut to happen at the weld. After the welding process, the cut must be removed by grinding back. Welders also can repair the welding by welding back. Figure 2.4 shows that undercut defect on the weldment (B. Leigh and V. Grant. 2009).

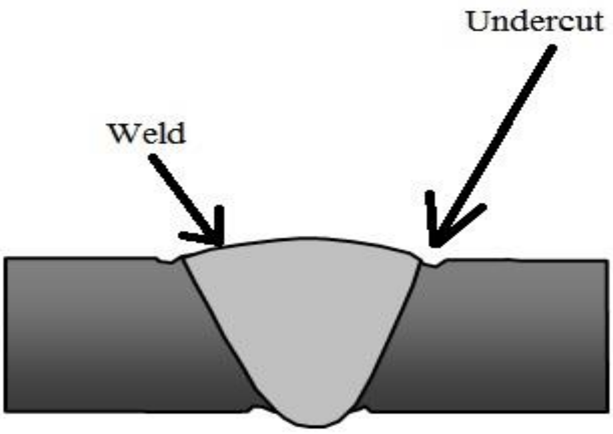


**Figure 2.4:** Welding defects- Undercut

Source: B. Leigh and V. Grant. (2009)

4. Overlap

Overlap can be defined as an imperfection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusing to it. Basically, overlap caused by contamination, slow travel speed, incorrect welding technique and low current. After the welding process, the overlap must be removed by grinding back (B. Leigh and V. Grant. 2009).

## 2.6 MASS SPECTROMETER

Spectrometer is one of machine used in determine and identify the chemical compositions of metal or molecule sample. It is an analytical method that measures the charged particle mass to charge ratio. In determining sample, a mass spectrometer changes molecules of sample to ions so that they can be moved and manipulated by magnetic fields and electrical field. The three important components of spectrometer consist:

(a) The ion source: convert gas phase molecules of sample into ions through, for example, electrospray ionization that let the ions turn into gas phase.
(b) The mass analyzer: sort and analyse each ions by the mass and charge by electromagnetic fields
(c) The detector: the ions that have been separated are then measured by the value of quantity indicators. From it, they will provided and the results will be shown on a chart

The spectrometer has practical usage in quantities and qualitative. The machine can also be used in other study in determining physical, chemical or biological properties of any variety of compounds.

## 2.7 MATERIAL SELECTION

### 2.7.1 MILD STEEL

In material selection, carbon steels generally are classified by their proportion (by weight) of carbon content. The low the carbon content, usually called as mild steel, which has less than 0.30 % C. Mild steel basically used for industries as a products, for example bolts, plates and nuts.

Secondly, medium-carbon steel has 0.30 to 0.60% C. It generally is used in applications requiring higher strength than is available in low-carbon steels, such as in machinery, automotive and agricultural equipment parts.

Third type is high-carbon steel has more than 0.60% C. Generally, high-carbon steel is used for parts requiring strength, hardness and wear resistance, such as cutting tools, cable, music wire and cutlery.

In carbon steel, the higher content of carbon, it has higher hardness, strength and wear resistance. Table 2.1 shows the carbon steel application in industries (K. Serope and S. Steven. 2006).

**Table 2.1:** Example of Carbon Steel Application

| Types | Application |
|---|---|
| Low Carbon Steel (Mild Steel) | Common industrial products such as bolts, nuts, sheet, plate and tubes) and for machine components that do not require high strength. |
| Medium Carbon Steel | Applications requiring higher strength than is available in low-carbon steels, such as in machinery, automotive and agricultural equipment parts. |
| High Carbon Steel | Generally, high-carbon steel is used for parts requiring strength, hardness and wear resistance, such as cutting tools, cable, music wire and cutlery. |

Source: K. Serope and S. Steven (2006)

### 2.7.2 STAINLESS STEEL

Stainless steels are characterized primarily by their corrosion resistance, high strength and ductility, and high chromium content. They are called stainless because, in the presence of oxygen (air), they develop a thin, hard, adherent film of chromium oxide that protects the metal from corrosion (K. Serope and S. Steven. 2006). Stainless steels generally are divided into five types as shown in Table 2.2.

**Table 2.2:** Example of Stainless Steel Application

| **Room- Temperature Mechanical Properties and Typical Applications of Selected Annealed Stainless Steels** | | | | |
|---|---|---|---|---|
| **AISI (UNS)** | **Ultimate tensile strength (MPa)** | **Yield strength (MPa)** | **Elongation in 50mm (%)** | **Characteristics and typical applications** |
| 303 (S30300) | 550-620 | 240-260 | 53-50 | Screw machine products (shafts, valves, bolts, bushings and nuts) and aircraft fittings (bolts, nuts, rivets, screws, studs). |
| 304 (S30400) | 5-620 | 240-290 | 60-55 | Chemical and food-processing equipment, brewing equipment, cryogenic vessels, gutters, downspouts and flashings. |
| 316 (S31600) | 50-590 | 210-290 | 60-55 | High corrosion resistance and high creep strength, chemical and pulp handling equipment, photographic equipment, brandy vats, fertilizer parts, ketchup-cooking kettles and yeast tubes. |
| 410 (S41000) | 480-520 | 240-310 | 35-25 | Machine parts, pump shafts, bolts, bushings, coal chutes, cutlery, tackle, hardware, jet engine parts, mining machinery, rifle barrels, screws and valves. |
| 416 (S41600) | 480-520 | 275 | 30-20 | Aircraft fittings, bolts nuts, fire extinguisher inserts, rivets and screws. |

Source: K. Serope and S. Steven (2006)

### 2.7.3 JOINING MILD STEEL AND STAINLESS STEEL

From British Stainless Steel Association, welding austenitic stainless steel to carbon and low alloy steels are important and needed method in the various industries such as process and construction industry. Advantage of this joining is the weld form is strong, because of composition of two different materials. Tensile strength and ductility are strong, so the joint will not fail in the weld.

## 2.8 MECHANICAL TESTING

There are three mechanical testing that will be done on the joints. They are Charpy’s Impact Test, and Tensile Test.

### 2.8.1 Charpy’s Impact Test

The Charpy’s Impact Test is an impact testing in order to study the behavior of welded objects under dynamic loading. Objective of this test is to determine the behavior of the welds when subjected to high load or impacts and the amount of impact a specimen will absorb before fracture. The relation of the high impact and toughness of the welds also occur from this test. Toughness is defined as the resistance of a metal to fracture after plastic deformation has begun (Messler, 1999).

In this test, a specimen will be struck and broken by a Charpy machine. From this test, the energy absorbed to break the specimen will be adopted. The dimension of Charpy’s test specimens is shown in Figure 2.5.

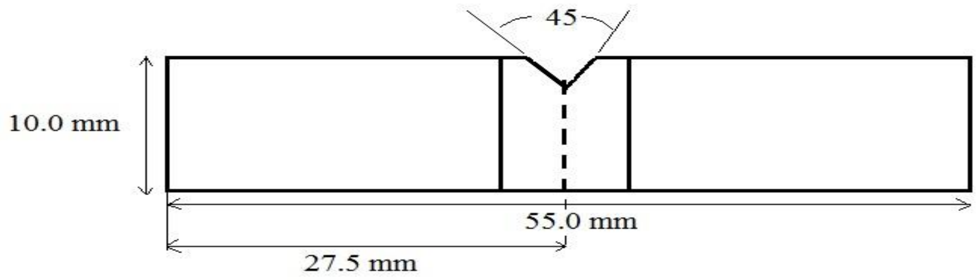


**Figure 2.5:** Schematic illustrations using Charpy specimens with V-notch

Source: Messler (1999)

### 2.8.2 Tensile Test

Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties.

The stress-strain curve as in Figure 2.6 relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. A typical engineering stress-strain curve is shown below. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture.

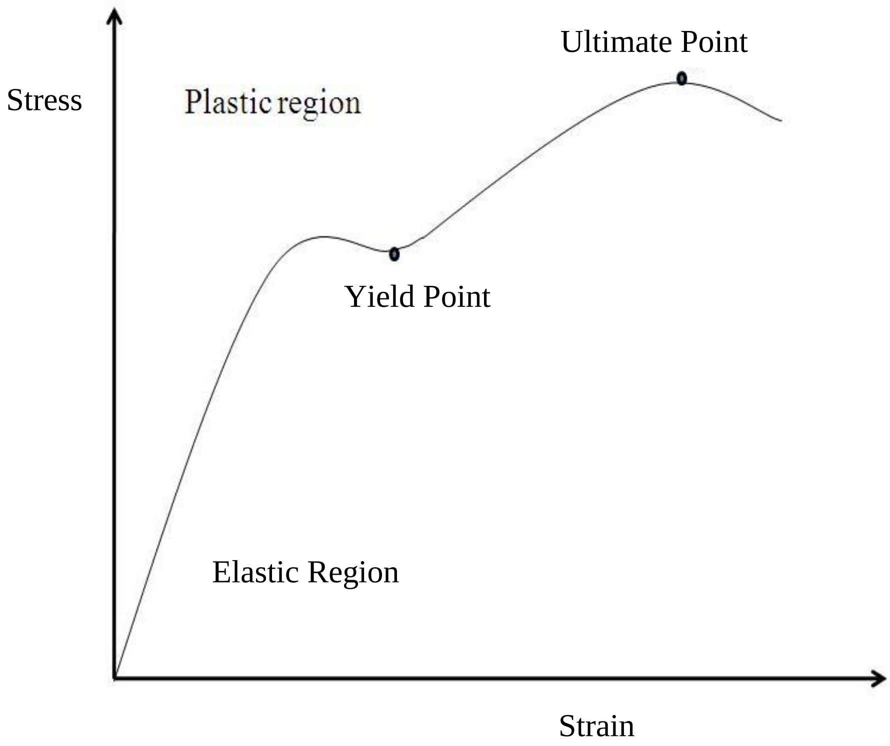


**Figure 2.6:** Stress-strain curve

Source: J. Haibin *et al*. (2009)

## 2.9 TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS

For this project research, the Taguchi Method was selected and analyzed. Taguchi Method was foundered by Dr. Taguchi and states this method is one of the important statistical tools of total quality management for designing high quality systems at lowest cost (P.J. Ross, 2005). Because of this purpose, the cost project can be reduced with high quality of systems.

By using Taguchi Method, an advantage is that it emphasizes a mean performance characteristics value close to the desired or target value, thus improving the quality of systems or products. Besides that, Taguchi Method for experimental design is easy to apply into many engineering problems or situations, such as in optimization of parameter welding process. Taguchi Method is straightforward and making it a powerful and simple tool (Fraley *et al*. 2006)

But, Taguchi Method also has disadvantage, in terms of the results obtained. The results are not indicating what parameter has the highest effect, and also only relative to the performance characteristics value. The second disadvantage is the orthogonal array used not includes all possible variable combination. Because of this imperfection, Taguchi method should not be used with all relationship between all variables. Lastly, this method is operates offline so the changing process is very limited (Unitek Miyachi Group, 1999).

In Taguchi Method, it recommends a three stage process to achieve desirable product quality which is system design, parameter design and tolerance design, as shown in Figure 2.7.

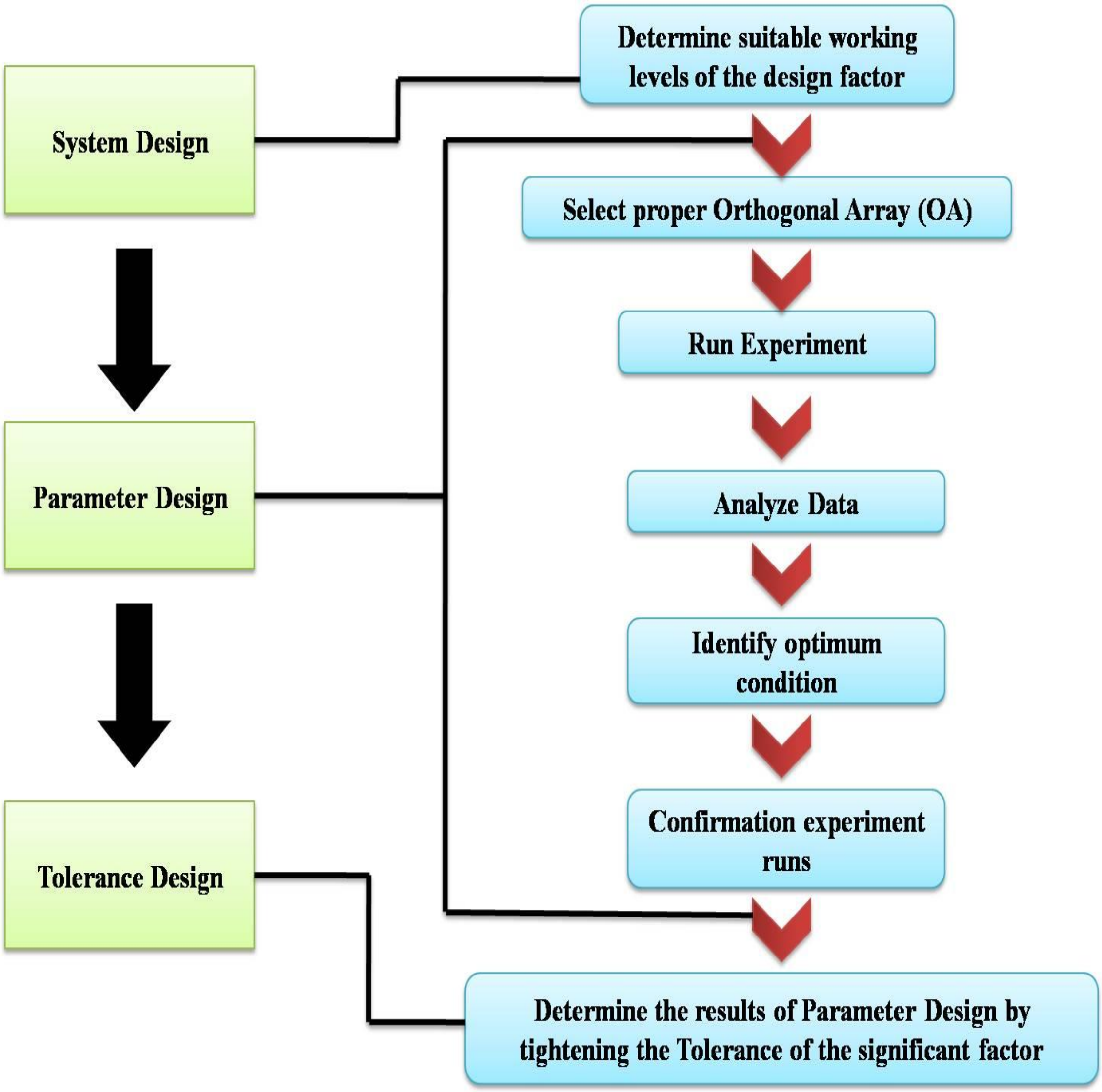


**Figure 2.7:** Taguchi Design Procedure Flow Chart

Source: W.C. Weng *et al*. (2006)

### 2.9.1 Orthogonal Array

Every systems or products usually have large number of experiments must have to be carried out. Eventually, when the process parameters increase, the number of experiments also increases. This is a problem because it can increase costs to do experiments. Taguchi method overcomes this problem by introducing and using orthogonal arrays (OA). OA is functioning in the study of the entire process parameter space. Appropriate number of experiment will be created by OA (Sharma, 2009).

