ABSTRACT

This final report or dissertation of Final Year Project outlines the background of the project "Investigation on the Effects of Welding Parameter on Resistance Spot Welding of Stainless Steel and Mild Steel Sheet". The resistance spot weld of metals such as mild steel generally more challenging than that of another metals due to difference in the physical, chemical and mechanical properties of the base metals. This Final Year Project aims to investigate the effect of weld current, weld time, and electrode force/pressure on resistance spot welding of stainless steel and mild steel sheet. Spot welding is the most economical way to join two pieces of sheet metal. While joining sheet metal is the most common use for the process, resistance welding (RW) equipment actually can be used for a large variety of joining and heat-treating projects, some of which are not so well-known. The research methodology on this project has been studied and identified. The experimental process that had been done throughout this semester is tensile test, microstructure inspection, and micro hardness test.

CERTIFICATION OF APPROVAL

Investigation of Welding Parameter on Resistance Spot Welding of Stainless Steel and Mild Steel Sheet

By

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

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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.

Muhibbullah bin Haji Salleh

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CHAPTER 1: INTRODUCTION

1.1: Project Background

Resistance spot welding that is one of the oldest electric welding processes in use by industry today is joining technique which is used for almost all known metals. Resistance spot welding is usually used in the fabrication of sheet metal assembly. It can be used to weld materials such as low carbon steel, nickel, aluminum, titanium, copper alloy, stainless steel and high strength low alloy steel. The weld is made by a combination of heat, pressure and time [1]. The electrical resistance of the material to be welded causes a localized heating at the interface of the metals to be joined. Because of the processes requires relatively simple equipment; it is easily and normally automated and once the welding parameters established it should be possible to produce repeatable welds. Dissimilar metal welds are common in welded construction, and their performance is often crucial to the function of the whole structure. Dissimilar metal welding involves the joining of two or more different metals or alloys. There are several types of dissimilar metal welds, and the most common type is the joining of stainless steel to non stainless steel. In the case of arc welding, filler metal is typically used, but in the case of resistance spot welding, the use of filler metal is very rare.

1.2: Problem Statement

Not much research had been done on study of resistance spot welding on stainless steel and mild steel in Universiti Teknologi Petronas before. As the process is well developed and being applied in various cases, an observation and analysis by experiment is needed to study extensively how the welding parameter will be affected by welding the dissimilar metals. There has been a recent series of research done on RSW on the process parameter, but for this project, we will use the different materials and determine the optimum welding parameter.

Previously, the resistance spot weld of dissimilar metals is generally more challenging than that of similar metals due to difference in the physical, chemical and mechanical properties of the base metals.

However, by varying the welding parameter, we can perform the laboratory test to determine the optimum welding parameter for stainless steel and mild steel for producing maximum joint strength.

1.3: Objective & Scope of Study

The scope of this study will be focusing on the thickness of the materials around 0.5 mm and 1.0 mm because the unavailability of the material at different thickness at market. So, the thickness of the materials chosen for this final year project is 0.5mm and 1.0mm. Below are the objectives of this study;

i. To investigate the effect of welding parameter on RSW of stainless steel and mild steel sheet.
ii. To study the effect of welding parameter on tensile testing, hardness distribution, nugget formation, and heat affected zone (HAZ) in stainless steel and mild steel

1.4: The Feasibility of the Project

Abide by the suggested milestone, the project scope has been narrowed down to make it feasible and accomplished within 14 weeks. The cost for this project is affordable as the author have to purchase only stainless steel sheet and mild steel sheet. All the equipment and consumable that will be used for this experiment will be discussed later in the methodology chapter.

