The Effect of Welding Parameters to Mechanical and Physical Properties during Resistance Welding of Titanium Alloys

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Mechanical Engineering with Honours

FYP II JANUARY 2020

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

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January 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Aidil

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AIDIL BIN AB RAHMAN

ABSTRACT

One of the most well-known manufacturing process is called the welding method and it can be separated to many types and categories depending on its application. Resistance Spot Welding (RSW) is commonly used method in the welding process due to the capability of the method to be used for high volume production to any types of pure metal and alloys such as aluminium, stainless steel and even titanium. Next, due to increase of demand in using titanium in many application such as high speed vehicles, aerospace and also medical makes the manufacturing process for the materials to be more efficient to comply with the request. However, titanium and/or titanium alloys are considered to be relatively expensive and also essentially more difficult to be fabricated by standard method compared to conventional metal and alloys. This lack of proper information and suitable method will result in wastage of the material and money. Hence, this research aims to determine the effects of welding parameters to the mechanical and physical properties during RSW of titanium alloys. The manipulated variable for this particular experiment would only focuses on the change of current the welding material. Then, result can be analysed and explained using the basic physical and mechanical test such as the Tensile Test method, Microstructure Test and also the Hardness (Vickers) test. By conducting this research, it can provide proper data and knowledge when handling material and also study the possibility for its future applications.

1. INTRODUCTION

1.1 Background

One of the most commonly used manufacturing process is the welding method. It can be defined as a method of joining materials under certain combination of conditions. Next, under the classification of welding category there is a method known as the Resistance Spot Welding (RSW). RSW works by generating the heat required for the welding from the resistance of the electric current passing through the materials or metal [1]. Mostly, RSW is used for a high volume or mass production industries due to its simplicity of handling the machine. Moreover, the material used consists of many metals such as the stainless steel, nickel and even titanium alloys.

Commonly, RSW uses metals that have high availability and also depends on the application for the material. So, it is very uncommon to use metals that have special properties such as titanium or titanium alloys. It was stated that titanium and titanium alloys considered as materials that possess an extraordinary combination of properties such as low density and possess a high melting point [2]. Titanium also considered to have high corrosion resistance that would usually applied in a corrosion resistant services [3]. The combination obtained from those material proposes many useful application in the industrial field such as in the medical or aerospace field. Recently, the demand on the use of titanium in equipment are quite common and have being increasing. So, the application of titanium alloys must not only limited to specific field and the usage must also not be restricted due to its value. It was stated that as the demand for more efficient and economical commercial material increases, the requirements for base material will also increase too. Welding of titanium structures can be a profitable manufacturing process and many other benefits can be obtained by applying proper knowledge of welding for titanium alloy structure.

By studying and determining the mechanical and physical properties of titanium for RSW techniques helps to produce the most desirable outputs for the material. Hence, an experiment was created in order to find a scientific based guidelines for Resistance Spot Welding of titanium alloys and also aid to evaluate the effects to the properties of the metal used [4].

1.2 Problem Statement

Inadequate numbers of research or information on the subject of Resistance Spot Welding (RSW) to titanium alloy contribute to the lack of its application in industries. It is revealed that RSW is a functional and well developed method capable of applying in various type of cases. However, without the proper method and proper data can leads to wasting the material and also causes major safety issues. So, an accurate observation or analysis through experiments must be conducted in order to discover the welding parameter that affects titanium alloy mechanical and physical properties.

Previously, various studies was executed regarding on RSW with metal such as stainless steel or low carbon steel, but for this experiment only focuses on the outcome of welding parameter to physical and mechanical properties of titanium alloys. When any titanium alloys are being used, extra precaution steps and study must be done due to its less availability, considered to be relatively expensive and also inherently more difficult to be fabricated by standard method compared to conventional metal alloys.

In order, to avoid any damages or wastage of material a simple experiment must be conducted. The experiment is done by changing the welding parameter and performing the suitable test helps to find out the optimum welding parameter for the desired output in its usage. In detail, this research emphases on what effects will occur to the physical and mechanical properties when the welding parameter were to be manipulated and how it can it be verified from the manipulated parameters.

1.3 Objectives and Scope of Studies

The experiment conducted for this project follows the correct standard stated in the ASTM standard. However, some of the sample used have also has been modified to fit the current situation due to the material used and the preparation method. So, it is important to standardize the material throughout the research experiment such as the thickness, length and wideness:

i. To find out the effects of welding parameter which focus on varying the current on the Resistance Spot Welding (RSW) using titanium alloy (Ti-6Al-4V);
ii. To observe the effect of altering the welding current on the physical and mechanical properties of titanium alloys through the process of Tensile Test, Hardness (Vickers) Test and the Metallography (Microstructure Analysis) Test.

The scope of this study will be emphases on the same dimensioning of the material so that the consistency of the result will be more accurate. Additionally, the reason for the selection of same thickness is due to the availability of the material with various thickness cannot be easily obtained. The scopes of study throughout this project are:

i. To identify and predict the effects that occurred to mechanical and physical properties of titanium alloy Ti-6Al-4V by manipulating welding current;
ii. To conduct the experiment using the titanium alloy Ti-6Al-4V with the thickness of 3 *mm* and also referring to the ASTM B265-08 Grade 5 for sample preparation;
iii. The welding parameters only focuses on the current used to weld but the factors such as the welding time and pressure are kept constant by using the DAIDEN Spot Welder SL-AJ 35-600 Machine;
iv. The mechanical and physical properties of the welded joint is studied using Universal Testing Machine (UTM), Hardness (Vickers) Test and Metallography (Microstructure Analysis) Test.