Advantage of orthogonal array is it can help to design the experiment by analyze and investigate the influence of multiple controllable factors (parameters). The analyze will going based on quality characteristics and variations, and not to mention it through in a fast and economic ways. OA also can be divided into several types, such as L4, L8, L9, L18 and others. When choosing the OA, the priority below must be considered (Thanigaivelan *et al*. 2012).

a) The number of factors and interactions of interest
b) The number of level for the factors of interest
c) The desired experimental resolution or cost limitations

For the first priority, “The number of factors and interactions of interest”, means that the number of process parameters in an experiment that to be considered. Next priority is “The number of level for the factors of interest” means that the number of level for process parameter meanwhile can be divided into minimum, medium and maximum value. The last priority is “The desired experimental resolution or cost limitations” means the number of experiment desired, in order to save budget. In this research project, the last priority not considered because there are no cost limitations consider. Table 2.3 shows the example of the three levels L9 orthogonal array.

**Table 2.3:** L9 Orthogonal Array

| Experiment | Control Factors and Levels | | |
|---|---|---|---|
| | **A** | **B** | **C** |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

### 2.9.2 Signal-to-Noise Ratio (S/N Ratio)

S/N Ratio is the ratio of "Signal" representing the desirable value, in example mean of output characteristics and the "noise" representing the undesirable value, in example squared deviation of the output characteristics.

For S/N Ratio, a loss function is the defined to calculate the deviation between the experimental value and desired value. By suggestion from Taguchi, the loss function is used to measure the deviation of the quality characteristics from the desired value. After the measurement, all of the loss function will used to calculate S/N Ratio. For the analysis of S/N Ratio, there are three quality characteristics will be performed. The first one is, the lower-the better, the larger-the better and the more-nominal –the better (Ugur, 2009).

From the analysis of S/N Ratio, results of better quality characteristics responses from a larger S/N Ratio. A lower S/N Ratio represent the bad quality characteristics. For the highest S/N Ratio, its represent the optimal level of the process parameters. Figure below shows the S/N Ratio formula.

$$S/N = -10 * \log\lfloor S(1/Y^2)\rfloor * (1/n) \quad (2.1)$$

Where; Y = responses for the given factor level combination and n = number of responses in the factor level combination.

### 2.9.3 Analysis of Variance (ANOVA)

ANOVA is performed to see and analyze which process parameters are statistically significant. Based on the ANOVA analysis, it predicts the optimal process parameters, which can be applied in the experiment.

The ANOVA is the statistical treatment mostly common applied to the result of experiment to determine the percentage contribution of each factor. The parameters are statistically significant are useful and need to be indicated, because it helps the designer to know which factor needed to be control.

With the ANOVA and main effect analyses as shown in Figure 2.8, the possible optimum process parameter can be predicted. It is determined by the highest value in the main effect plot graph. A confirmation experiment needs to be conducted using predicted optimum parameter process to verify the optimum process parameter based on the comparison with the predicted output value get from ANOVA analysis.

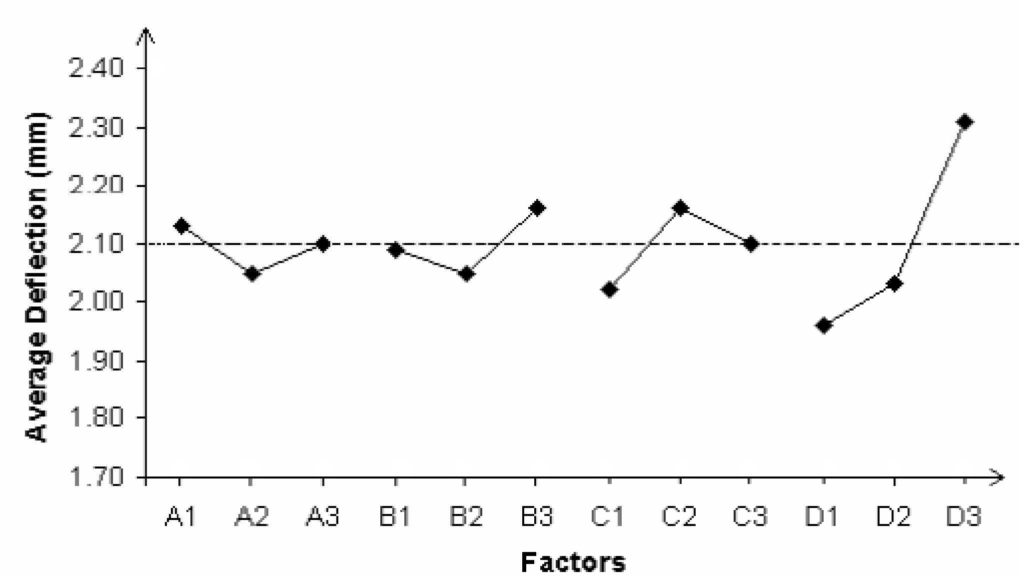


**Figure 2.8:** Example for main effect graph; Main effects graph for bending deflection under constant load

Source: S. Kamaruddin (2004)

Based on the average of output value at each parameter level, main effect analysis is performed to determine the influence level of each parameter. Analysis of variance (ANOVA) as shown in Table 2.4 then is used to determine which process parameter is statistically significant and the contribution of each process parameters to the output characteristic. The value of degree of freedom (DF), sum of squares (SM), mean square (MS) and f-function (F) also need to be calculated.

**Table 2.4:** Analysis of Variance (ANOVA)

| **Source of Variation** | **Degree of Freedom** | **Sum of Squares** | **Mean Square** | **F value** |
|---|---|---|---|---|
| Regression | 1 | $SS_R$ | $MSR = \frac{S_R}{1}$ | $F = \frac{MSR}{1MSE}$ |
| Error | n-2 | $SS_E$ | $MSR = \frac{SS_E}{n-2}$ | |
| Total | n-1 | $SS_T$ | | |

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

The experimental methods and procedures used in order to get the experiment results are discussed clearly step by step in this chapter. This systematic planning of methodology is very important to keep the experiment in running smoothly.

## 3.2 METHODOLOGY FLOW CHART

In order to achieve the aim and objectives of this research, a sequence of works has been planned as shown in Figure 3.1. This flow chart is useful to make sure that the experiment is carried out smoothly. The process involved in achieving objectives are included literature study based on a related topic, determining material, method and parameters, conducting experiments, analysis data and data discussion.

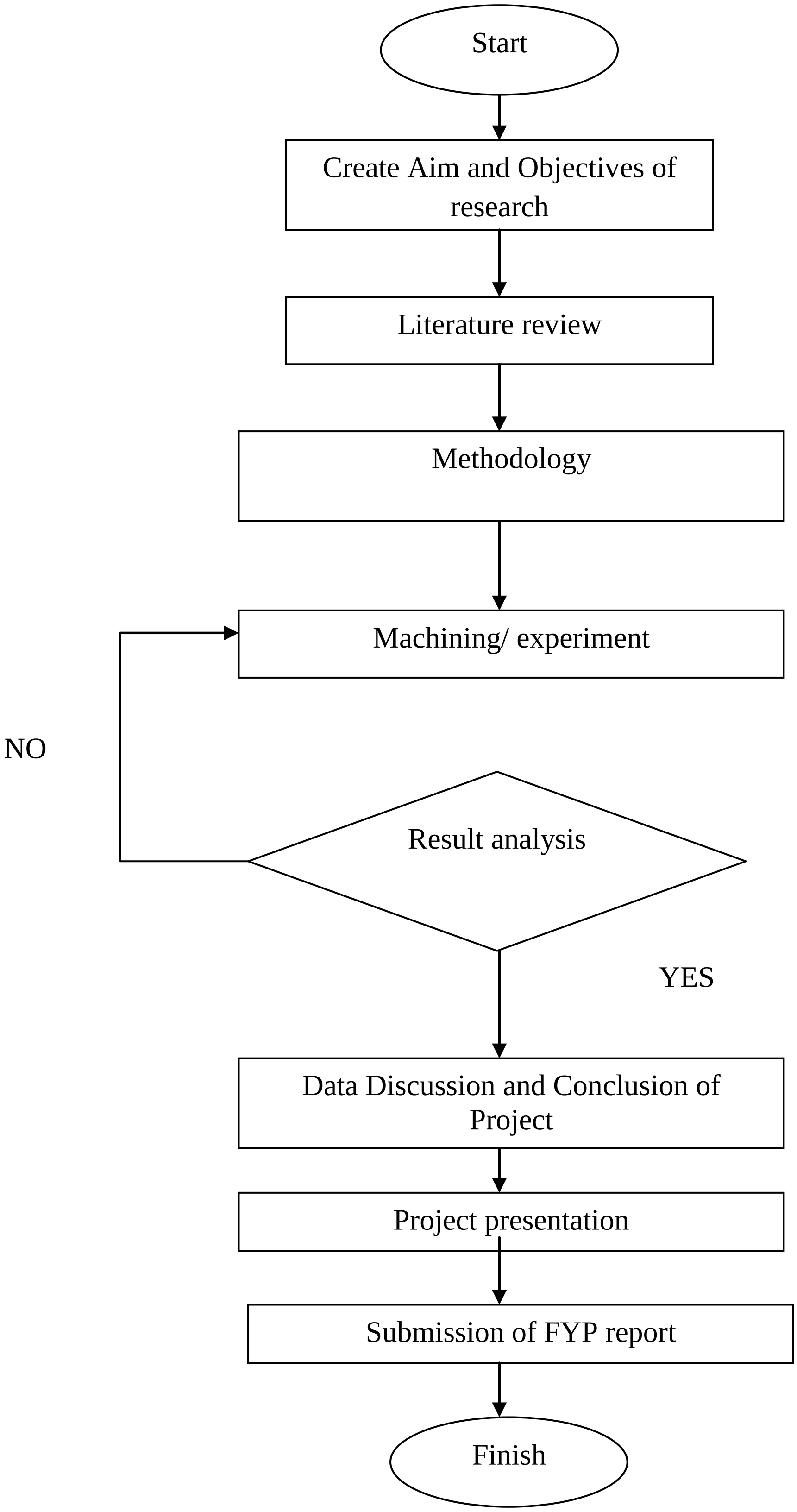


**Figure 3.1:** Methodology Flow Chart

## 3.3 EXPERIMENT DETAILS

After finishing finding and gathering all the information needs, the project start by preparing the materials which are mild steel and stainless steel, which available at FKM Laboratory. After finishing the preparing material, the pre-test and experiment start by following the parameter. Design of Experiment (DOE) of Taguchi method has used in order to obtain the selecting parameter for the experiment. After experimenting was done, mechanical test (Tensile and Charpy test) were tested to specimens. Next, microstructure also done to get the weld nugget dimension, and lastly Taguchi method was analyzed to obtain the optimal parameter.

### 3.3.1 Preparing Material by Using Shearing Machine

Sample material with thickness 2mm will be cut using shearing machine with dimensions specified for mechanical tests. Switch on the machine, make sure the hydraulic lever is open.  Insert the length value based on the dimensions given. Press start button. Set lever thickness, clearances and angle according to the material thickness and type of it. If not done this, the material dimension will not accurate because of these important settings.


**Figure 3.2:** Shearing machine

**Table 3.1:** Setting for cutting samples

| **No.** | **Sheet Thickness** | **Blade Clearance** | | **Rake Angle** | |
|---|---|---|---|---|---|
| | | **Min Pos** | **Max Pos** | **Material <= Steel** | **Material > Steel** |
| **1** | 0.5 mm | 1 | 1 | 0.5 | 1 |
| **2** | 1.0 to 1.5 mm | 1 | 2 | 005 | 1 |
| **3** | 2.0 to 2.5 mm | 2 | 3 | 1 | 1.5 |
| **4** | 3.0 mm | 2 | 4 | 1.5 | 1.5 |
| **5** | 4.0 mm | 3 | 4 | 1.5 | 2 |
| **6** | 5.0 mm | 3 | 5 | 2 | 2 |
| **7** | 6.0 mm | 4 | 6 | 2 | 2.5 |

The material was used is Stainless Steel and Mild Steel sheet. The figure below shows the material and the table shows the chemical composition of materials.

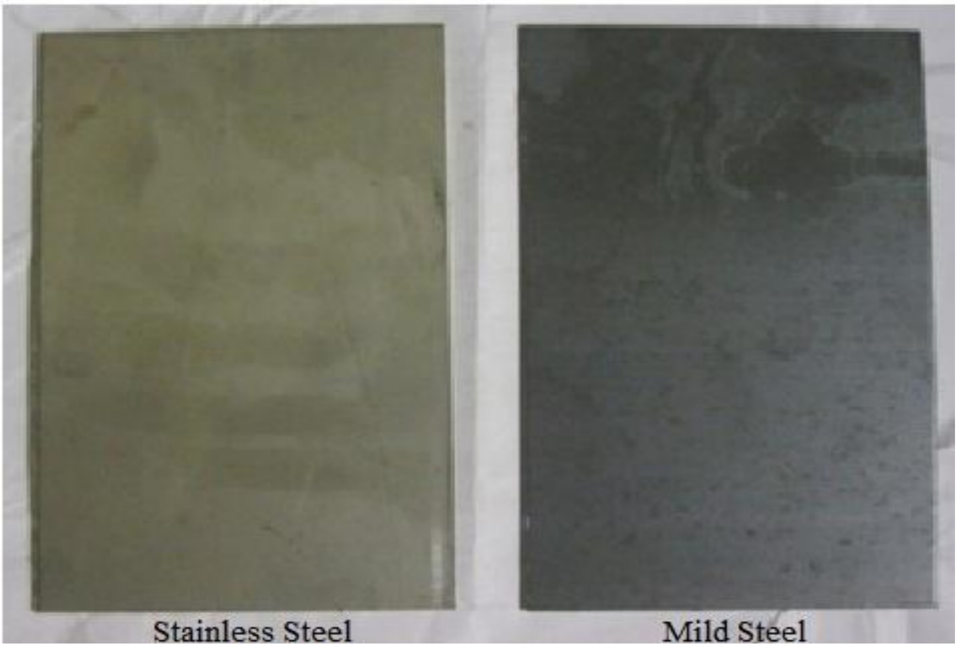


**Figure 3.3** Stainless steel and mild steel sheet

**Table 3.2:** Chemical composition of materials

| Percentage | Fe | C | Si | Mn | Cr | Mo | Ni | Co | Cu |
|---|---|---|---|---|---|---|---|---|---|
| **Stainless Steel** | 71.5 | 0.0617 | 0.473 | 1.36 | 17.1 | 0.0888 | 8.39 | 0.149 | 0.601 |
| **Mild Steel** | 99.5 | 0.0910 | 0.005 | 0.196 | 0.0493 | 0.0158 | 0.0371 | 0.001 | 0.001 |