1.5: The Relevancy of Project

Spot Welding is the most used technique in fabrication of the sheet metal, especially in automotive industry. It can be used to weld materials such as low carbon steel, nickel, aluminum, titanium, copper alloy, stainless steel and high strength low alloy steel. Quality of resistance spot weld is one of the major concerns for both automobile and aerospace industry. The austenitic stainless steels are used for a very broad range of applications when an excellent combination of strength and corrosion resistance in aqueous solutions at ambient temperature is required[2]. Current design trends in automotive manufacture have shifted emphasis to lightweight materials in order to produce vehicles with higher fuel efficiency and lower the vehicle emission level. This project is very relevant with today's technologies and automotive industry as this study will discover the behaviour of spot welding on different type of metal sheet. This study will bring contribution in knowledge and technology beneficial to the many party.

CHAPTER 2: LITERATURE REVIEW

2.1: Introduction to Resistance Spot Welding

Resistance welding is a highly efficient production method that is particularly well-suited for automated production lines and mass production. Resistance welding is also suitable for small batch production, because the method is flexible, equipment simple and the welding process is easy to control. In addition, an important advantage of the method is that it can be used for joining a great number of metallic materials. Resistance welding is also suitable for the welding of the most common metal coated steel sheets.

The most commonly used welding method is resistance spot welding, where work pieces are joined by means of a lap joint. The maximum thickness of work pieces when producing lap joints by means of resistance welding is approximately 6 mm for uncoated steels and 4 mm for coated steels. Lap joints can also be made using projection welding and seam welding.

Sheets can also be joint using butt joints by means of flash welding or resistance butt welding. These welding methods are often used for the making of butt joints between tubes, profiles or thicker sheets. Profiles and, for example, fixing bolts can also be welded to level surfaces by means of stud welding. Resistance welding can also be used for welding nuts and other fixing tools on the work piece surface.

2.2: Resistance Welding in Steel Sheet Lap Joints

Resistance welding methods are inexpensive and efficient, which has made them highly popular in the making of sheet joints. The major appliers of the method are the automotive industry and household appliance manufacturers. Resistance welding methods can best be exploited in automated production with high production quantities.

The greatest total thickness of work pieces in spot, roller seam and projection welding is 6 mm. When joining work pieces of different thicknesses, the welding current is chosen according to the thinnest sheet. Lap joints can also be made by joining several sheets at the same time. In this case, the welding current is also selected on the basis of the thinnest component. When joining work pieces with different thicknesses by means of roller seam or spot resistance welding, the proportionate thickness of the components must not exceed 3:1. Such limitation is not applicable in projection welding.

Resistance welding is a very useful way of joining galvanized steel sheets. When making lap joints, the zinc layer melts before the parent metal in the joint and is directed away from the weld. Therefore, the actual weld consists of the parent metal and the zinc coating remains intact in the electrode contact point and at the edges of the weld between the contact surfaces.

Thanks to its low costs and high efficiency, resistance welding is superior to other welding methods when making metal sheet lap joints. The equipment and its use are inexpensive. The lap joining methods that can, to some extent, compete with resistance welding are mechanical joining and gluing. Compared to resistance welding, an advantage of some mechanical jointing methods is that they can be re open without breaking the actual product.

The use of lap joints must be taken into account when designing the end product. The making of lap joints requires sufficient overlapping of work pieces. The degree of overlapping depends on the welding method used and thickness of the work piece. Also, the space needed for welding electrodes and electrode adaptors must be taken into consideration in case of box sections and complex work pieces.

2.3 Adjustable Resistance Spot Welding Parameters

The most important adjustable resistance welding parameters are welding current, weld time, electrode pressing force and electrode geometry, and the choice of electrode materials. The other adjustable parameters include the duration of squeeze and hold time, possible heat treatments before or after welding, adjustment of the up- and downslope of the welding current (slope function), changes in electrode force and timing on the basis of work stage, and pulsation of welding current.

2.3.1. Welding Current and Welding Time

The amount of heat generated in the weld mainly depends on welding current. A slight increase in welding current rapidly increases the diameter of the weld, root penetration and therefore also the strength of the weld. In most resistance welding machines, welding current is adjusted as a percentage of the nominal power of the machine, although in some equipment adjustment is made by changing the transformation ratio of the welding transformer.