2. LITERATURE REVIEW/ THEORY

2.1 Resistance Spot Welding

Resistance Spot Welding (RSW) known as a process that joins material at a discrete spots using current as the heat supply. This promotes the method to be acknowledged as the most effective and easiest way in the manufacturing industries that generally uses metal sheets [5]. There are numerous type of sheet material can be used such as joining stainless steel, aluminium, nickel and even with titanium alloys. RSW can be categorized as an easy automation manufacturing process due to its flexibility and simplicity in mass or high volume production. However, this welding method has some issues caused from the inconsistency welding qualities caused from the RSW. In addition to that, other problems were suggested to be caused from many sources of unpredictability such as from the changing to automation system can reduces the quality of the welding standard. Therefore, it is necessary to identify and control the parameters affecting the quality of the weld.

2.1.1 Working Principle of RSW

RSW works when current are forced through the electrode tips and the workpieces or the metal to be joined which uses the resistance to heat up a point. The localized heating in the joint is formed when there are electrical current flow through it [6]. It can be proven and applied using the Ohm's Law. The conductor that causes flow of current will cause heat to be generated and it can be proven with the formula for heat generation: [6]

$$H = I^2 R \tag{1}$$

where H = Heat, I^2 = Current squared, R = Resistance

RSW machines are designed to bring the welding current to the weldment in the most by manipulating the resistance of the current. The scope for different resistance may be caused from:

- The distance between the electrodes and the workpiece.
- The type of material used.
- The interaction point between the workpieces.
- The resistance of the electrode tips.

The Time Factor

Next, the other important factor is time. It is important method to control the amount of current flow using time taken. Time is the only controllable variable in the RSW process method due to current are difficult to control during the process.

Previously, the formula for heat generation was used but in the addition of the time element, the formula is completed as follows:

$$H = I^2RTK \tag{2}$$

where H = Heat, I^2 = Current squared, R = Resistance, T = Time and K = Heat Lost

Pressure or Welding Force

Adequate pressures between the interaction point of the electrode tip and the workpiece should be considered. The pressure applied by the callipers and the electrode tips on the workpiece contribute to major impact on flow of current through the weld point [6].

RSW is a method that is applicable to any metal. The process of welding starts with the contact of the workpiece that will be joined using the heat caused from the heating localized point from the electrical resistance [6].

2.2 Titanium Alloys

Studies shown as the increase of demand for more efficient and economical marketable gadget or equipment, increases the requirements for better material to be implemented. Commonly, titanium alloys show a suitable substitution or a suitable material in the improvement of technologies [7]. However, the application of titanium alloys would be very expensive so it is used in special field such as the aerospace field. Titanium alloy has its own benefits, and it is a crucial objective to reveal of the characteristics and its properties of the alloys by matching certain alloys and processes to the appropriate application to make sure maximum usage. Equally important is the ability to develop a fabrication method that does not severely degrade material properties and implemented at reasonable cost [7]. Generally, it shows that the titanium alloys capable to be welded by the RSW technique [4]. Hence, the correlation between RSW parameters and titanium alloys can be studied for improving the efficiency when handling the materials.

2.3 Tensile test

Tensile test is labelled as an important standard procedure and capable of finding out information regarding to the mechanical properties of any materials [8]. It is usually used to determine the characteristics of the material under specified forces or tension and it is also generally focuses to find out the strength of the material [9]. The evaluation for the data for strength can be measured by how much load that the material can endure to experience plastic deformation or the maximum stress. The standard procedure also consider to use suitable precaution step such as the implementation of safety factors during the tensile test especially in the specified engineering design. The material's ductility is also considered whereas, function to know the limit of the material before it fractures. However, the ductility of material are not commonly incorporated in the engineering design because material specifications must be included priory so that quality and toughness of the design is ensured. It was stated, low ductility in this method is often can be relate with the material properties of low resistance [9]. Furthermore, elasticity of the material in tensile testing must be evaluated which can be obtained more accuracy by using any ultrasonic method [9].

2.3.1 Tensile Testing Machines

The tensile test typically uses a machines which consist of either electromechanical or hydraulic and the difference are the system application for the force to the specimen. Usually, universal testing machine will be used because the functionality of the machine to conduct in tension, compression, or bending test. Most significantly, Universal Testing Machine main task is to measure and tabulate a stress-strain curve for the material used. A tensile test works by mounting the material in the machine and subjecting it to tension depending to the required specification or application. Hence, the tensile force will be recorded and proportionally the increased with the increase of the gauge length.

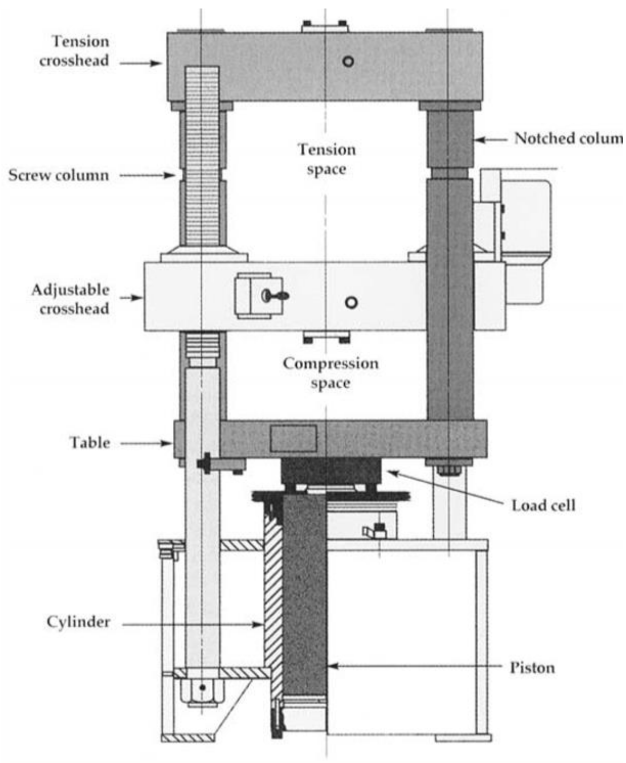
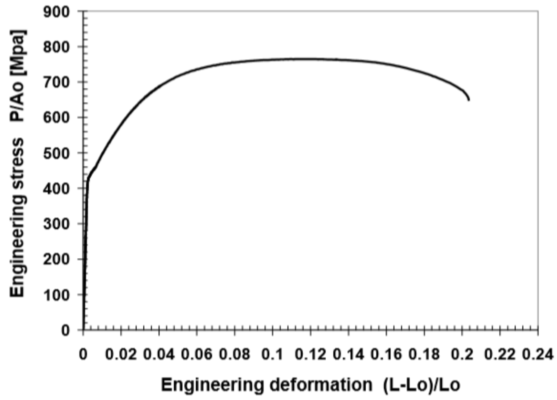