### 3.3.2 Spot Welding Machine

The machine that involves in this experiment is Miller Spot Welder (SSW-2040 ATT903827). Details of the machine are listed as below:

**(a)** **Applications:** Sheet Metal Work, Light Fabrication and Maintenance Work

**(b)** **Process:** Resistance Spot Welding

**(c)** **Work Capacity:** 20 kVA units weld total thicknesses up to 1/4 in (6.3 mm). Not recommended for aluminum or copper alloys

**(d)** **Rated Output:** 20 kVA at 40% duty cycle depending on model, based on 10-second time period

**(e)** **Range of parameters:** Current (kA) = 1.0~~10.0
Weld Time (cycle) = 0.01~~9.99
Squeeze Time (cycle) = 0.01~~9.99

**Figure 3.4:** Miller Spot Welder (SSW-2040 ATT 903827)

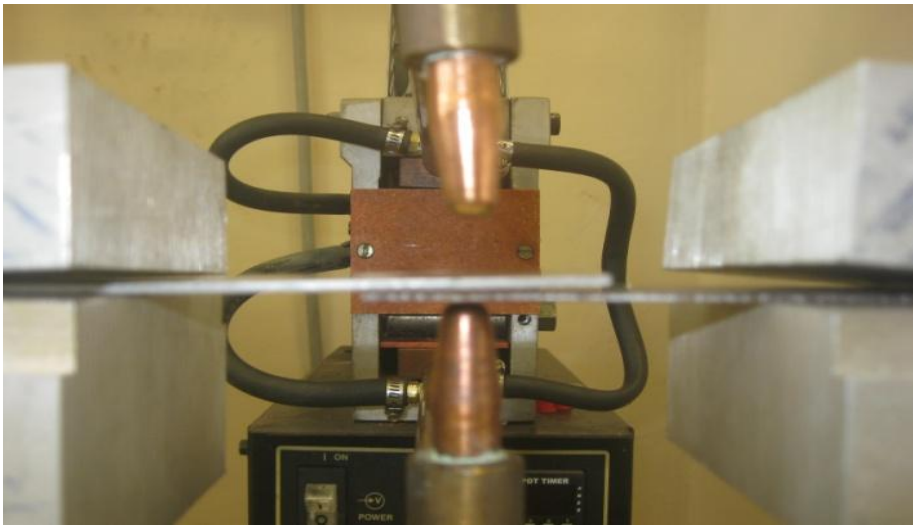


**Figure 3.5:** Placing specimen in between electrode

### 3.3.3 Pre-Test Experiment

For the pre - test experiment, two graphs were used; Current (kA) vs Weld Time (cycle) and Squeeze Time (cycle) vs Pressure (psi). There are three conditions of specimens after pre-test, which are the first is “joint and strong”, second one is “not joint and few strong” and last is “not joint and not strong”.

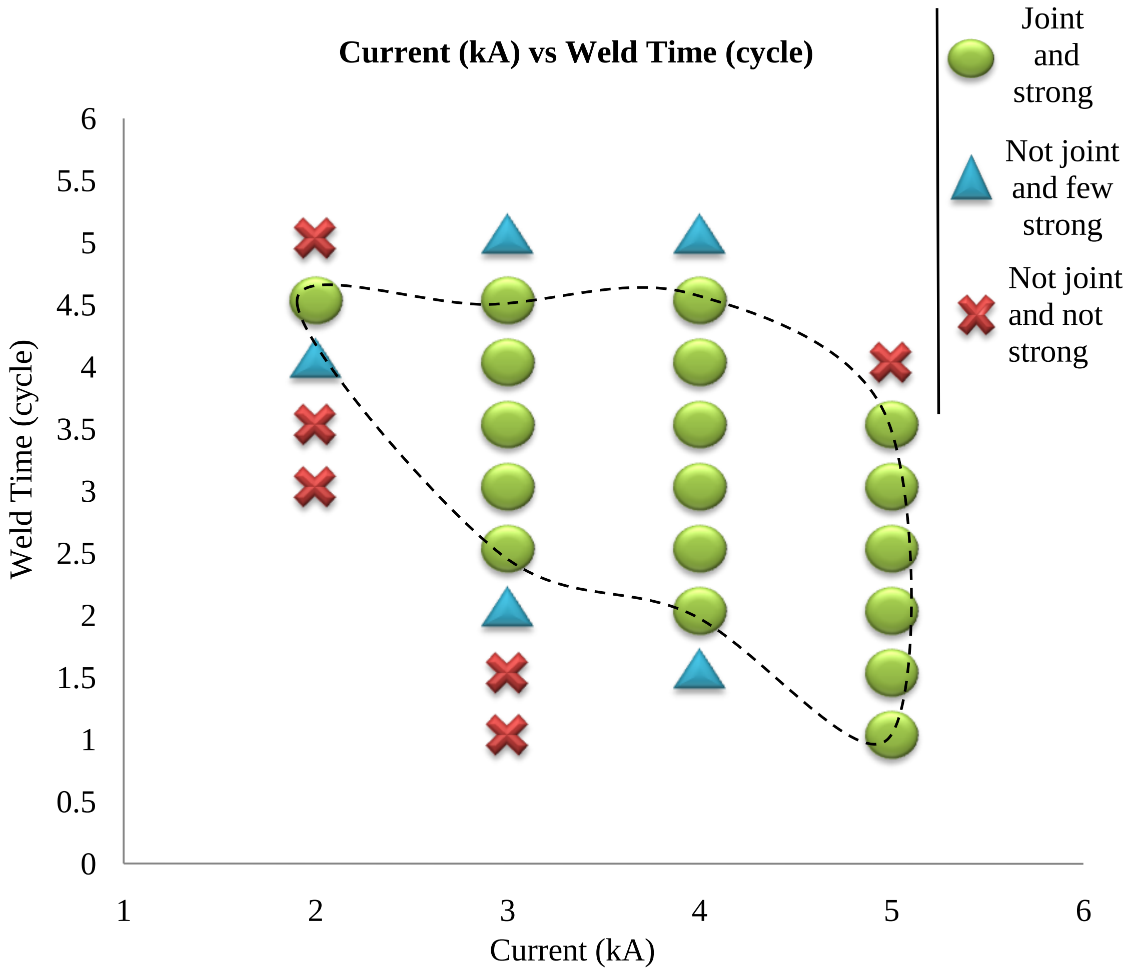


**Figure 3.6:** Graph of Pre-Test (Current vs Weld Time)

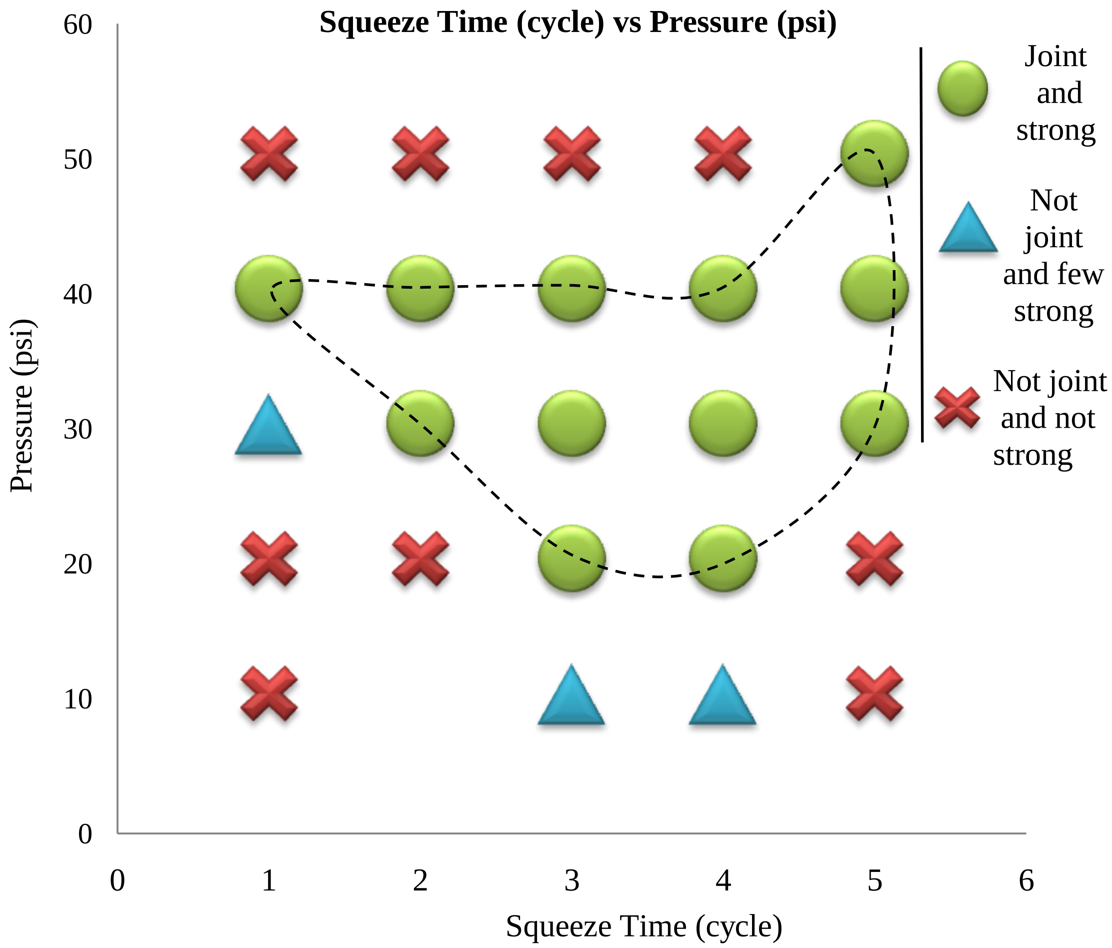


**Figure 3.7:** Graphs for Pre-Test (Squeeze Time vs Pressure)

From the pre-test experiment, the levels for parameter will be obtained in order to proceed into the experiment. The table below shows the levels and parameters.

**Table 3.3:** Selecting Parameters and Their Levels

| Parameter | Level | Value |
|---|---|---|
| **Current (kA)** | 1 | 3.0 |
| | 2 | 4.0 |
| | 3 | 5.0 |
| **Weld Time (cycle)** | 1 | 2.5 |
| | 2 | 3.0 |
| | 3 | 3.5 |
| **Pressure (psi)** | 1 | 30 |
| | 2 | 35 |
| | 3 | 40 |

### 3.3.4 Designing Parameter of Experiment

The orthogonal array (OA) usually can be concerned with the Taguchi method in terms of design of experiment (DOE). Selecting orthogonal array is L9. OA has many advantages, they are able to reduce the number of experiments and tests will be done. OA also has capabilities inconsistency of design by different experiments or tests.

**Table 3.4:** DOE (L9 Orthogonal Array)

| No. of Experiments | Current (kA) A | Weld Time (cycle) B | Pressure (psi) C | Parameter of Experiment |
|---|---|---|---|---|
| **A** | 1 | 1 | 1 | |
| **B** | 1 | 2 | 2 | |
| **C** | 1 | 3 | 3 | |
| **D** | 2 | 1 | 2 | |
| **E** | 2 | 2 | 3 | Levels |
| **F** | 2 | 3 | 1 | |
| **G** | 3 | 1 | 3 | |
| **H** | 3 | 2 | 1 | |
| **I** | 3 | 3 | 2 | |

### 3.3.5 Mechanical Tests (Charpy and Tensile Test)

After experimenting was done, two mechanical tests were tested to the specimens. Several tables are being used to record the reading during Tensile and Charpy test analysis. For Tensile test, the selected data are a maximum force (Newton) and the maximum displacement (mm), stress (N/mm2) and yield strength (N/mm2), and for Charpy test, the selected data are Impact Energy (Joule). Some figures below shows the dimension of the specimen and machine was used for Tensile and Charpy test.

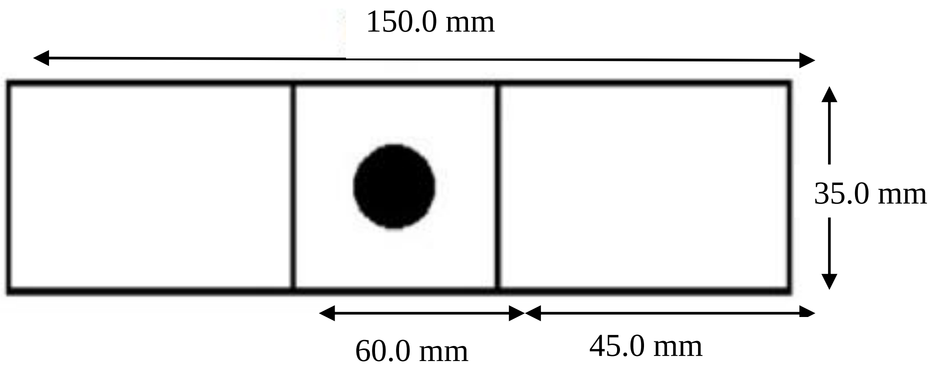


**Figure 3.8:** Dimension of specimen for Tensile test

Source: Majid and Pirooz (2009)

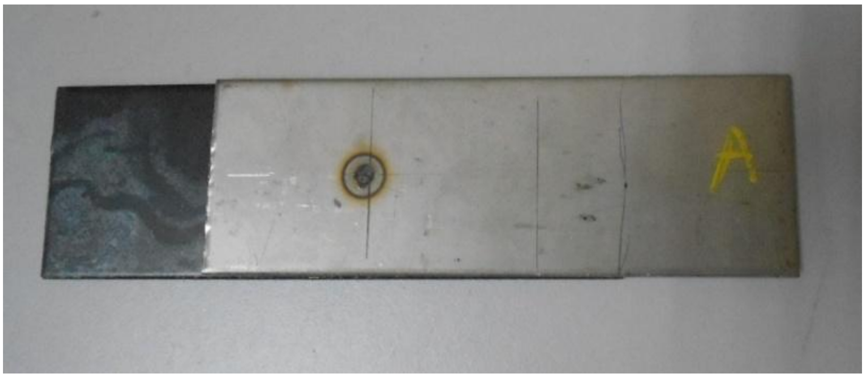


**Figure 3.9:** Sample of specimen for Tensile test


**Figure 3.10:** Shimadzu Tensile Test Machine

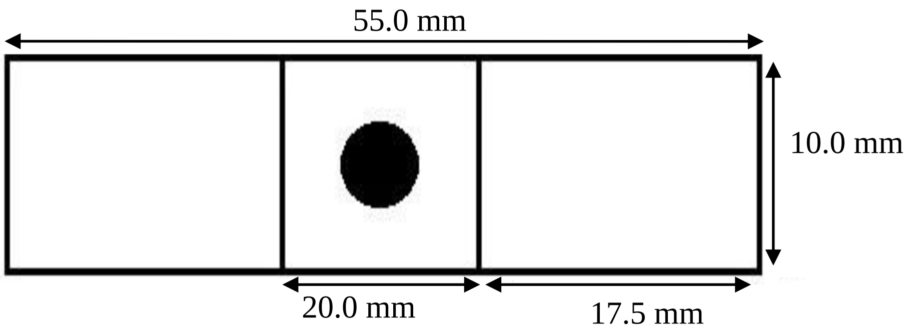


**Figure 3.11:** Dimension of specimen for Charpy test

Source: ASTM A370-9

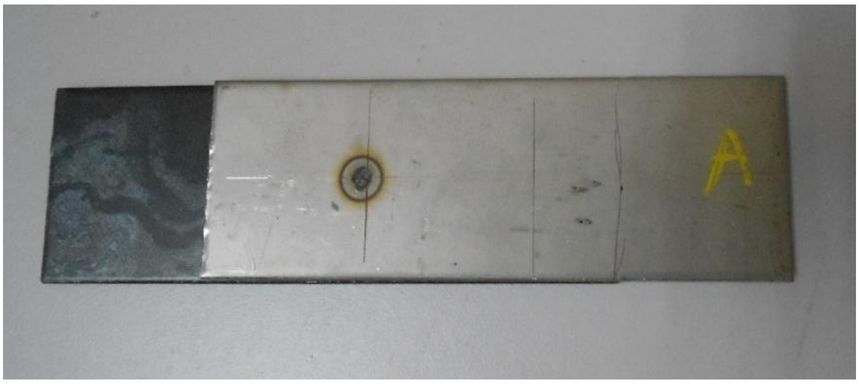

**Figure 3.12:** Sample of specimen for Charpy test

**Figure 3.13:** Charpy Test Machine (Digital)

### 3.3.6 Weld Nugget Dimension Views

After the experiment was done, specimens will be undergoing microstructure test for investigating the weld nugget dimension. This was done by using the optical microscope. The weld will divide into three regions, which are Fusion Zone **(FZ)**, Heat Affected Zone **(HAZ)** and Base Metal **(BM)**. Width, **W** and depth, **D** of welds also indicates for this test. Width and depth of the welds also calculated and recorded. Figures 3.14 until 3.17 show the picture and the machine were used.