The size of the weld increases more slowly when adjusting the weld time (current time) than when adjusting the actual welding current. Weld time is adjusted in cycles. The duration of one cycle is 0.02 seconds in the 50 Hz power frequency (in the USA 60 Hz).

The amount of energy input in the weld depends on the welding current used and weld time. Short cycle times are usually preferred in resistance welding, which means higher welding current and as short a weld time as possible. In this case, less heat is conducted to the areas immediately surrounding the weld and therefore thermal expansion remains at a lower level, in addition to which the weld also solidifies and cools down faster.

When using too low a welding current, the work piece and electrodes conduct all heat away from the connecting surface and no weld pool is created. Due to the high conductivity of aluminium and copper, they have significantly higher minimum welding current values than steel.

Increase in weld time increases the wear of the electrodes and indentation on the work piece. In addition, heat will have more time to conduct to a wider area around the weld. This results in a longer cooling time, which may be useful when welding materials with a tendency to be brittle or harden. Longer cooling time must, however, be taken into consideration in terms of a sufficiently long hold time.

2.3.2: Electrodes and Electrode Forces

Electrodes convey the force and welding current to the desired location. Electrodes also cool down the weld during the entire welding process. Electrode force affects the contact between electrode tips and the work piece. Too little force does not create the required contact between work pieces and between the electrodes and the work piece. In this case, sparking, splashing and rapid wear of electrodes may occur.

Sufficient electrode force keeps the weld pool inside the joint so that it cannot protrude or splash outside the area supported by contact surfaces. When welding using the correct electrode force, contact resistance in the interfaces remains at such a low level that no melting occurs in the interface and the electrodes can cool down the weld properly. In this case, the weld has good heat balance: most of the heat generated by welding energy is created at the faying surfaces of the work pieces where the weld is intended to be.

Too high electrode force presses the electrodes too much on the work piece surface, which causes indentation. Large indentation lowers the strength of the weld. Some welding machine models allow the adjustment of electrode force during the welding process, which allows to better control the problems caused by high contact resistance or good conductivity.

The geometry and diameter of welding electrodes have a great impact on the welding process and weld properties in spot and seam welding. The proportion between the diameter of the electrodes and the work piece thickness must be correct. In spot and seam welding, the electrode tip diameter is usually $5\sqrt{t}$, where t is work piece thickness. The geometry and diameter of electrodes affect the focalization of the force and current density in the weld interface and therefore, to an extent, also the location of the weldability area. Problems in the positioning of the work piece or aiming of the electrodes can be compensated by using convex electrodes. The material of the electrodes has, up to a point, impact on the cooling ability and heat balance of the weld interface.