Figure 2.1 [9] Components of Universal Testing Machine



Graph 2.3.1 [5] Analysis for sample specimen: average experimental stress-strain curve for sheet samples.

Based from the graph, the beginning of the deformation for the material will still possesses its elasticity but when certain value has reached (yield strength), the plastic deformation will starts to occur. The load or pulling force will gradually increases up to a maximum point which the material will also elongates at specific length. Then, the load decreases since the effect of the reduction of the transversal area at the necking zone is stronger than that of the hardening mechanism [8]. This shows that the experimental data measured and collected will consists of the yield point, ultimate tensile strength, maximum engineering stress and elongation at the fracture stage for the material used for tensile testing method.

It was emphases by Davis [9] that engineering stress, *s*, can be determined by

$$s = F/A_0 \tag{3}$$

where F is the tensile force and A_0 is the initial cross-sectional area of the gauge section.

Then, engineering strain, or nominal strain, *e*, is defined as

$$e = \Delta L/L_0 \tag{4}$$

where L_0 is the initial gauge length and ΔL is the change in gauge length (L - L_0).

2.4 Metallography

Microstructure of a material and their properties shows as a crucial role in the understanding and development of any materials made of metals. The examination of the microstructure of any type of metals which also known as metallography is considered to be an important inspection method for detecting fabricating defects and also helps to discover the causes of any material failures [10]. Researches have shown that most inspection method for microstructure are conducted with an incident light microscopy which the shows the patterns of microstructural features for the specimen [11].

2.4.1 Optical Metallography

Optical metallography consist of many ways that can be used. To be more specific, it involves with the analysis of materials using visible light to provide a magnified image of the material's structure. Then, there is the Scanning Electron Microscopy (SEM) that works by bombarding the material surface with ray of electrons which will able to display an image. After that, is the Transmission Electron Microscopy (TEM) that work similar with SEM but consisting of passing electrons through a very thin material and processing the transmitted ray for the essential information [12]. Microscopy involves zooming the material 50 times higher while macroscopy is in the range of 50 times lower [12].

Optical microscopy and SEM are frequently used to distinguish the structure by showing grain boundaries, phase boundaries, inclusion distribution, and any possibilities of mechanical deformation of the material used. Furthermore, SEM is also used to characterize fracture surfaces, corroded specimen and other rough surfaces if small features of the material is required. Next, TEM is used to visualize the different arrangements or molecular structures of the materials. Usually, optical metallography will be used to find out the:

- Differences in yield strength and hardness of a materials with different grain size;
- Tendency for the ductility of the specimen with different inclusion content;
- Correlations of weld penetration, heat affected zone (HAZ) size, and weld defect density by the methods used for welding;
- Associations of fatigue crack growth rates and fracture point with material properties.

The reason metallographic characterization is commonly used is due to the connections between structure and the metals properties which are for materials selection, quality or process control, and failure analysis of the materials [12]. It was stated that optical metallography is suitable to any research studies including from new research up to evaluations of any production.