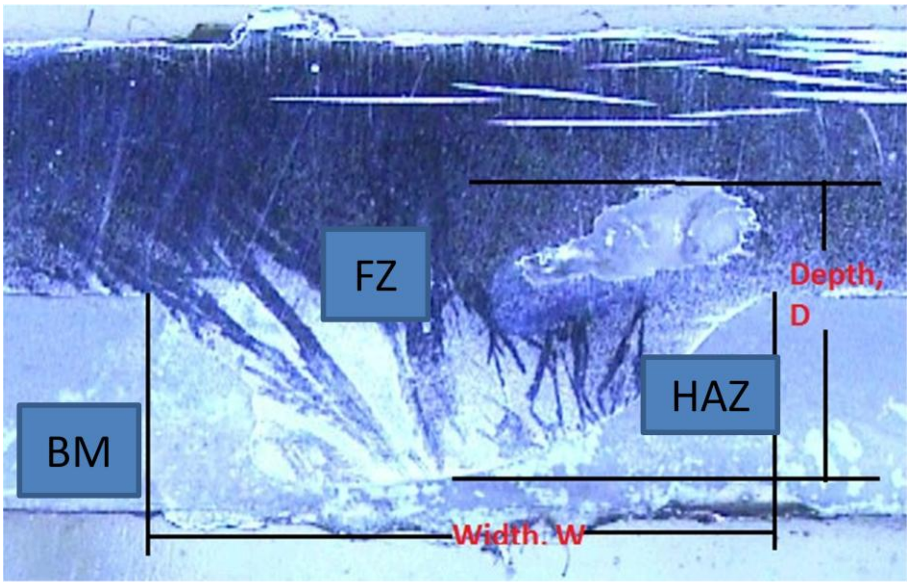


**Figure 3.14:** Example of the specimen shows the three regions of the weld

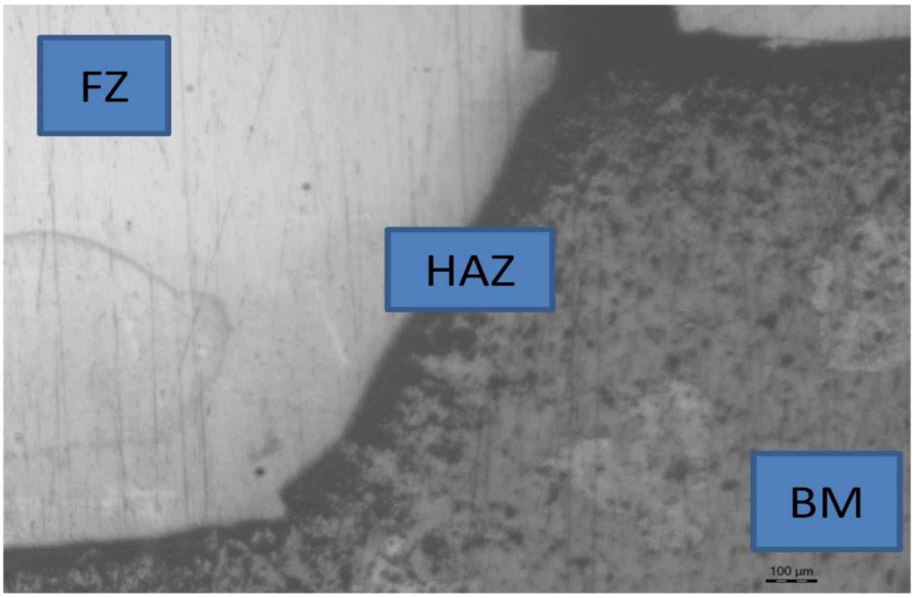


**Figure 3.15:** Example of the specimen shows the three regions of the weld.

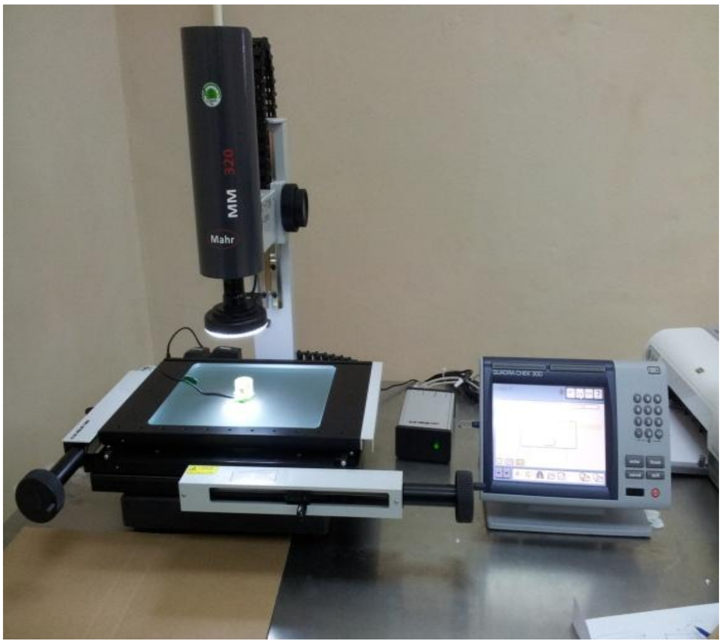


**Figure 3.16:** Optical Measurement Microscope


**Figure 3.17:** Optical Microscope

## 3.4 Application Taguchi Method into Design of Experiment

After mechanical tests (Tensile and Charpy test) were done, the value of results and the parameter of the experiment will recorded into the table 3.4 as shown.

**Table 3.5:** Inputs (Parameters) and Outputs (Results)

| Number of Experiment | Current (kA) | Weld Time (cycle) | Pressure (psi) | Tensile Test, Force (N) | Charpy Impact Energy (J) |
|---|---|---|---|---|---|
| **A** | 3.0 | 2.5 | 30 | * | ** |
| **B** | 3.0 | 3.0 | 35 | * | ** |
| **C** | 3.0 | 3.5 | 40 | * | ** |
| **D** | 4.0 | 2.5 | 35 | * | ** |
| **E** | 4.0 | 3.0 | 40 | * | ** |
| **F** | 4.0 | 3.5 | 30 | * | ** |
| **G** | 5.0 | 2.5 | 40 | * | ** |
| **H** | 5.0 | 3.0 | 30 | * | ** |
| **I** | 5.0 | 3.5 | 35 | * | ** |

* and ** value indicated in Chapter 4

The next step is, calculate the Signal-to-Noise Ratio (S/N Ratio), by using the formula 3.1. The values indicated will be recorded into the table 3.6.

$$S/N = -10 * \log[S(1/Y^2)] * (1/n) \qquad (3.1)$$

Where; Y = responses for the given factor level combination and n = number of responses in the factor level combination.

**Table 3.6:** S/N Ratio for Tensile Test (Force) and Charpy Impact Energy

| Experiment Number | Tensile Test, Force (kN) (average) | S/N ratio for T-S strength in db | Charpy Impact Energy (J)(average) | S/N ratio for Charpy Energy in db |
|---|---|---|---|---|
| **A** | * | ** | *** | **** |
| **B** | * | ** | *** | **** |
| **C** | * | ** | *** | **** |
| **D** | * | ** | *** | **** |
| **E** | * | ** | *** | **** |
| **F** | * | ** | *** | **** |
| **G** | * | ** | *** | **** |
| **H** | * | ** | *** | **** |
| **I** | * | ** | *** | **** |

* until **** values indicated in Chapter 4

After S/N Ratio was calculated, the next analysis will be to obtain Linear Model Analysis of Means versus Current, Weld Time and Pressure, and also analysis of Variance (ANOVA). The tables 3.7 and 3.8 show the both analyses.

**Table 3.7:** Estimated Model Coefficient for Means

| Term | Coefficient | Sum of Error Coefficient | T (T-value) | P (P-value) |
|---|---|---|---|---|
| **Constant** | * | ** | *** | **** |
| **Current 3** | * | ** | *** | **** |
| **Current 4** | * | ** | *** | **** |
| **Weld Time 2.5** | * | ** | *** | **** |
| **Weld Time 3.0** | * | ** | *** | **** |
| **Pressure 30** | * | ** | *** | **** |
| **Pressure 35** | * | ** | *** | **** |

* until **** values indicated in Chapter 4

**Table 3.8:** Analysis of Variance for Means

| Source | Degree of Freedom | Sequence Sum of Square | Adjusted Sum of Square | Adjusted Mean of Square | F (F-test) | P (P-value) |
|---|---|---|---|---|---|---|
| **Welding Current (A)** | * | ** | *** | **** | ***** | ****** |
| **Weld Time (B)** | * | ** | *** | **** | ***** | ****** |
| **Pressure (C)** | * | ** | *** | **** | ***** | ****** |
| **Residual Error** | * | ** | *** | **** | | |
| **Total** | * | ** | | | | |

* until ****** values indicated in Chapter 4

The next analysis predicts the optimal parameter by investigating the Response Table for S/N Ratios. S/N Ratio used is “Larger is Better”, and the graph of Main Effects and S/N Ratio will be indicated from the analysis. From the Response Table, it will show the rank of the most affected parameter in the results of spot welding, and from the graph, it will show the parameters were being optimized.

**Table 3.9:** Response Table for S/N Ratios

| Level | Current | Weld Time | Pressure |
|---|---|---|---|
| **1** | * | ** | *** |
| **2** | * | ** | *** |
| **3** | * | ** | *** |
| **Delta** | * | ** | *** |
| **Rank** | * | ** | *** |

* until *** values indicated in Chapter 4

**Table 3.10:** Prediction of Optimize parameter

| Current (kA) | Weld Time (cycle) | Pressure (psi) |
|---|---|---|
| * | * | * |

* values indicated in Chapter 4

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

For this chapter, it's brief about the results from the experiment. From mechanical tests, (Tensile and Charpy test) will discuss in details. From the results, Taguchi method will be used in order to calculate and obtain the optimal parameter for spot welding joining. Microstructure views were done in order to investigate weld nugget dimension.

## 4.2 TENSILE TEST

For Tensile test, an experiment was done with three times, and the average was calculated. The values of the Tensile test were recorded and show in the table below:

**Table 4.1:** Tensile test findings (Force, Displacement, Stress, Strain and Yield Strength)

| Experiment | Force (N) | Displacement (mm) | Stress (N/mm2) | Strain (%) | Yield Strength (N/mm2) |
|---|---|---|---|---|---|
| **A** | 4650.29 | 0.41007 | 66.4327 | 0.45563 | 62.33 |
| **B** | 6052.80 | 0.62029 | 86.4687 | 0.68921 | 82.00 |
| **C** | 6942.88 | 0.76601 | 99.1840 | 0.85112 | 94.00 |
| **D** | 8217.00 | 0.93712 | 117.3856 | 1.04125 | 100.33 |
| **E** | 10467.60 | 1.60040 | 149.5373 | 1.77822 | 112.33 |
| **F** | 11025.33 | 1.75556 | 157.5036 | 1.95062 | 116.67 |
| **G** | 13177.23 | 2.33828 | 188.2466 | 2.59415 | 125.00 |
| **H** | 14049.36 | 2.47957 | 200.7050 | 2.73285 | 140.00 |
| **I** | 12798.70 | 2.06707 | 182.8380 | 2.29674 | 122.67 |

### 4.2.1 The Tensile Strength Graphs

From the data of tensile strength above, in terms of Force (N), the graph is shown below:

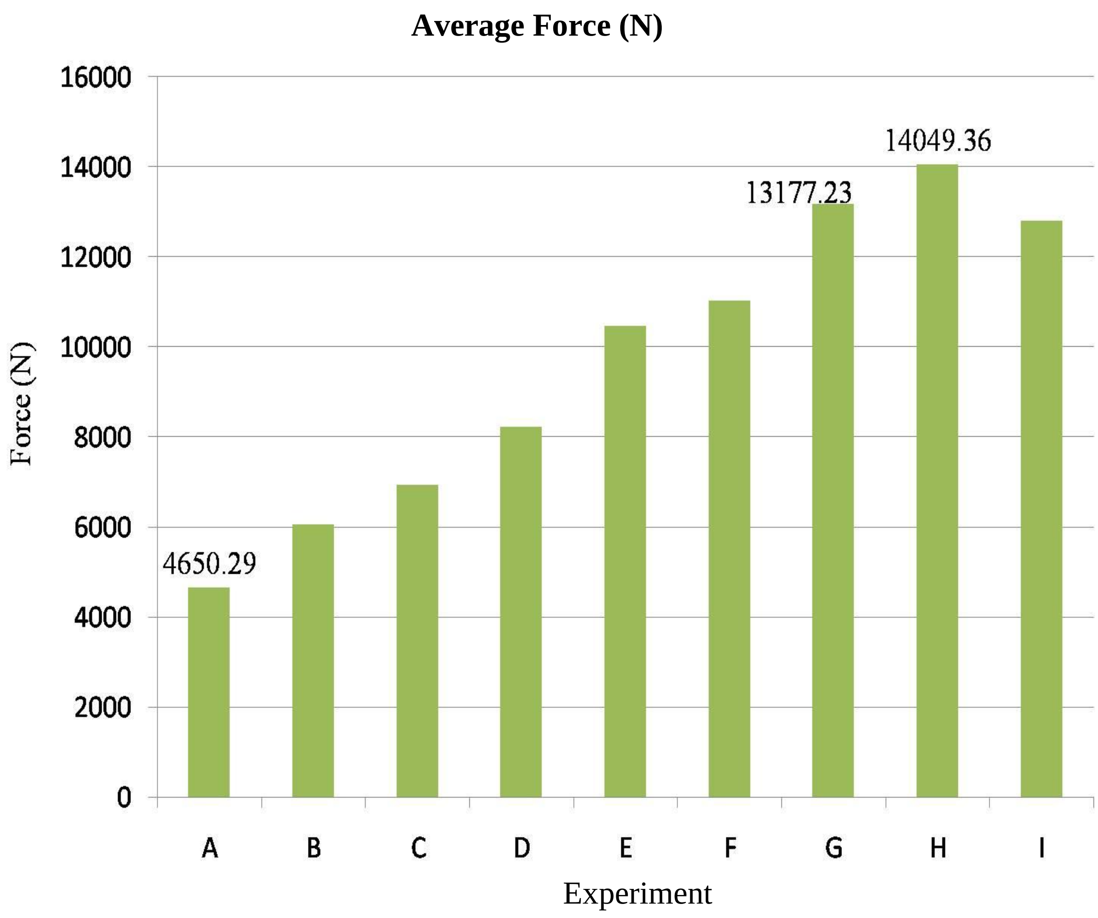


**Figure 4.1:** The Tensile Strength (Force) graph

From the graph, experiment number H shows the higher value of force with 14049.36 N. The second higher is in experiment number G, which the value of force is 13177.23 N. The lower one is in experiment number A, which the value of force is 4650.29 N.