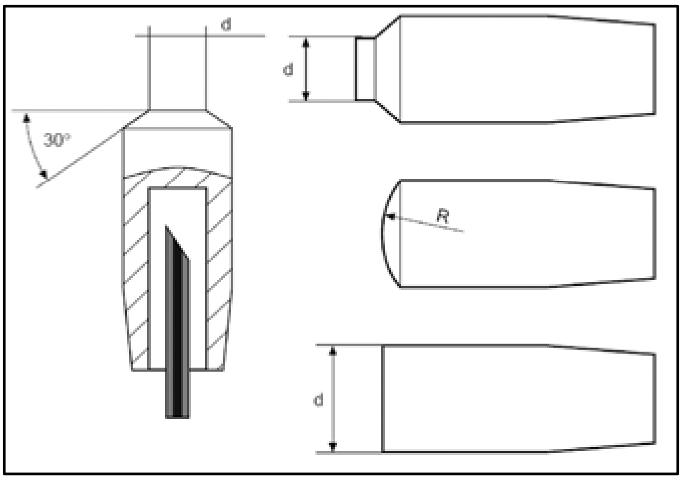


Figure 2.1: Different electrode types

2.3.4: Squeeze and Hold Time

The pre-welding squeeze time does not affect the technical properties of the weld. However, it must be long enough to allow the electrode pressing force to reach the adjusted level before welding current is switched on. Too short a squeeze period may lead to molten metal expulsions from the weld or expulsions between the electrode and work piece surface. The post-welding hold time must be long enough for the molten metal to solidify and achieve sufficient strength to bear loads directed at the weld. Therefore, increased thickness of the work piece and longer weld time require longer hold time. Common value for hold time in can spot welding is 10–50 cycles. A very short hold time be used for materials susceptible to becoming brittle in order to quickly eliminate the cooling effect of electrodes from the weld (10–20 cycles). The hold time of galvanized sheets is adjusted to be as short as possible to minimize wear of the electrodes.

2.4: Principle of Resistance Spot Welding [3]

Resistance welding is accomplished when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The resistance of the base metal to electrical current flow causes localized heating in the joint, and the weld is made.

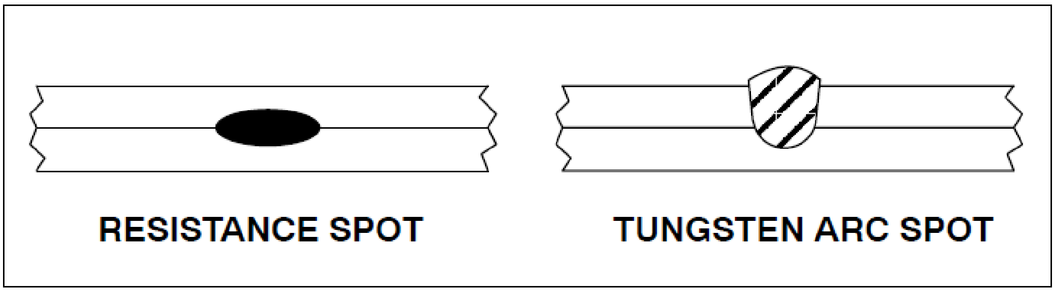


Figure 2.2: Resistance Spot Weld and TIG Weld Comparison

The gas tungsten-arc spot is made from one side only. The resistance spot weld is normally made with electrodes on each side of the work piece. Resistance spot welds may be made with the work piece in any position. The resistance spot weld nugget is formed when the interface of the weld joint is heated due to the resistance of the joint surfaces to electrical current flow. In all cases, of course, the current must flow or

the weld cannot be made. The pressure of the electrode tips on the work piece holds the part in close and intimate contact during the making of the weld.

A modification of Ohm's Law may be made when watts and heat are considered synonymous. When current is passed through a conductor the electrical

resistance of the conductor to current flow will cause heat to be generated. The basic formula for heat generation may be stated:

$H = I^2R$ where H = Heat

I^2 = Welding Current Squared

R = Resistance

Figure 2.3 : Heat Generation in Resistance Welding

The amount of heat (energy) delivered to the spot is determined by the resistance between the electrodes and the amperage and duration of the current[4].The secondary portion of a resistance spot welding circuit, including the parts to be welded, is actually a series of resistances. The total additive value of this electrical resistance affects the current output of the resistance spot welding machine and the heat generation of the circuit. The key fact is, although current value is the same in all parts of the electrical circuit, the resistance values may vary considerably at different points in the circuit. The heat generated is directly proportional to the resistance at any point in the circuit.

2.5 Stages of Resistance Spot Welding [5]

The stages of resistance spot welding resistance welding are as follows: electrodes press the welded work pieces together; electrode force decreases the transfer resistance of work pieces between the electrodes, which allows directing welding current through the work pieces through the desired route. Welding current is connected after the termination of the squeeze time. Welding current produces heat at the faying surfaces and thus creates a weld pool between the work pieces. Welding current is switched off as the weld time ends. Electrode force still presses the work pieces together and electrodes cool the weld down. The weld pool must solidify and the weld must achieve sufficient strength properties during the post-weld hold time. After the end of the hold time, electrodes are retracted from the work piece and the total weld time required for the production of one spot weld ends.