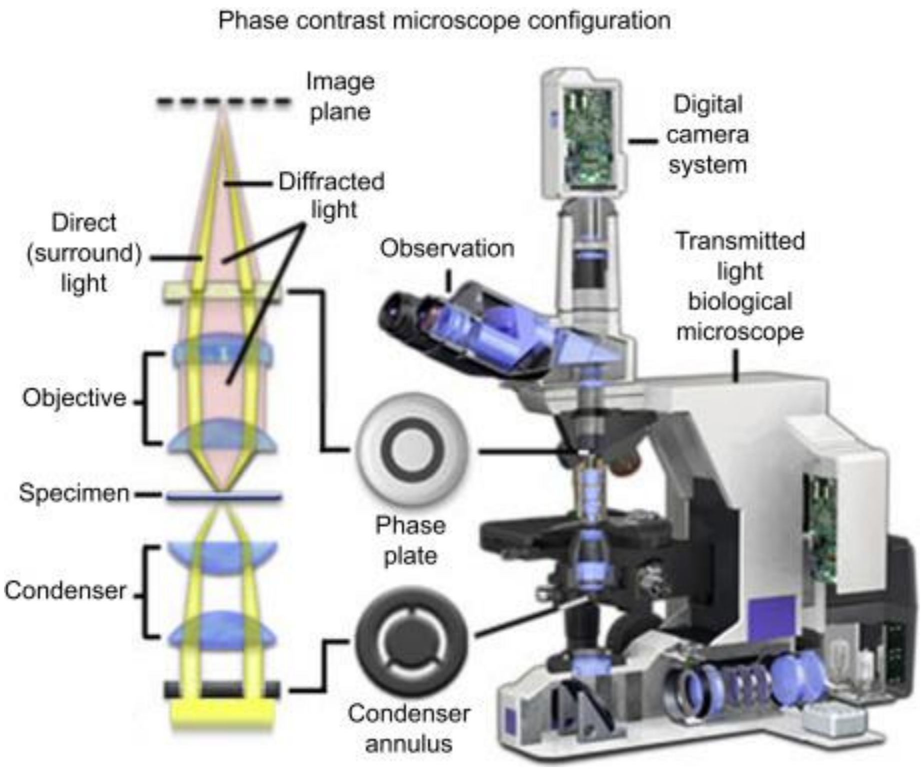


Figure 2.4.1

Figure 2.2 Illustration of an Optical Microscope

2.4.2 Preparation of Metallographic Specimens

Metallography contribute to one of the most useful method for the inspection of metals microstructure. The test operates by using a polished sections of metallic specimen using a specialized microscope that reflects light passing through the objective lens onto the specimen surface. The reflected light helps to discover and study the surface structure of the metals [13]. Preparation for metallographic test for macroscopic and microscopic analysis are not only limited to one procedure so there is no specific method for all the demands for this process preparation. The preparation for identification for microstructure needs specific operational steps which are to section, mount, identify, grind, polish, clean, and etch it. Referring to the material properties used, different may be used. However, wrong preparation steps can cause a distorted structure leading to incorrect results and information. In order, to differentiate a good microstructure image, specimen surface must be free from changes caused external factors such as surface deformation or scratches. So, the specimen surface must be preserved and protected using proper precautionary steps. The preparation of the specimen metallography require some patience even for simple analysis because poor preparation of the specimen is unacceptable in resulting a conclusion.

Sectioning

Sectioning is to produce a flat surface for the microscopic image analysis without causing critical damages to the material. As mentioned before, slight changes in the microstructure of any materials can caused by poor preparation. To avoid any major damages the usage of adequate amounts of lubricants or coolants should be used. The material must be at adequate size so that the final sample is to remain in its original condition. Although, the goal is to use such material-preserving methods for sectioning in the first place without the damaging the original workpiece, these methods are not economical due it slow-paced, time consuming method and only be useful for specified materials such as single crystalline structure metals, semi-conductors, or brittle materials. It was mentioned that the most flexible and normally used sectioning method is abrasive cutting [11]. The method is considered to be faster and universal due to the usage of thin, fast rotating, consumable abrasive wheel that will result in providing a high-quality, low-distortion cuts to the end-product. Additionally, wheel composition, coolant condition, and technique must be also considered. The selection of suitable abrasive wheels are the grain size and the wheel thickness for cutter. Different compositions of cutting wheels depends on the type of materials that needs to be cut. The selection of wheel is determined by hardness and ductility of the material used for the experiment. Cutting wheel machines are available with variable speeds, aided with or without a feeding device, and even with guided sample holders [11].

Mounting

Mounting is required when preparing the analysis materials. In most cases, mounting follows sectioning however, if many amount of very small specimens, it may be faster and more efficient to reverse start with sectioning first [11]. The shape, size, and numbers as well as the hardness, brittleness, porosity, and heat and pressure sensitivity of the specimens have to be considered when mounting. Some cases, the mounting medium must be electrically conductive so that electrolytic polishing SEM examination and even the microprobe analysis can be executed [11].

Etching

This process is named as “chemical etching” or “etching” where it is uses to show microstructural features because a microscopic examination specimen of a properly polished that does no undergo step will be seen properly. Sometimes, only the non-metallic inclusions, porosities and cracks may be easily seen from the surface. An un-etched with polished specimens will only capable of reflecting the same lighting so the contrast for the sample surface will not show properly. Thus, the crystalline structure which is the grains and grain boundaries can be shown by undergoing etching [11]. Etchants commonly used are diluted acid or diluted alkalis with water or alcohol. The etching process is usually accomplished by merely applying the appropriate solution to the specimen surface for several seconds to several minutes. Then, the specimen sample is washed under running water then, with an alcohol and will be dried in an air blast machine [11].

The most common way of conducting the metallographic analysis:

1. Bright Field (BF) illumination

It is the commonly used illumination method for metallographic analysis. The light path for BF illumination comes from the source, through the objective lens, reflected off the surface, returning through the objective, and back the eyepiece. It shows the non-flat surfaces appearing to be darker compared to the flat surfaces which produce the bright background [14].

2. Dark Field (DF) illumination

The light path for the DF illumination is caused from the source located down the outside of the objective, reflected off the surface, returning through the objective, and back to the eyepiece. Its illumination is the opposite of the BF illumination method [14].

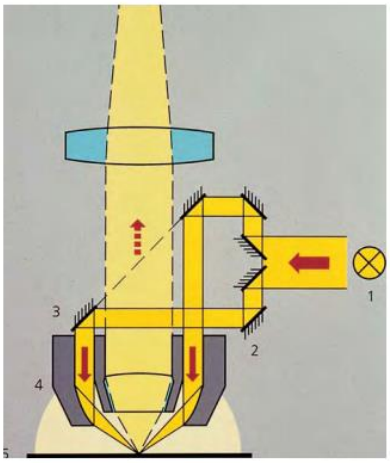


Figure 2.3 [15] Dark field DF illumination in reflected light, with light source (1), mirror step assembly (2), mirror with an oval hole (3), light, directed in a second housing case towards the objective (4), sample surface (5).

3. Differential Interference Contrast (DIC)

A type of microscopic analysis can also be called as Nomarski Contrast and it helps to visualize small changes in height on the surface of the observed specimen [14].