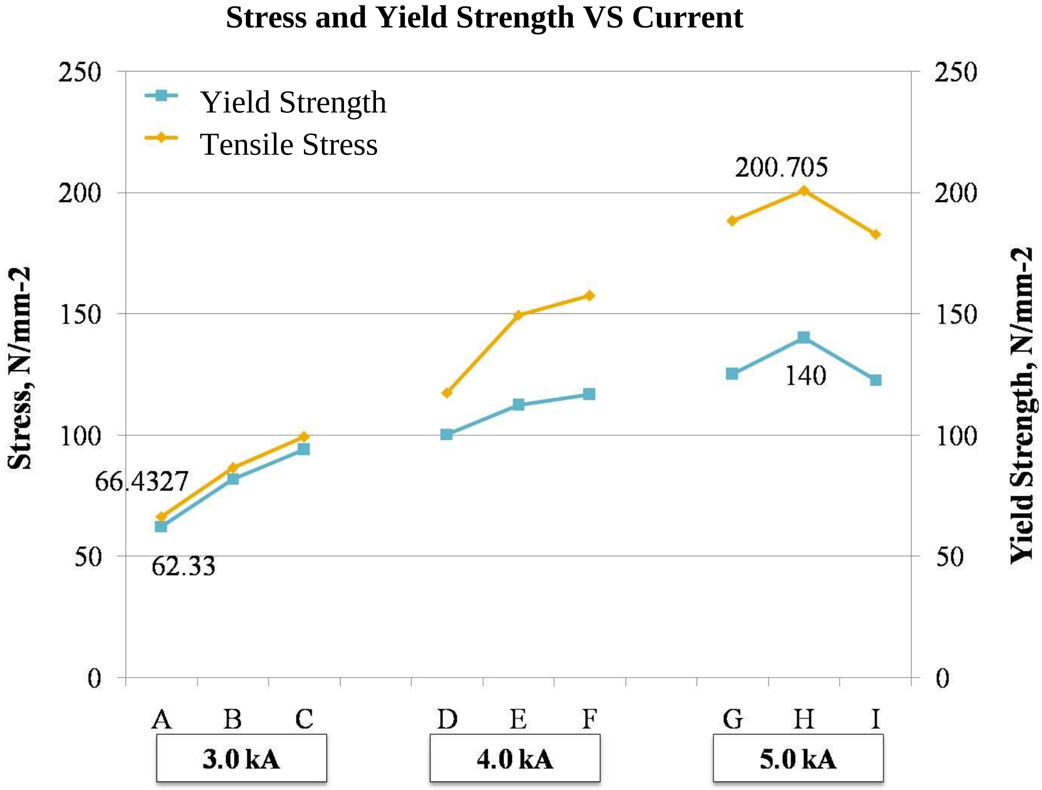


**Figure 4.2:** Stress and Yield Strength VS Current

From the graph in Figure 4.2 above, the higher value is in experiment number H, which means in terms of stress and yield strength is 200.705 N/mm2 and 140 N/mm2 respectively. For the lower value, is in experiment number A, in terms of stress and yield strength is 66.4327 N/mm2 and 62.33 N/mm2 respectively.

This graph also shows the experiments from A to I have shown stress and yield strength increments due to current increments from 3kA to 5kA. But, in experiment number I, the value of stress and yield strength was decreased. It is because, in experiment number I was occur defect.

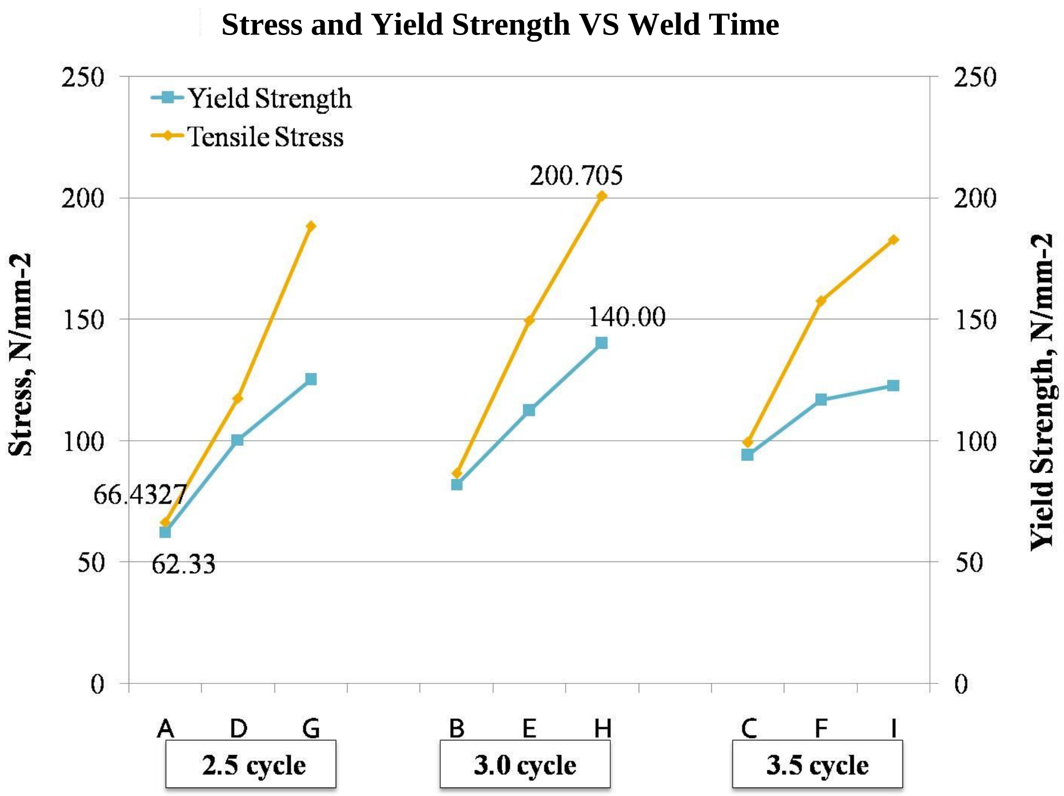


**Figure 4.3:** Stress and Yield Strength VS Weld Time

From the graph in Figure 4.3 above, the higher value is in experiment number H, which means in terms of stress and yield strength is 200.705 N/mm2 and 140 N/mm2 respectively. For the lower value, is in experiment number A, in terms of stress and yield strength is 66.4327 N/mm2 and 62.33 N/mm2 respectively.

This graph also shows the experiments from A to I have shown stress and yield strength increments due to weld time increments from 2.5 cycles to 3.5 cycles. But, in experiment number I, the value of stress and yield strength was decreased. It is because, in experiment number I was occur defect.

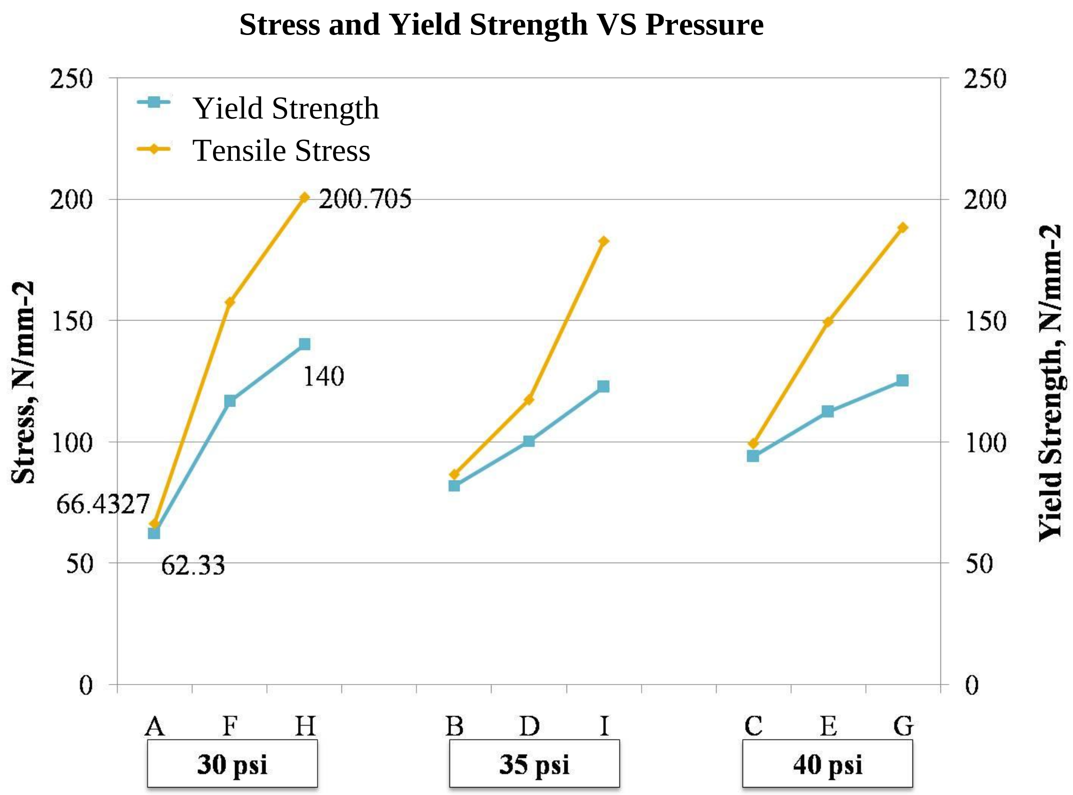


**Figure 4.4:** Stress and Yield Strength VS Pressure

From the graph in Figure 4.3 above, the higher value is in experiment number H, which means in terms of stress and yield strength is 200.705 N/mm2 and 140 N/mm2 respectively. For the lower value, is in experiment number A, in terms of stress and yield strength is 66.4327 N/mm2 and 62.33 N/mm2 respectively.

This graph also shows the experiments from A to I have shown stress and yield strength increments due to pressure increments from 30 psi to 40 psi. But, in experiment number I, the value of stress and yield strength was decreased. It is because, in experiment number I was occur defect.

## 4.3 CHARPY TEST

For the Charpy test, the experiments were done two times and impact energy was indicated and recorded. Impact energy is a measure of the work done to fracture a specimen.

**Table 4.2:** Charpy Test findings (Impact Energy)

| Experiment Number | Impact Energy (J) | | |
|---|---|---|---|
| | 1 | 2 | AVE |
| **A** | 30.0 | 32.0 | 31.0 |
| **B** | 31.0 | 33.0 | 32.0 |
| **C** | 35.0 | 35.0 | 35.0 |
| **D** | 38.0 | 36.0 | 37.0 |
| **E** | 39.0 | 41.0 | 40.0 |
| **F** | 40.0 | 42.0 | 41.0 |
| **G** | 43.0 | 42.0 | 42.5 |
| **H** | 45.0 | 47.0 | 46.0 |
| **I** | 38.0 | 42.0 | 40.0 |

### 4.3.1 The Charpy (Impact Energy) Graphs

From the data of the Charpy test above, in terms of Impact Energy (J), the graph is shown below:

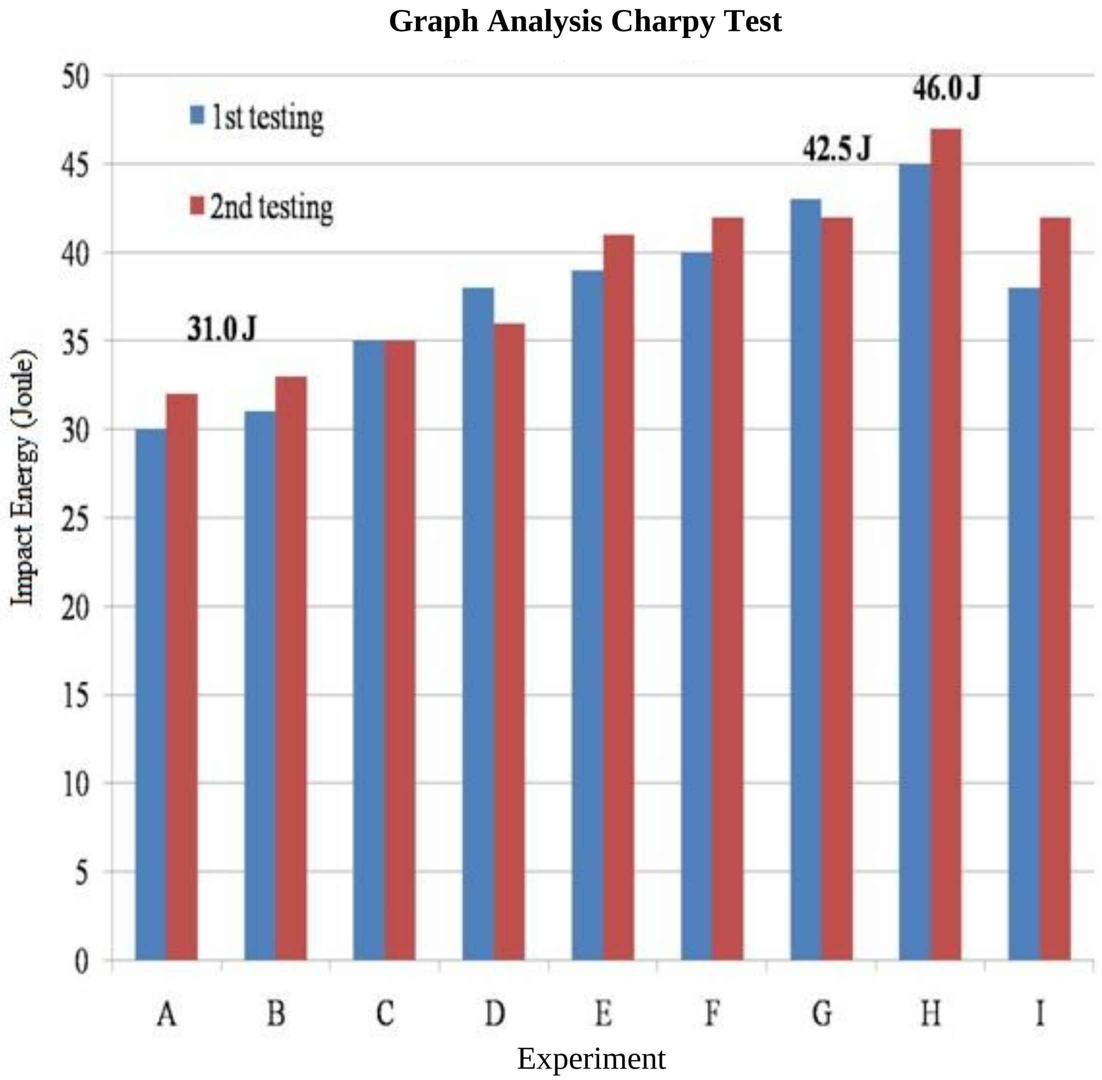


**Figure 4.5:** The Impact Energy from Charpy test

From the graph above, experiment number H shows the higher value of impact energy which is 46.0 J. For the second higher, in experiment number G, represent 42.5 J. The lowest value is in experiment number A, which the value is 31.0 J.