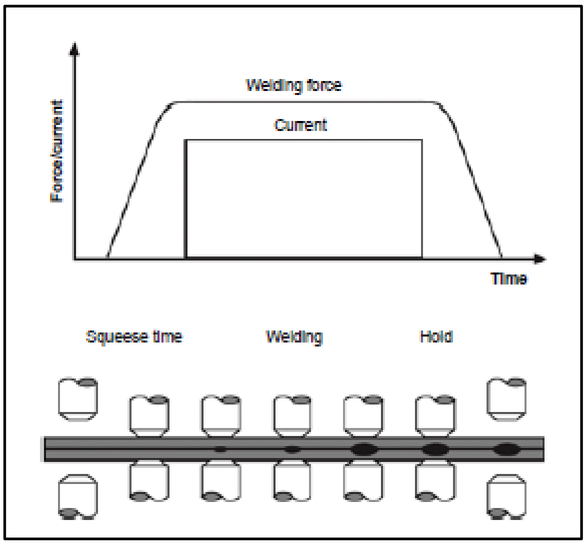


Figure 2.4 : The Principle Stages of Resistance Spot Welding

Stages suitable for the welding of ordinary cold rolled steel are described above. Pulsed welding current, changing of electrode force during the welding process or up- and downslope adjustment (slope function) can be used when welding more challenging materials such as aluminium or coated or thick steel sheets. The most basic spot welding machines may not have these options available.

2.6 Hardness

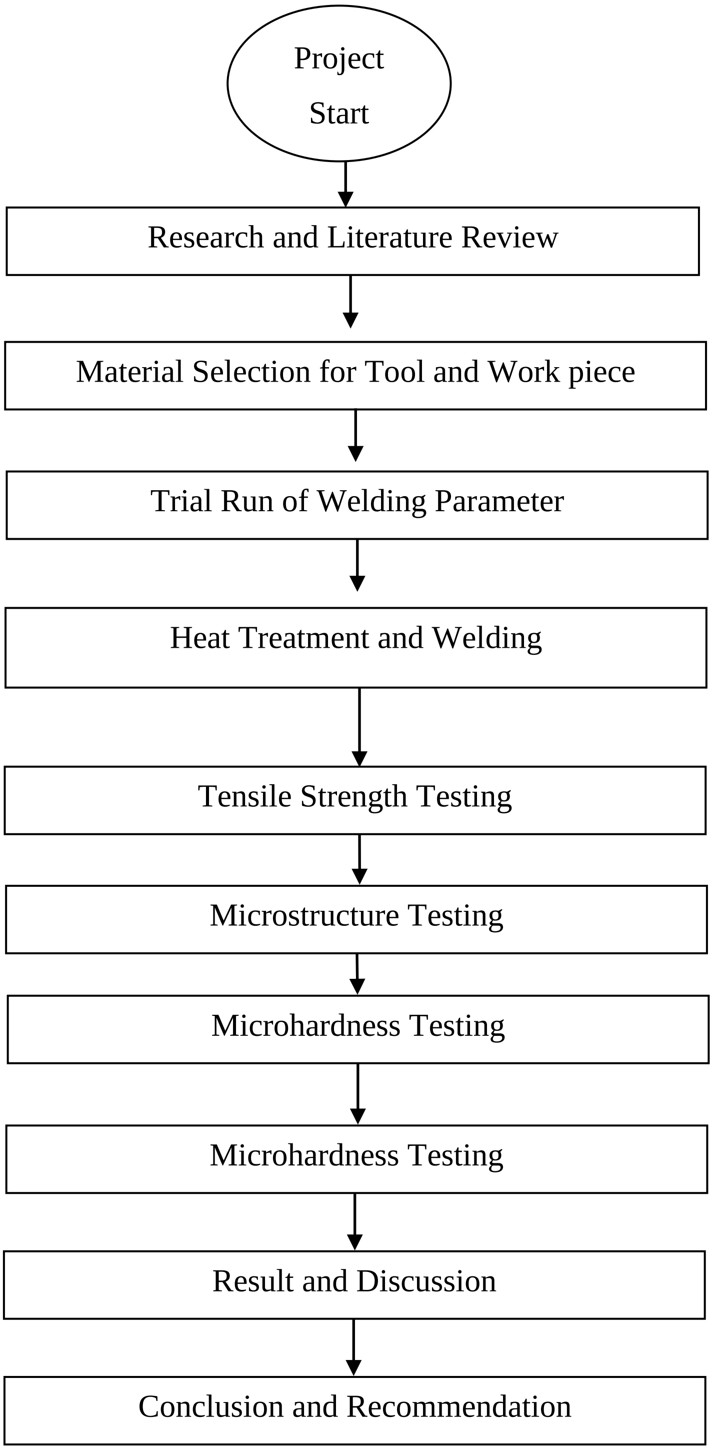
Hardness is one of the most basic mechanical properties of engineering materials. Hardness test is practical and provide a quick assessment and the result can be used as a good indicator for material selections. This is for example, the selection of materials suitable for metal forming dies or cutting tools. Hardness test is also employed for quality assurance in parts which require high wear resistance such as gears.