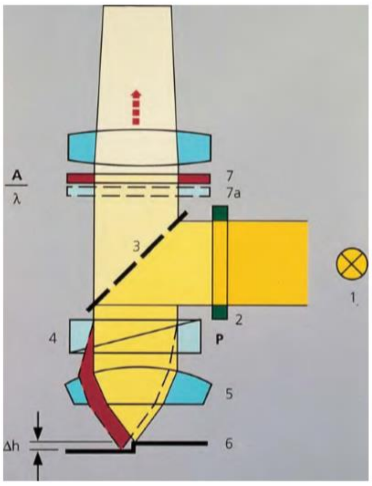


Figure 2.4 [15] Differential interference contrast DIC in reflected light, with doubly refracting prism (4), objective (5), specimen (6) and analyser (7)

2.5 Hardness (Vickers)

The hardness of a material usually is stated as the resistance to permanent indentation. The hardness test is commonly used in determining the properties of metals and other materials [16]. The use of diamond allowed the Vickers test to be used to evaluate any metals. It works by using an indenter that is pressed into the surface of the metal under a specific load for a definite time interval, and the evaluation is calculated based from size or depth of the indentation. In the Vickers test, the load is applied smoothly, without impact, forcing the indenter into the test piece which is held in place for few seconds. The main aim of the hardness test is to determine the suitability of a material for a given application to any certain field or cases [17]. The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys. To simplify a micro-indentation hardness testing is generally performed to quantify variations in hardness that occur over small distances which are determined with small indentation to the workpiece [15].

The Vickers hardness (HV) is calculated using:

$$\mathrm{HV} = \frac{1854.4L}{d^2} \tag{5}$$

Load, L calculated gram/force and d is the average diagonal in unit of μm.

3. METHODOLOGY

3.1 Process Flow Chart

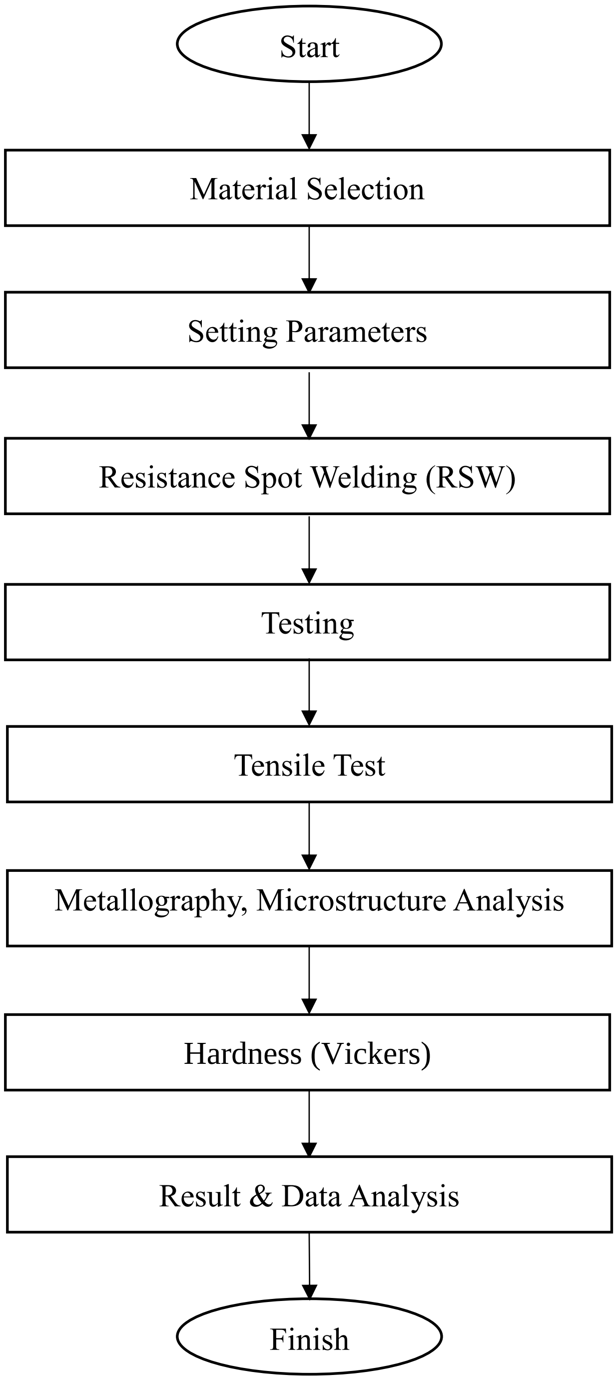


Figure 3.1 Process Flow Chart

Developing the Sample Process and Conducting Analysis

Sample Preparation

- To determine the standard size of specimen for spot welding and for the tensile testing from the ASTM standard.

Welding Machine Preparation

- The welding machine is calibrated and adjusted the suitable electrode for the experiment's subject.

Welding Process

- The specimens are welded based form the standardized manual.

Hardness (Vickers) Test, Tensile Test and Metallography (Microstructure Inspection)

- The method was conducted to find out the mechanical and physical properties of the specimen
- Finding out the ability of the specimen to resist plastic deformation.
- To analyse the grain and grain boundaries structure of the material used

3.2 Equipment and Apparatus Required

The DAIDEN Spot Welder SL-AJ 35-600 Machine is used to perform the welding operation with the usage of specific welding parameters. This machine can operational up to 91 *kVA* for maximum welding input and maximum current up to 16 600 *A*. The experiment was carried out using RSW machines. The machine used for the research was equipped with the pneumatic pressure system. The machine employed pure copper electrodes with 5 *mm* end diameter. Additionally, the shows the resistance spot welding machines and its accessories.