## 4.4 ANALYSIS OF TAGUCHI METHOD

Analysis of Taguchi was investigated, in order to obtain optimal parameter. The first step was done, which input (parameter) and output (results from tensile and Charpy test) listed in the table below.

**Table 4.3:** Inputs (Parameters) and Outputs (Results)

| Number of Experiment | Current (kA) | Weld Time (cycle) | Pressure (psi) | Tensile Test, Force (N) | Charpy Impact Energy (J) |
|---|---|---|---|---|---|
| **A** | 3.0 | 2.5 | 30 | 4650.29 | 31.0 |
| **B** | 3.0 | 3.0 | 35 | 6052.80 | 32.0 |
| **C** | 3.0 | 3.5 | 40 | 6942.88 | 35.0 |
| **D** | 4.0 | 2.5 | 35 | 8217.00 | 37.0 |
| **E** | 4.0 | 3.0 | 40 | 10467.60 | 40.0 |
| **F** | 4.0 | 3.5 | 30 | 11025.33 | 41.0 |
| **G** | 5.0 | 2.5 | 40 | 13177.23 | 42.5 |
| **H** | 5.0 | 3.0 | 30 | 14049.36 | 46.0 |
| **I** | 5.0 | 3.5 | 35 | 12798.70 | 40.0 |

After the listing, Signal-to-Noise Ratio (S/N Ratio) was calculated based on Tensile Test (Force) and Charpy Impact Energy, by using this formula. After calculate, the value was recorded and listed in the table below.

$$\text{S/N} = -10 * \log\lfloor S(1/Y^2) \rfloor * (1/n) \qquad (4.1)$$

**Table 4.4:** S/N Ratio for Tensile Test, Force and Charpy Impact Energy

| Experiment Number | Tensile Test, Force (kN) (average) | S/N ratio for T-S strength in db | Charpy Impact Energy (J)(average) | S/N ratio for Charpy Energy in db |
|---|---|---|---|---|
| **A** | 4.65029 | 13.3496 | 31.0 | 29.8272 |
| **B** | 6.05280 | 15.6391 | 32.0 | 30.1029 |
| **C** | 6.94288 | 16.8307 | 35.0 | 30.8813 |
| **D** | 8.21700 | 18.2942 | 37.0 | 31.3640 |
| **E** | 10.46760 | 20.3969 | 40.0 | 32.0411 |
| **F** | 11.02533 | 20.8478 | 41.0 | 32.2556 |
| **G** | 13.17723 | 22.3964 | 42.5 | 32.5677 |
| **H** | 14.04936 | 22.9531 | 46.0 | 33.2551 |
| **I** | 12.79870 | 22.1433 | 40.0 | 32.0411 |

The third step is obtained Linear Model Analysis for Means versus Current, Weld Time and Pressure and analysis of variance (ANOVA). ANOVA is used to determine which one, among the three parameters contributing the most effect to the strength of the spot welding.

This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The table below shows the both analyses.

**Table 4.5:** Estimated Model Coefficients for Means

| Term | Coefficient | Sum of Error Coefficient | T (T-value) | P (P-value) |
|---|---|---|---|---|
| **Constant** | 4873.65 | 113.0 | 43.143 | 0.001 |
| **Current 3** | -1916.32 | 159.8 | -11.995 | 0.007 |
| **Current 4** | 97.67 | 159.8 | 0.611 | 0.603 |
| **Weld Time 2.5** | -514.48 | 159.8 | -3.220 | 0.084 |
| **Weld Time 3.0** | 240.98 | 159.8 | 1.508 | 0.270 |
| **Pressure 30** | 100.18 | 159.8 | 0.627 | 0.595 |
| **Pressure 35** | -344.07 | 159.8 | -2.154 | 0.164 |

**Table 4.6:** Analysis of Variance for Means

| Source | Degree of Freedom | Sequence Sum of Square | Adjusted Sum of Square | Adjusted Mean of Square | F (F-test) | P (P-value) |
|---|---|---|---|---|---|---|
| **Welding Current (A)** | 2 | 20967931 | 20967931 | 10483965 | 91.28 | 0.011 |
| **Weld Time (B)** | 2 | 1192688 | 1192688 | 596344 | 5.19 | 0.161 |
| **Pressure (C)** | 2 | 563693 | 563693 | 281847 | 2.45 | 0.290 |
| **Residual Error** | 2 | 229699 | 229699 | 114849 | | |
| **Total** | 8 | 22954010 | | | | |

The forth step is analyzed and predict optimize parameter, by investigating the Response Table for S/N Ratios. S/N Ratio used is "Larger is Better", and the graph of "Main Effects Plot for Means and for S/N Ratio" also indicated from the analysis. From these graphs, it shows the parameters were being optimized.

**Table 4.7:** Response Table for S/N Ratios

| Level | Current | Weld Time | Pressure |
|---|---|---|---|
| **1** | 33.28 | 34.26 | 34.79 |
| **2** | 34.90 | 34.81 | 34.18 |
| **3** | 35.63 | 34.74 | 38.84 |
| **Delta** | 2.35 | 0.55 | 0.66 |
| **Rank** | 1 | 3 | 2 |

The effects of resistance spot welding parameters different between various their levels. The resistance spot welding parameters on all the levels by means of S/N ratio are summarized and presented in the Figure 4.6 and 4.7.

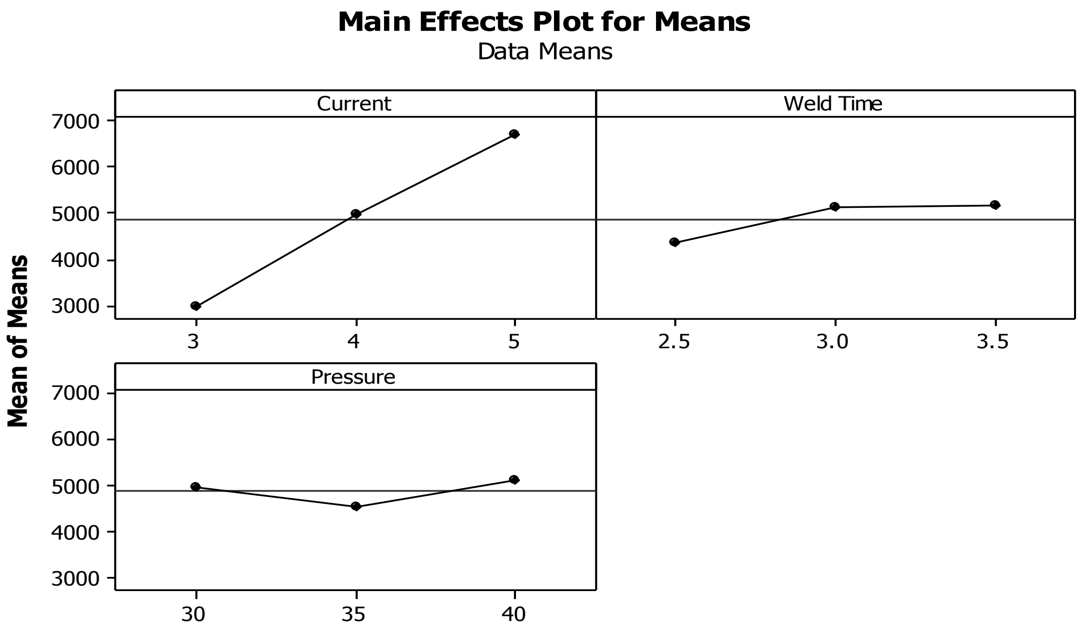


**Figure 4.6:** Main Effects Plot for Means

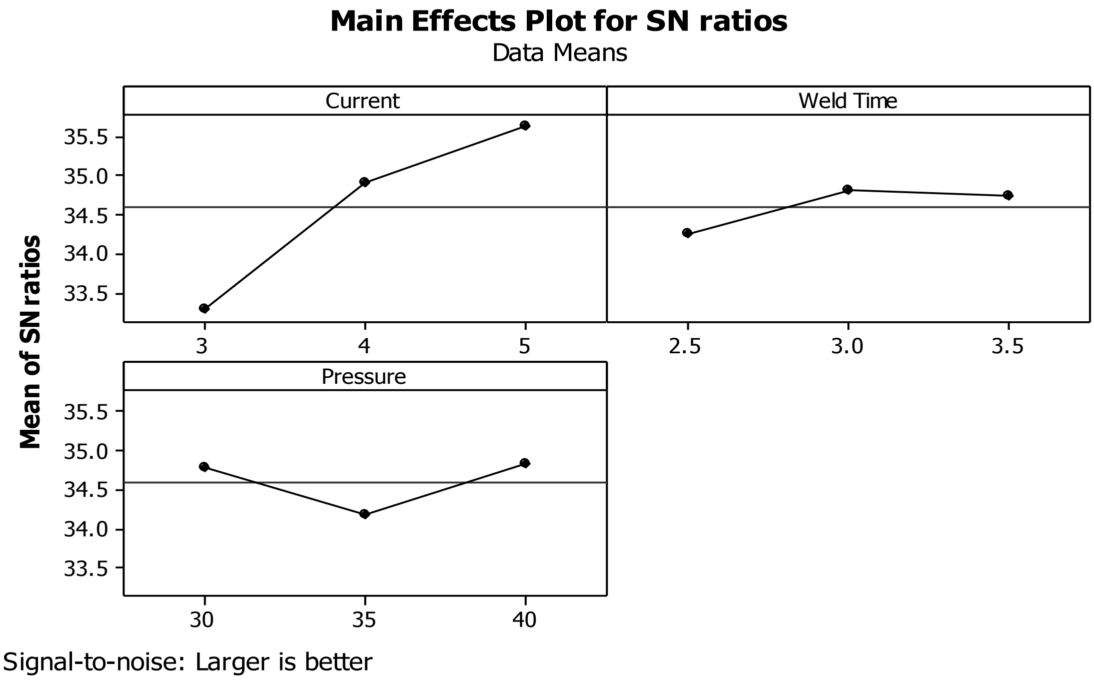


**Figure 4.7:** Main Effects Plot for S/N Ratios

From the figures above, shows that the welding current has the highest effect on the process by means of residual stresses. It followed by pressure and weld time respectively.

**Table 4.8:** Prediction of Optimize parameter

| Current (kA) | Weld Time (cycle) | Pressure (psi) |
|---|---|---|
| 5.0 | 3.0 | 40.0 |

## 4.5 REGRESSION ANALYSIS

The next analysis done is Regression analysis, in order to obtain the regression equation for Tensile Test and for Charpy Test. Regression analysis is used to generate an equation to describe the relationship between the predictors (parameters) and the response variable (results from Tensile and Charpy Test). It also used to predict new observations. Formula below shows the Regression formula for Tensile.

$$TENSILE = -10939 + 3730\ CURRENT + 1574\ WELD\ TIME + 28.8\ PRESSURE \quad (4.2)$$

**Table 4.9:** Estimated Model Coefficients for Means for Regression Analysis of Tensile Test

| Predictor | Coefficient | Sum of Error Coefficient | T (T-value) | P (P-value) |
|---|---|---|---|---|
| **Constant** | -10939 | 3793 | -2.88 | 0.034 |
| **Current** | 3729.9 | 376.1 | 9.92 | 0.000 |
| **Weld Time** | 1574.1 | 752.3 | 2.09 | 0.091 |
| **Pressure** | 28.76 | 75.23 | 0.38 | 0.718 |

S = 921.348 R-Sq = 95.4% R-Sq(adj) = 92.6%

**Table 4.10** Analysis of Variance for Regression Analysis of Tensile Test

| Source | Degree of Freedom | Sum of Square | Mean of square | F (F-test) | P (P-value) |
|---|---|---|---|---|---|
| **Regression** | 3 | 87313206 | 29104402 | 34.29 | 0.001 |
| **Residual Error** | 5 | 4244412 | 848882 | | |
| **Total** | 8 | 91557618 | | | |

*CHARPY = 13.0 + 5.08 CURRENT + 1.83 WELD TIME – 0.017 PRESSURE* (4.3)

**Table 4.11:** Estimated Model Coefficients for Means for Regression Analysis of Charpy Test

| Predictor | Coefficient | Sum of Error Coefficient | T (T-value) | P (P-value) |
|---|---|---|---|---|
| **Constant** | 13.03 | 10.96 | 1.19 | 0.288 |
| **Current** | 5.083 | 1.087 | 4.68 | 0.005 |
| **Weld Time** | 1.833 | 2.173 | 0.84 | 0.437 |
| **Pressure** | -0.0167 | 0.2173 | -0.08 | 0.942 |

S = 2.66198 R-Sq = 81.9% R-Sq(adj) = 71.0%

**Table 4.12:** Analysis of Variance for Regression Analysis of Charpy Test

| Source | Degree of Freedom | Sum of Square | Mean of square | F (F-test) | P (P-value) |
|---|---|---|---|---|---|
| **Regression** | 3 | 160.125 | 53.375 | 7.53 | 0.027 |
| **Residual Error** | 5 | 35.341 | 7.086 | | |
| **Total** | 8 | 195.556 | | | |