The nomenclature of hardness comes in various terms depending on the techniques used for hardness testing and also depends on the hardness levels of various types of materials. A scratch hardness test is generally used for minerals, giving a wide range of hardness values in a Mohrs scale at minimum and maximum values of 1 and 10 respectively. For example, talcum provides the lowest value of 1 while diamond gives the highest of 10. The basic principle is that the harder material will leave a scratch on a softer material. Hardness values of metals generally fall in a range of 4-8 in Mohrs scale, which is not practical to differentiate hardness properties for engineering applications. Therefore, indentation hardness measurement is conveniently used for metallic materials. A deeper or wider indentation indicates a less resistance to plastic deformation of the material being tested, resulting in a lower hardness value.

The indentation techniques involve Brinell, Rockwell, Vickers and Knoop. Different types of indenters are applied for each type. The standard test methods according to the American Society Testing and Materials (ASTM) available are, for instance, ASTM E10-07a (Standard test method for Brinell hardness of metallic materials), ASTM E18-08 (Standard test method for Rockwell hardness of metallic materials) and ASTM E92-41 (Standard test method for Vickers hardness of metallic materials) These hardness testing techniques are selected in relation to specimen dimensions, type of materials and the required hardness information.

CHAPTER 3: RESEARCH METHODOLOGY

Before this project can commence, the basic physical concept governing the process must first be understood. Therefore, thorough research and literature review will be conducted using resources from the library, online journal database and the internet.



3.1: Process of Developing The Sample and Analysis

Sample Preparation

Determine the standard size of specimen for spot welding.

Welding Machine Preparation

The welding machine is calibrated. Change the suitable electrode for the experiments.

Welding Process

The samples are welded according to its standard size and thickness.

Tensile Test

To determine the maximum amount of tensile stress that it can take before failure, for example breaking.

Micro Hardness Test (Vickers Scale)

To observe the material's ability to resist plastic deformation from a standard source.

Microstructure Inspection

The purpose of this test is to identify and analyze the spot zone and Thermo-mechanically affected zone.

3.2: Equipment and Consumables Required

3.2.1: Daiden Spot Welder SL-AJ 35-600

Figure 3.1: Daiden Spot Welder Machine in Block 20 laboratory

The Daiden Spot Welder machine is a resistance spot welding used to perform the welding operation under specific welding parameters. This machine can operational up to 91 kVA for maximum welding input and maximum current up to 16 600 A.