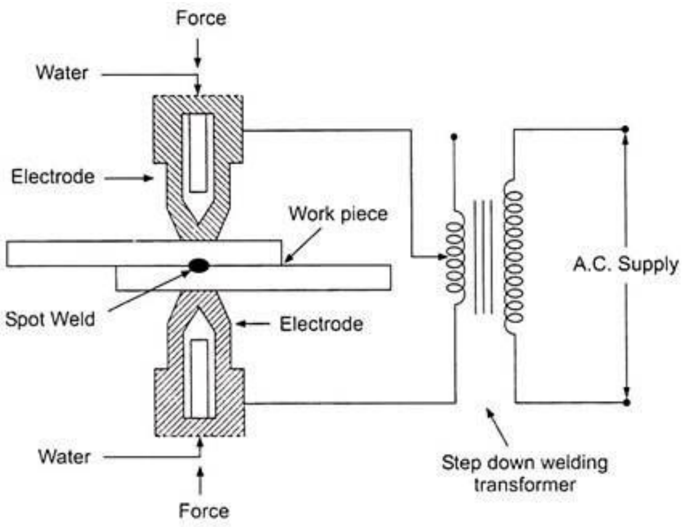


Figure 3.2 Principle of Resistance Spot Welding (RSW)

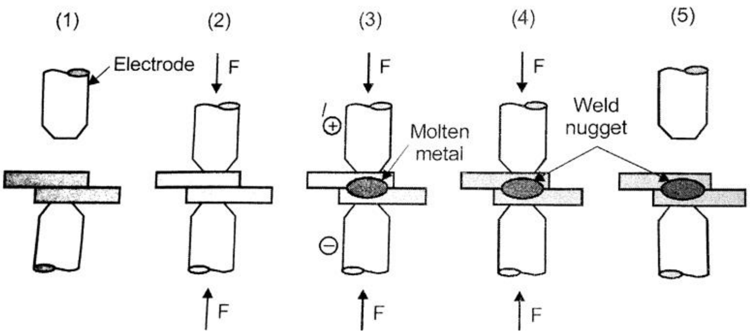


Figure 3.3 Process for RSW

3.2.1 Selecting the Material

Titanium or Titanium alloys are not commonly used for normal application because it is also reported to be relatively expensive. Selection of the material that will undergo the examination will follow the guideline stated in the ASTM standards [18]. In this study, specimen made of titanium or titanium alloys that follows the proper standard based from the ASTM Guideline for metal sheets were used as the base material.

3.2.2 Tensile Strength Experiment

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before necking which is when the specimen to undergo fracture point. So, the tensile test was to measure the spot welding joint.

The specimen selected undergoes the tensile test according to the current used during the RSW. The machine used for the tensile strength is Universal Testing Machine and the parameters used for the tensile strength was maintained around 50*kN*. The limitation for stretching the specimen for the machine will be approximately 100*mm* within the room temperature condition.

The tests were performed based from the ASTM E8-00b standard and the feed rate used during the elongation process is 0.001 *mm/sec*. However, to obtain the result faster or reduce the time taken for fracture, the speed of the test has been altered depending to the situation. Next, the exact values of tensile strength for the specimens are not known so the clamping force used must be sufficient enough without damaging it. Specifically, the specimen used must be suitable for the machine especially the dimension and the shape that was specified [19].

The simulation of the deformation process during the whole test is performed with a proper observation for the tabulation of data formulation. Finally, the experimental validation of the obtained numerical results help the performance of the in getting the result and discussion part. Mechanical tensile test and the engineering stress–strain curves acquired can also help to show the mechanical behaviour of a material. Based from, the force-elongation data an engineering stress and strain can be tabulated.

3.2.3 Optical Metallography

The optical microscope is a type of microscope which uses visible light and magnification system to visualize an image of the microstructure of titanium alloy. Specifically, images form from the microscope are then be captured and helps to generate a micrograph which will then be analysed and studied. The process is conducted after the RSW and the Tensile Test so that the microstructure of Welding Spot Zone and Thermo-Mechanical Affected Zone of the metal can be seen. Before that, a few preparations need to be done to the workpiece. It consists of several processes to obtain the microstructure of the material [15].

Sectioning

Sectioning is the removal of a conveniently sized and representative specimen from a larger piece using an abrasive cutter machine. The specified areas that will be examined would be the welded part.

Mounting

After, sectioning the specimen, it undergo the mounting process. The purpose for the mounting is to help when handling the material for the polishing. The mounting used with the sample is the Black Epoxy Thermosetting Powder and will be mounted using The Auto Mounting Press Machine.

Grinding

Then, to reveal the surface of the metal it will undergo grinding process using abrasive paper made of Silicon Carbide. The purpose is to make it plane surface and removes extra layer of the material. It helps to provide a clearer image for the metallography procedure.

Etching

This step is to reveal the microstructure of the metal using chemical made of a mixture from an acid and alcohol. In creates contrast between different regions through differences in topography or the reflectivity of the different phases such as the grains and grain boundaries. This cause due to different energy level of the grains and the grain boundaries. The contrast from etching helps to distinguish the physical properties of the specimen used. The specimen is etched using a reagent.

Below shows the general for etching process:

1. After polished, the mounted specimen is placed under the Fume Hood and the machine is switch on.
2. Then the surface of the material is washed using an alcohol and the dried using a drier machine. (The material surface should only be coated with the alcohol and does not touch with other material).
3. Next, few drops of etchant is applied again to the surface which covers the entire metallic surface of the specimen in order to increase the contrast of the metal surface.
4. After few seconds, the etchant is rinsed again but with water first and then using an alcohol.
5. The specimen are placed again in the drier machine.
6. Then, it undergoes the microscopic inspection using specified microscope.
7. Depending to the contrast for image analysis step 1 until 6 needs to be repeated until clear image can be seen.