**Table 4.13:** Comparison between Experimental Results and Prediction Results

| Specimen | Tensile Force,N (Experimental) | Tensile Force, N (Prediction from Taguchi) | Charpy, J (Experimental) | Charpy, J (Prediction from Taguchi) |
|---|---|---|---|---|
| **A** | 4650.29 | 5050.00 | 31.0 | 32.305 |
| **B** | 6052.80 | 5981.00 | 32.0 | 33.135 |
| **C** | 6942.88 | 6912.00 | 35.0 | 33.965 |
| **D** | 8217.00 | 8924.00 | 37.0 | 37.300 |
| **E** | 10467.60 | 9855.00 | 40.0 | 38.130 |
| **F** | 11025.33 | 10354.00 | 41.0 | 39.215 |
| **G** | 13177.23 | 12798.00 | 42.5 | 42.295 |
| **H** | 14049.36 | 13297.00 | 46.0 | 43.380 |
| **I** | 12798.70 | 14228.00 | 40.0 | 44.210 |
| **OP** | 14863.30 | 13585.00 | 46.0 | 43.210 |

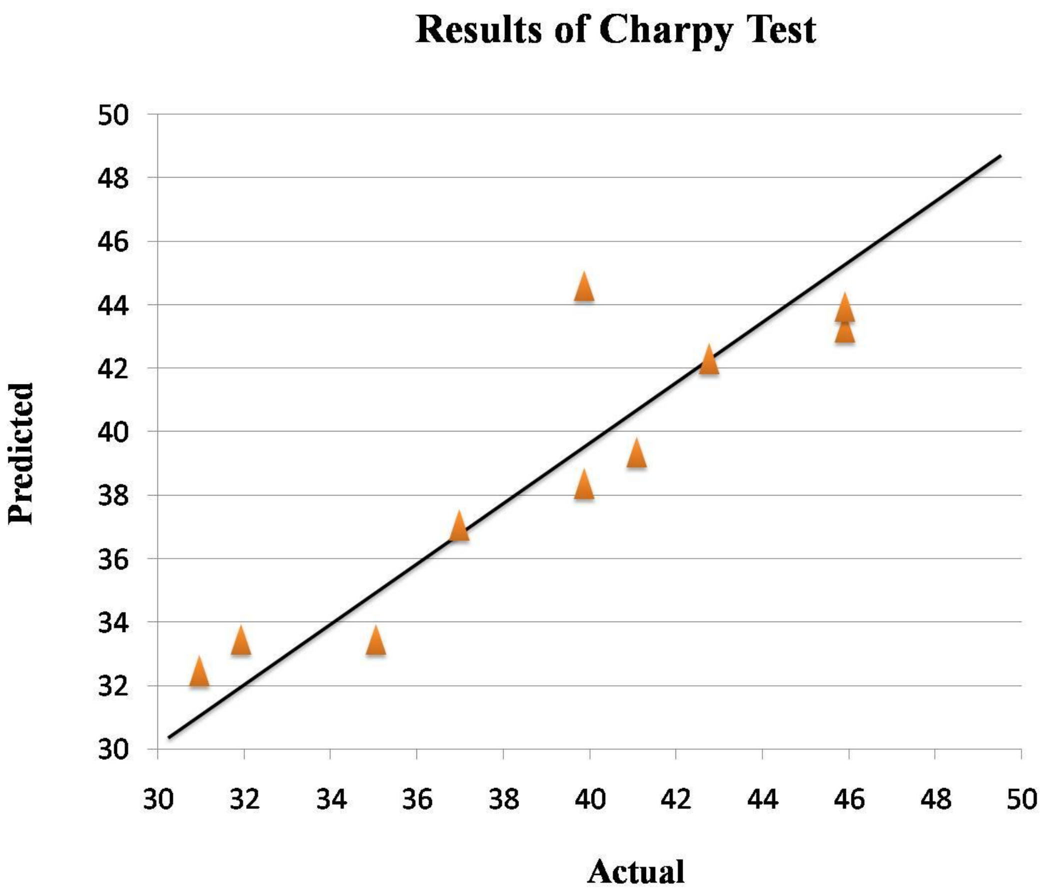


**Figure 4.8:** Results of Charpy Test (Predicted against Actual Experimental)

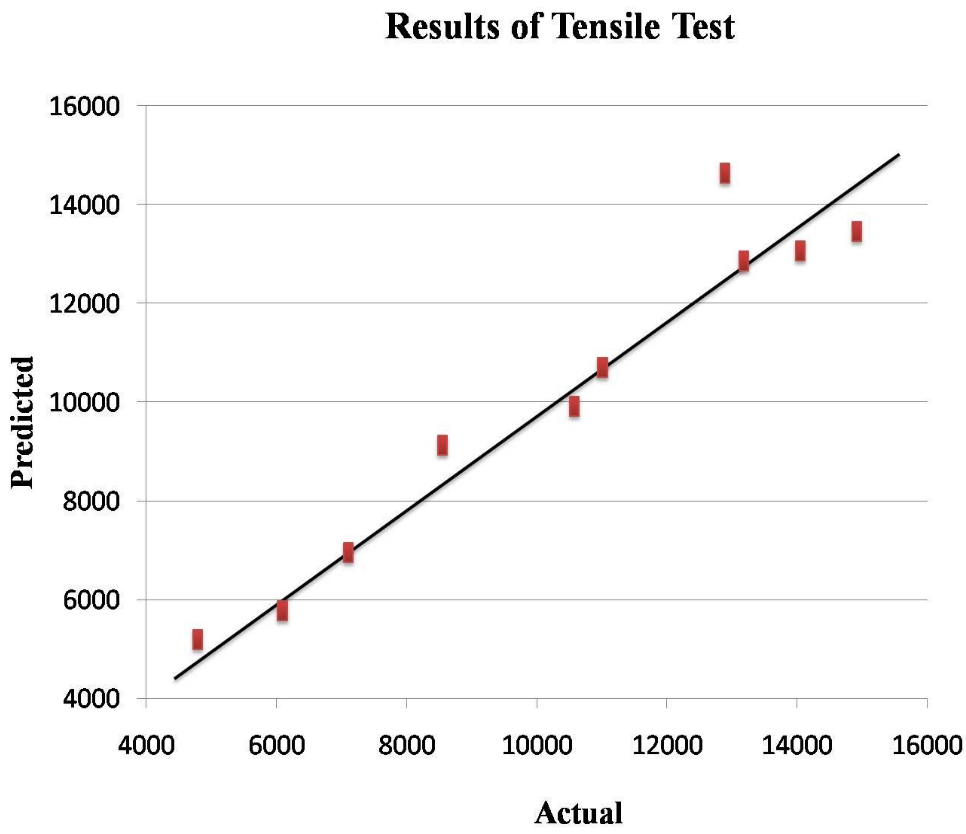


**Figure 4.9:** Results of Tensile Test (Predicted against Actual Experimental)

Figure 4.9 and 4.10 shows the relationship between the actual and predicted value of Charpy and Tensile test results. These figures show that the developed models are adequate because the residuals in prediction of each response are negligible, since the residuals tend to be close to the diagonal line (Anawa and Olabi. 2008).

In addition, to verify the satisfactoriness of the developed models, a confirmation experiments were carried out using new test conditions at optimal parameters conditions.

## 4.6 SURFACE AND CONTOUR PLOT

Surface and contour plot also were obtained from the analysis, to show the relationship of parameter to the results of the experiment. It also shows the most contribute parameter affected the results. The figures below shows the Charpy and Tensile versus the first and second rank most affected parameter (Pressure and Current).