The operational procedures for this machine can be simplified as :-

1) Open the air and water valve
2) Adjust the air pressure
3) Adjust the stroke for the work by stopper
4) Turn on the primary welding power source
5) Turn on the control power source, and establish the welding condition
6) Turn on the foot switch
7) Actual welding process
8) Turn off the primary welding power source
9) Closed the air and water valve

3.2.2: Universal Testing Machine

Samples from each combination of work piece were taken for tensile strength test. Machine used for tensile strength is Universal Testing Machine which is available at UTP Block 17. Parameters used for the tensile strength test were constant for each sample with limit of load is 50 kN and the limit for stretching or pulling length is 100 mm.

Figure 3.2 : Universal Testing Machine

3.2.3: Optical Microscope

Figure 3.3 : Optical Microscope

The optical microscope is a type of microscope which uses visible light and a system of lenses to magnify images of small sample. For each specimen, the microstructure is examined by having several magnifications, e.g 10×, 50×.

The images from the optical microscope are then be captured by normal light-sensitive camera to generate a micrograph. Then, the images will be saved and ready to be analysed and discussed further.

3.2.4: Material Selection

Consumables that will use for this project are 1.0 mm Stainless Steel Plate 304 and mild steel sheet. These sheet metal need to be brought from outside with the help of university lab technician.

The properties and composition of stainless steel are shown in the table below:

Table 3.1. Composition ranges for 304 grade stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
304	min.	-	-	-	-	-	18.0	-	8.0	-
	max.	0.08	2.0	0.75	0.045	0.030	20.0		10.5	0.10
304L	min.	-	-	-	-	-	18.0	-	8.0	-
	max.	0.030	2.0	0.75	0.045	0.030	20.0		12.0	0.10
304H	min.	0.04	-	-	-	-	18.0	-	8.0	-
	max.	0.10	2.0	0.75	0.045	0.030	20.0		10.5	

Table 3.2. Mechanical properties of 304 grade stainless steel

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Hardness	
				Rockwell B (HR B) max	Brinell (HB) max
304	515	205	40	92	201
304L	485	170	40	92	201
304H	515	205	40	92	201

304H also has a requirement for a grain size of ASTM No 7 or coarser.

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon; making it malleable and ductile, but it cannot be hardened by heat treatment. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (7850 kg/m^3 or 0.284 lb/in^3) and the Young's modulus is 210 GPa (30,000,000 psi).

Low carbon steels suffer from yield-point runout where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If a low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop Lüder bands. Low carbon steels contain less carbon that other steels and are easier to cold-form, making them easier to handle.

3.2.5: Spot Welding Experimental Procedure

The operational procedures for this machine can be simplified as :-

1) Open the air and water valve
2) Adjust the air pressure
3) Adjust the stroke for the work by stopper
4) Turn on the primary welding power source
5) Turn on the control power source, and establish the welding condition
6) Turn on the foot switch
7) Actual welding process
8) Turn off the primary welding power source
9) Closed the air and water valve

The machine used in the experiment is typical of many resistance spot welding machines with a foot-operated control which initiates both the pressure and current cycles. The type of the machine is a swinging arm machine, the top arm being pivoted.

The default pressure or electrode force applied when perform the experiment is 5.4 kN, while the air pressure supplied to the welding machine is 0.3 MPa. The welding machine’s pressure cannot be changed since the machine use the pneumatic system, not hydraulic type of machine.

The thickness of the material is not the same for stainless steel and mild steel since there are some difficulty in finding the same thickness for both materials. The thickness for mild steel is 0.8 mm, while 0.5 mm for stainless steel.

The sheets metal will be joint using resistance spot welding. The specimens are the combination of same sheets metal which is Stainless steel sheet joints with Stainless steel sheet metal and Mild Steel joints with Mild Steel sheet metal.