8. If any damages occurred to the surface or the microstructure cannot be seen, grinding process must be repeated.

3.2.4 Hardness Vickers Test

Hardness test is practical inspection method and the result can be used as a good indicator for material selections. The method aids to determine the mechanical properties of the material. Hardness values of metals ranges around 48 in the *Mohrs* scale, which is not suitable in differentiating the material hardness properties. Therefore, indentation hardness measurement that uses Vickers indenter is conveniently used for metallic materials. A larger indentation shows that the material has low yield strength, resulting in a lower hardness value. The standard test methods used was followed using the ASTM E92-41 [20].

On each specimen, several hardness measurements have to be executed which help to obtain the average value. This test only involves with two axis which is x and y axis. So, the measurements were made in two directions which are at the one located to the radius of the nugget and along the sheet thickness area.

The Vickers hardness test method consists of indenting the test material with a diamond shaped indenter. The angle for the indenter is 136 degrees between opposite faces using the load around 1*gf* and 100*kgf* with a time interval of 10 to 15 *s*. The indentation caused from the load are measured using a microscope which will then calculate the average value. The area of the sloping surfaces of the indentation is also calculated and both of acquired value will be used for the hardness Vickers equation.

3.3 Gantt Chart and Milestones

Table 3.1 Gantt chart for the Project

Semester	**September 2019**														**January 2020**													
Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Phase 1																												
Understanding Project Title	Δ	Δ																										
Literature Review			Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ																		
Planning the Experiment				Δ	Δ	Δ																						
Phase 2																												
Site Visit						Δ	Δ	Δ																				
Submission of Interim Report I												Δ																
Phase 3																												
Conducting the Experiment															Δ	Δ	Δ	Δ	Δ	Δ								
Collection of Data																					Δ	Δ	Δ	Δ				
Performance Analysis of Data																					Δ	Δ	Δ	Δ				
Phase 4																												
Oral Presentation																									Δ	Δ		
Submission of Dissertation																											Δ	Δ

Legends	Colour
Plan	
Milestone	Δ

4. RESULT AND DISCUSSION

4.1 Preliminary Result

Before, executing the actual test that was planned in chapter 3 several samples was prepared to make sure that the experiment results were more accurate and dependable. The testing involved was only the resistance spot welding. The experiment conducted was to use the same materials with constant parameters excluding the weld current flow while still follows the dimensions according to the ASTM D1002 Standard.

4.1.1 Founding of Preliminary Results

Resistance Spot Welding

By using the DAIDEN Spot Welder SL-AJ 35-600 Machine there were few options that must be kept at the same parameters on the Ti-6Al-4V plates such as:

i. The weld time = 29 cycles
ii. The clamping force = 4kN
iii. The squeeze time = 35 cycles
iv. The hold time = 15 cycles
v. The off time = 0 cycles

The current was the only variable that was manipulated and the value were only limited to 8 *kA*, 9 *kA* and 10 *kA*. Moreover, when the current used were to be higher may result some weld metal expulsion and also increase the depth of indentation from the welding. It was mentioned that increasing the current flow is directly proportional to the weld nugget width, W and it is inversely proportional to the weld nugget height, H resulting to higher heat generation on the material used [21]. So, it shows that flowing more current can cause may cause harm to the result and also to the user of the machine.

4.2 Expected Result

4.2.1 Resistance Spot Welding Area

Based, from the condition used in preliminary specimen it shows that the resistance spot welding process shows some dependable specimens for them to be used for the actual testing in the tensile strength, Hardness (Vickers) and microstructure test. It proves that the size of the weld nugget increases, when the welding current is increased within to a certain limit. Similarly, if higher current is to be used would only produce unreliable specimen and data which may be caused from the damaged electrode surface and also increase the vulnerability to the weld metal expulsion of the Titanium alloy. Importantly, the observation in spot weld area of Ti-6Al-4V used shows that the nugget diameter can act as an indicator to show the joint quality and also secure the reliability of the material prepared to be used for the testing mentioned. Additionally, the Ti-6Al-4V plates are prepared according to the ASTM D1002 standards with the lap joint was used as the study point. After that, the weld spot known as the weld nugget or Fusion Zone (FZ) is measured to determine the diameter.

Figure 4.1 Top view of weld nugget for Ti-6Al-4V sample

Figure 4.2 Side view of weld nugget for Ti-6Al-4V sample

4.2.2 Tensile-shear strength

The tensile test are conducted using the UTM machine with the speed of 3 mm/minutes and required to use specimen that follows the standard [23]. However, there were some issue that the specimen were not compatible to the UTM machine so, an additional modification were done to the Titanium plates which is to use spacer near the gripper area of the machine. Furthermore, the standard ASTM D1002 stated that the direction of pulling force must be coincided through the centre line of the grip assembly [22]. So, it means that it is very important to make sure that the pulling force applied were to be in exactly the same direction as the centre line before conducting the test because slipping might happened during the test. Hence, a spacers were to be welded at the end of the specimen avoiding the slipping problem.