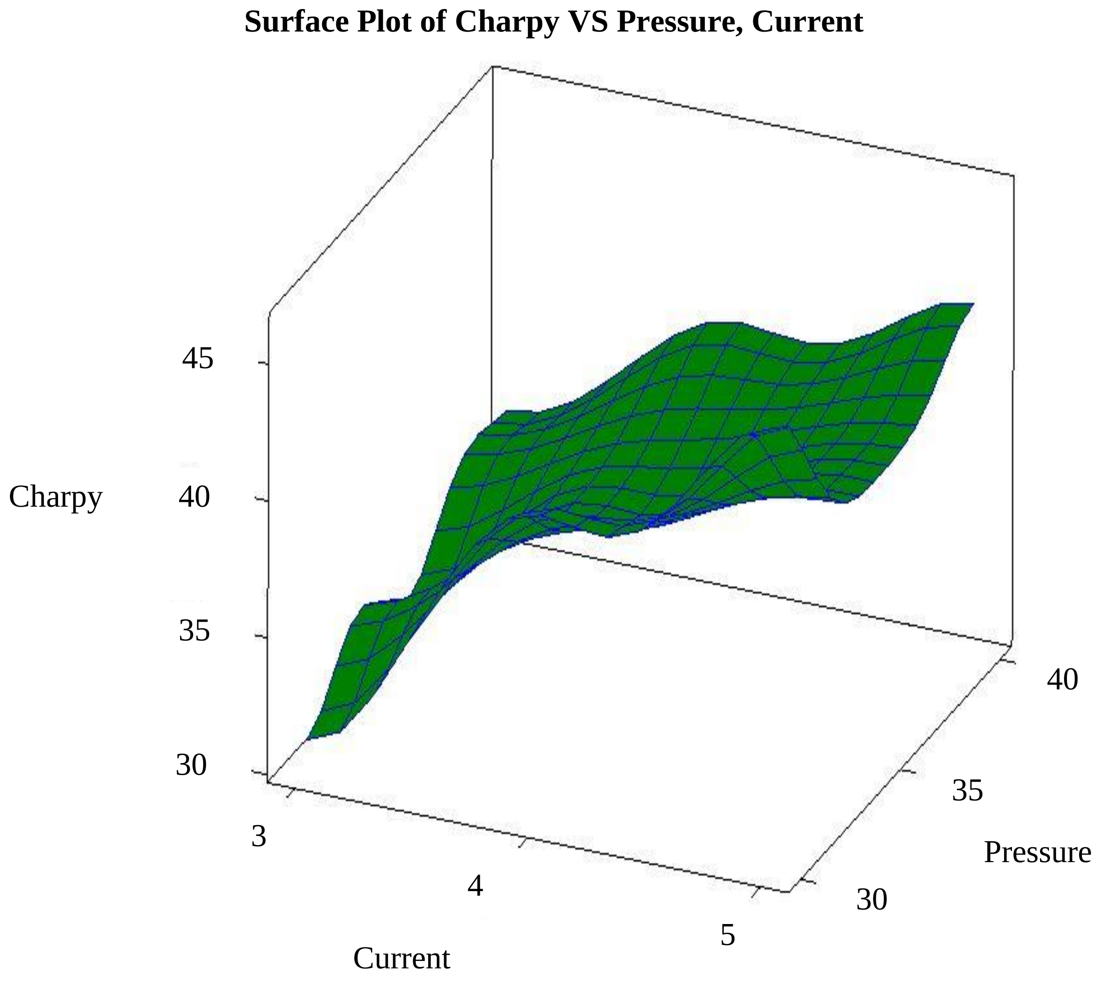


**Figure 4.10:** Surface Plot of Charpy vs Pressure and Current

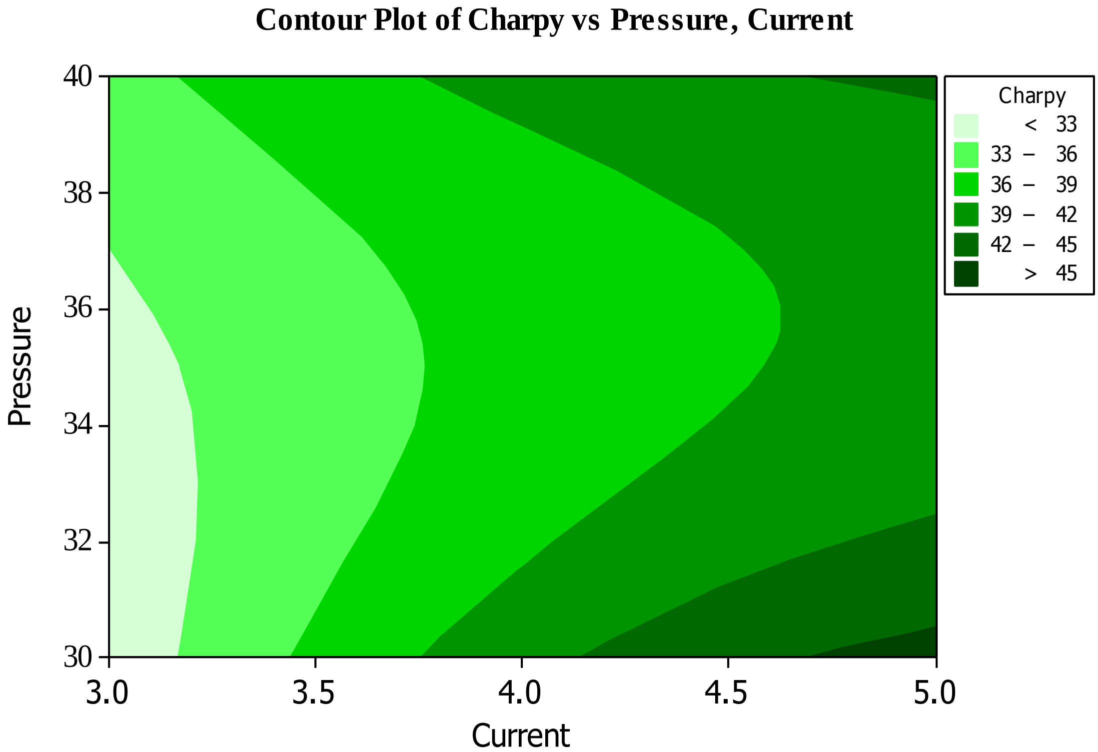


**Figure 4.11:** Contour Plot of Charpy vs Pressure and Current

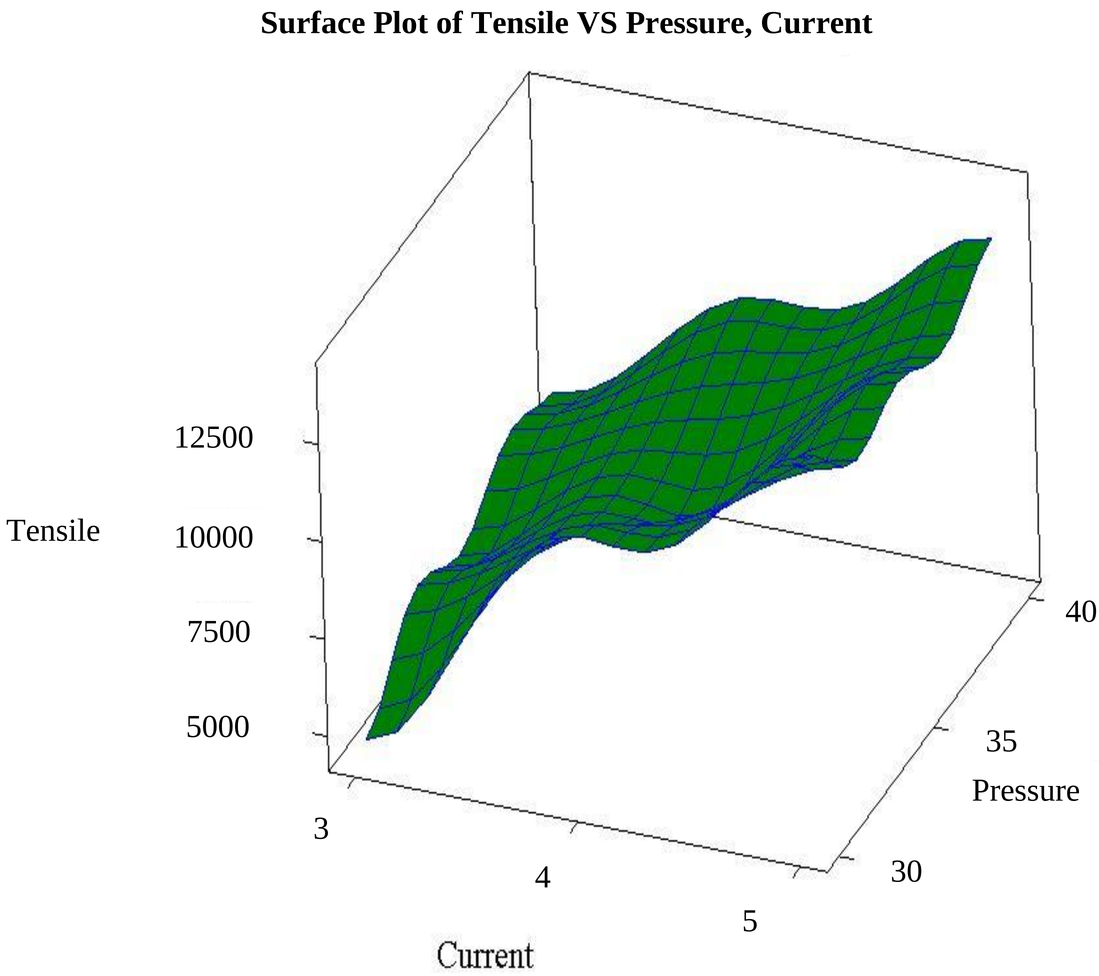


**Figure 4.12:** Surface Plot of Tensile vs Pressure and Current

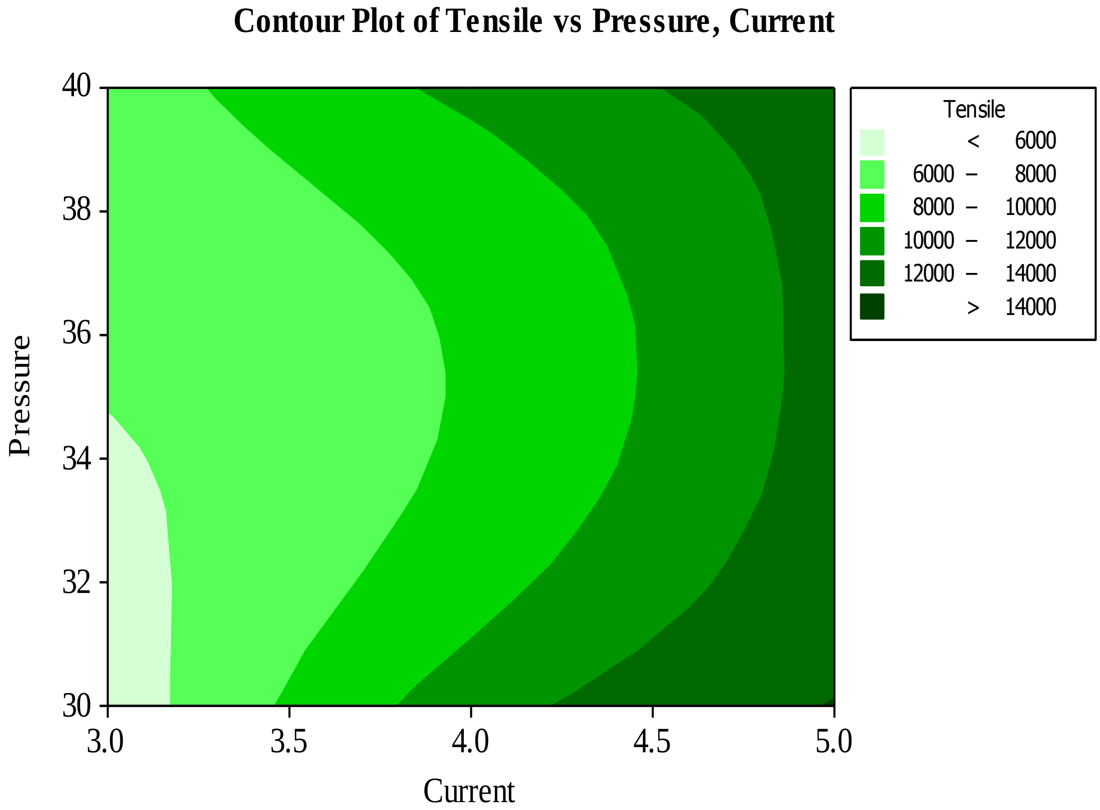


**Figure 4.13:** Contour Plot of Tensile vs Pressure and Current

From the figures 4.10 until 4.13, the dark green region represents the higher values of Tensile Force and Charpy Impact Energy. It shows that, when parameter increases, the value of Tensile and Charpy also increase. It can conclude that the three parameters are significantly affecting the Tensile and Charpy results.

## 4.7 CONFIRMATION EXPERIMENT

After getting the optimize parameter, the confirmation experiment must be done, in order to compare the results between experimental and optimize specimen. The table below shows the comparison.

**Table 4.14:** Comparison between experimental (A~I) and optimize specimen (OP) in terms of Tensile and Charpy test

| Experiment Number | Charpy Impact Energy (J) | Tensile Test Force (N) | Tensile Stress (N/mm-2) | Tensile Yield Strength (N/mm-2) |
|---|---|---|---|---|
| **A** | 31.0 | 4650.29 | 66.4327 | 62.33 |
| **B** | 32.0 | 6052.80 | 86.4687 | 82.00 |
| **C** | 35.0 | 6942.88 | 99.1840 | 94.00 |
| **D** | 37.0 | 8217.00 | 117.3856 | 100.33 |
| **E** | 40.0 | 10467.60 | 149.5373 | 112.33 |
| **F** | 41.0 | 11025.33 | 157.5036 | 116.67 |
| **G** | 42.5 | 13177.23 | 188.2466 | 125.00 |
| **H** | 46.0 | 14049.36 | 200.7050 | 140.00 |
| **I** | 40.0 | 12798.70 | 182.8380 | 122.67 |
| **OP** | 46.0 | 14863.30 | 212.3326 | 164.00 |

Based on the table above, the results of the optimize parameter was higher than the experimental specimen. Therefore, the prediction of optimum parameter can be verified for the analysis.

## 4.8 MICROGRAPH VIEWS

For the micrograph views, weld nugget dimension were investigated and calculated, in terms of width and depth of welds. The graph below shows the weld nugget dimension for each specimen (including optimize specimen).

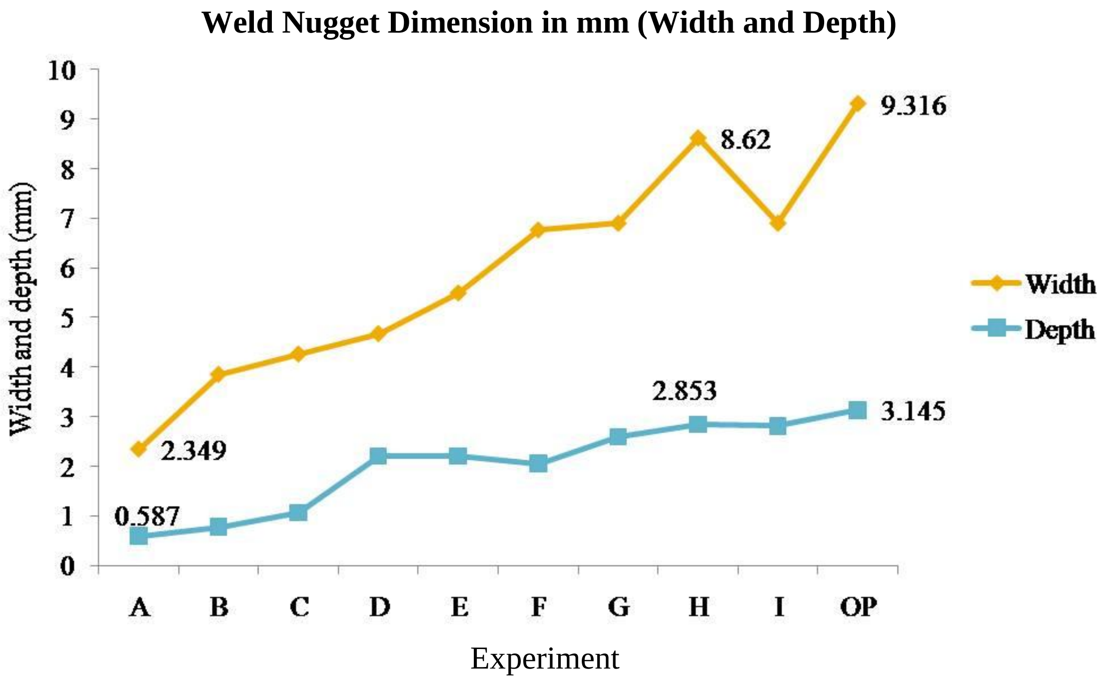


**Figure 4.14:** Weld Nugget Dimension (W, width and D, depth)

From the graph above, the optimum specimen has higher width and depth of welds, 9.316 mm and 3.145 mm respectively. The second higher is from the specimen H, which 8.62 mm (width) and 2.853 mm (depth). For the lowest is from specimen A, which width is 2.349 mm and depth is 0.587 mm. The figure below shows the picture microstructure for specimen A, H and OP.

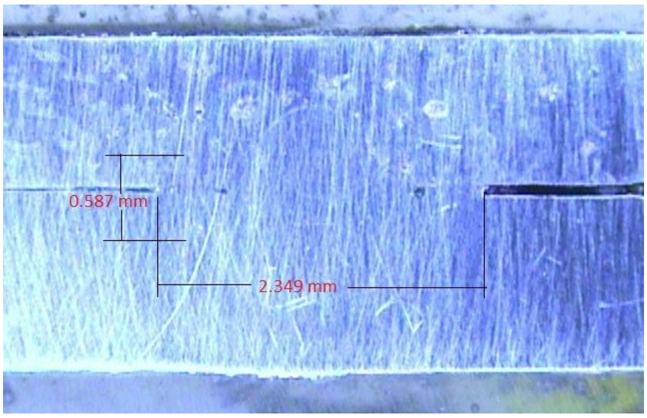


**Figure 4.15:** Specimen A (**W= 2.349 mm** and **D= 0.587 mm**)

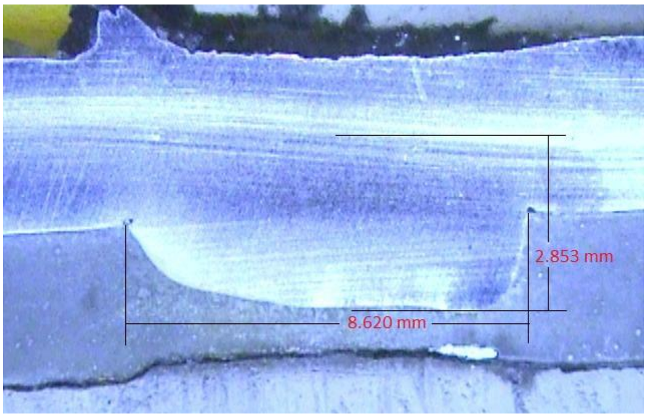


**Figure 4.16:** Specimen H (**W= 8.620 mm** and **D= 2.853 mm**)

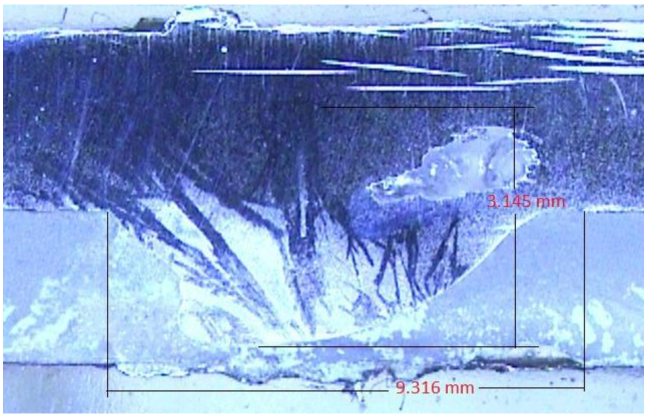


**Figure 4.17:** Specimen OP (**W= 9.316 mm** and **D= 3.145 mm**)

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 CONCLUSION

1. Specimen H (5.0 kA, 3.0 cycle, and 30 psi) welds produced higher Tensile strength **(14049.36 N)** and Charpy Impact energy **(46.0 J)** compared to the other experimental specimen. The optimize parameter; specimen OP (5.0 kA, 3.0 cycle and 40 psi) has the highest tensile strength **(14863.30 N)** and same value of Impact energy **(46.0 J)** as specimen H.

2. Higher Tensile strength and Impact energy is due to increase in width and depth of weld nugget. It was found that weld nugget dimension for specimen OP higher than specimen H.

3. From Taguchi analysis, it can be concluded that the best combination of parameters is Current (5.0 kA), Weld Time (3.0 cycle) and Pressure (40 psi). The rank of parameter affected the resistance spot welding experiment is Current, Pressure and Weld Time respectively.

4. From Regression analysis, the equation below was generated for both Tensile and Charpy test.

$$\textbf{\textit{Tensile}} = -10939 + 3730\ \textbf{\textit{Current}} + 1574\ \textbf{\textit{Weld Time}} + 28.8\ \textbf{\textit{Pressure}} \quad (5.1)$$

$$\textbf{\textit{Charpy}} = 13.0 + 5.08\ \textbf{\textit{Current}} + 1.83\ \textbf{\textit{Weld Time}} - 0.017\ \textbf{\textit{Pressure}} \quad (5.2)$$

When using Taguchi analysis, the prediction result is agreed with verification experiment.

## 5.2 RECOMMENDATIONS

For recommendations, it is suggested that the improvement below should be done to improve the research of spot welding.

1. In this experiment, only three parameters are involved (current, weld time and pressure). For further studies, instead of these three parameters, the other parameters such as the diameters of electrode and hold time can be added.

2. Other material such as aluminum alloys can be used, because nowadays aluminum alloys are increasingly being used in the automotive industry.

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# APPENDIX A

## PSM GANTT CHART

| No | Activities | Month | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SEPT | OCT | NOV | DEC | JAN | FEB | MAC | APR | MAY | JUNE |
| 1 | Literature review study | | | | | | | | | | |
| 2 | Preparing material | | | | | | | | | | |
| 3 | Making slide & presentation | | | | | | | | | | |
| 4 | Spot Welding Pre-Test | | | | | | | | | | |
| 5 | Spot Welding Experiment | | | | | | | | | | |
| 6 | Tensile Test | | | | | | | | | | |
| 7 | Charpy's Impact Test | | | | | | | | | | |
| 8 | Microstructure Analysis | | | | | | | | | | |
| 9 | Writing Thesis | | | | | | | | | | |