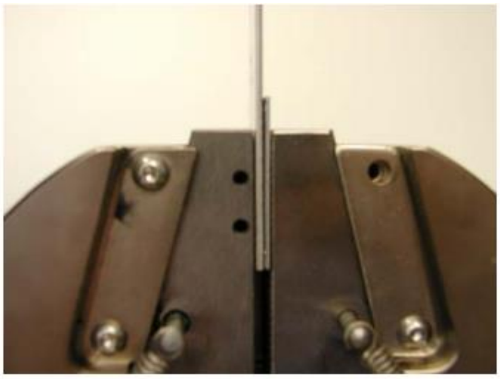


Figure 4.3 Spacer used to align the specimen with the machine during the tensile test

The resistance spot welding in this experiment constrict the time factors and clamping force while only focusing to the current used for the weld. Furthermore, the time used is considered to be suitable for the test due to the restricting of excess heat generation at the weld nugget. It was stated that both the tensile and shear strengths can be improved simultaneously when increasing one of those three parameters such as weld current, time and force. The increase of welding current, force and time will increase the tensile and shear strength [23]. Hence, it can be stated that the expected result obtained from the experiment shows an increased in the Ultimate Tensile Strength (UTS) if the welding current are also increased. More importantly, during the preliminary specimen tensile test shows that the value obtained would be around $50kN$ within the limitation of the UTM machine. Moreover, the expected broken area should be along the HAZ and the base metal until the side of specimen. So it shows that the weld joint is strong and capable to be taken as a valid result.

Table 4.1 Number of samples prepared and each sample's diameters

Sample	Weld Current (*A*)	Average Diameter of Weld Nugget (*cm*)
1	8	0.68
2	8	0.72
3	9	0.72
4	9	0.70
5	10	0.72
6	10	0.72

4.2.3 Microstructures

Based, from the observation from the naked eye the boundary or the limits of the welding nugget, Heat Affected Zone (HAZ) and Base Metal (BM) can be obviously seen. However, to analysis the pattern a micrographic method was conducted. The result from this test shows that the BM and HAZ were much finer compared to the weld nugget area in terms of grain structure due to heat generated from the flow of current through the Titanium plates. Specifically, any titanium alloys would be consisting two main crystal structure which are Hexagonal Closed Packed (HCP), α phase and also the Body Centred Cubic (BCC), β phase. Hence, the phenomenon caused by the RSW process does slightly change and produce different grain structure to the Titanium used [24].

By increasing the welding current, heat generated will be higher which causes α phase and β phase disrupt and change their original structure. Additionally, this would also be related to the rate of cooling of medium and its temperature used which in this case is the air. The focused aspect for this this test would be at the weld nugget or fusion zone. So, the expected microstructures at the area be lamellar α+β and α grain structure. The justification can be found from the weld process that form heat passing through the Ti-6Al-4V alloy plates so the weld nugget would have higher temperature compared to the HAZ area that had expose area (cooling process).

4.2.4 Hardness Vickers Test

A Vickers indenter is pressed into the surface of Ti-6Al-4V weld nugget area under the force of 1000 gf and from the micro-indentation an evaluation of the hardness for the Titanium alloy can be determined [20]. The size of the indentation is measured using a light microscope which quantify the Vickers Hardness Numbers (VHN). According, to a study it was shown that the Vickers hardness for a normal Ti-6Al-4V alloy plates would be around (340.51 VHN) [25]. Based, from that value it assist to set a benchmark to justify whether RSW method improves the hardness for Ti-6Al-4V alloy plates used for this experiment. It was found that the effects heat caused from the resistance spot weld affect the titanium alloys and shows to have higher hardness values compared to the standard normal Ti-6Al-4V alloy plates [25].

Alternatively, several variables or factors would show different kind of result or the mechanical behaviour due to major factors such as α, α+ β and β phases occurred during the weld or the cooling rate or method used for the formation of the joint itself [25]. However, the factors would not be considered for this particular experiment due to the fact that any time related factors were kept constant. Next, the region that does experienced increased in VHN value would only covers from the HAZ to the weld nugget. This proofs that the hardness were only improved at the weld nugget until the end of the weld nugget area that was created during the RSW. The HV for the fusion zone shows the highest and the lowest would be at the BM. Hence, by increasing the current does helps to increase the HV for the Titanium alloy.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the main reason for conducting this research was to obtain new information regarding the effect of varying the current to its mechanical and physical properties during resistance welding of titanium alloys. As mention earlier it is to obtain the suitable parameters during Resistance Spot Welding because it helps to maximize the usage or getting the desired output from the titanium alloy while also preventing wastage. The method identifying the result are shown using the method of Tensile (Pulling) Test, Hardness (Vickers) Test and also the Metallography (Microstructure) Test.

From, the finding it also aids to learn more about the properties of titanium alloys because it can be applied in many application other than the aerospace and medical field. Additionally, Resistance Spot Welding is the most popular and an important process that is implemented in automotive industries. RSW can also be completely automated, and many of the industrial robots found on assembly lines are spot welders. The studies shown in the expected result show that every test that were performed does help to increase the UTS and the HV for Ti-6Al-4V alloy. Furthermore, that result can be further research to make sure the knowledge can be expand and be applied to the world. So, more study and research should be done so that the method can be optimized for the application of the method and also the material used.

5.2 Recommendations

1) Several samples which required more investment for each process with different parameter should be prepared to avoid any unpredictable events, such as scratches on the specimen.
2) Further research need to be done to test the microstructure of the sample since the etching technique is not standard and the sample size are quite small.
3) Several plunge test are recommended to get a suitable welding key parameter that can produce a high strength and good quality of spot weld joints. A good result of spot weld joint is needed to obtain a good microstructure samples.
4) The weld sample is made from thicker materials, such as with thickness of 5 mm to 10 mm to make the analysis process much easier and precise.
5) When doing the RSW make sure to clean the electrodes surface after using it. The cleaning can be done using the sand paper which helps with obtaining an accurate result due to the efficiency of the welded joint formation can be reduced throughout the welding process.

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