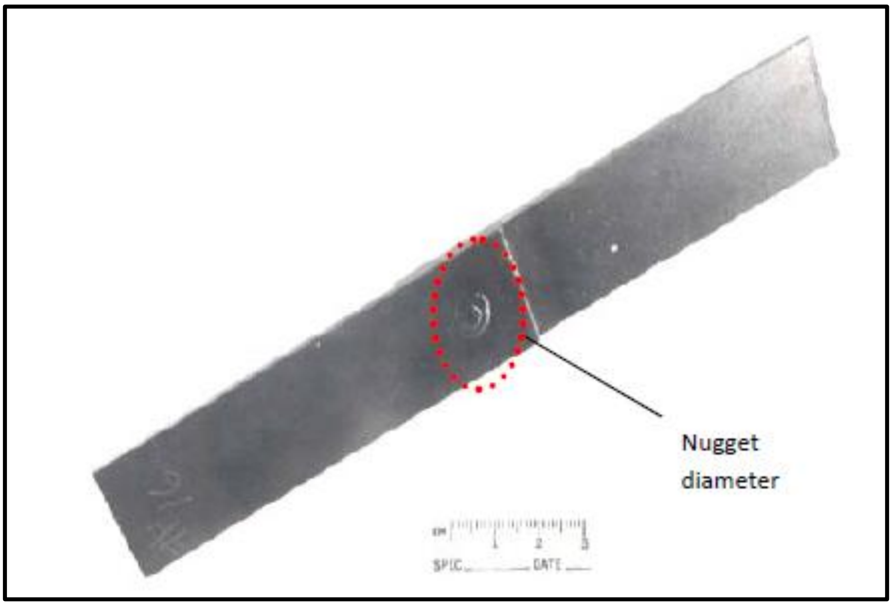


Figure 3.4 : Specimen of Sheet Metal which is Lap Joints using the Resistance Spot Welding Machine

3.2.6: 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 starts to break. The tensile strength for spot welding joint of a few sample were measured.

The tests were performed according to ASTM E8-00b Standard Test Methods for Tension Testing of Metallic Materials. To obtain the accurate and good results, the feed rate for tensile strength test should be started at the lowest speed rate possible to prevent any damage before the test and also to get the best plot from the graph. For this particular test, the feed rate used is 0.001 mm/sec. However, this setting caused the specimen too long to break, which is 7 hours. To reduce the time taken to break the sample, we change the speed to 0.02 mm/sec. Because the theoretical values of tensile strength for samples are unknown, the clamping process should be handled with care to prevent damage to the sample.

Sample from each material were taken for the test. Machine used for the tensile strength is Universal Testing Machine which is available at ground floor of Block 17. Parameter used for the tensile strength were constant for each sample with the limit of load is 50 kN, limit for stretching or pulling length is 100 mm, and at the room temperature.

3.2.7: Microstructure Experiment

After the resistance spot welding, next process is to see the microstructure of spot zone, Thermo Mechanical Affected Zone and base metal. Before that, a few preparations need to be done to the workpiece. It consists of several processes to obtain the microstructure with smooth and mirror-like surfaces.

Figure 3.5 : Flow of microstructure sample preparation

a) Sectioning

Sectioning is the removal of a conveniently sized and representative specimen from a larger piece. The hand saw, abrasive cutter, or Electrical Discharge Machine is used to cut for sectioning part. The intended areas to be examined will be the cross section of the welded region.

Figure 3.6 : Abrasive cutter (ferrous) at Block 17 used to cut the intended region

b) Mounting

Figure 3.7 : Auto Mounting Press Machine at Block 17

The next step after the sectioning process will be the mounting process. Reason for the sample to be mounting is often for desirable or necessary for subsequent handling and metallographic polishing. The examined sample is mounted in Black Epoxy Thermosetting Powder. The Auto Mounting Press Machine was used for this stage.

Below are the steps of mounting: steering

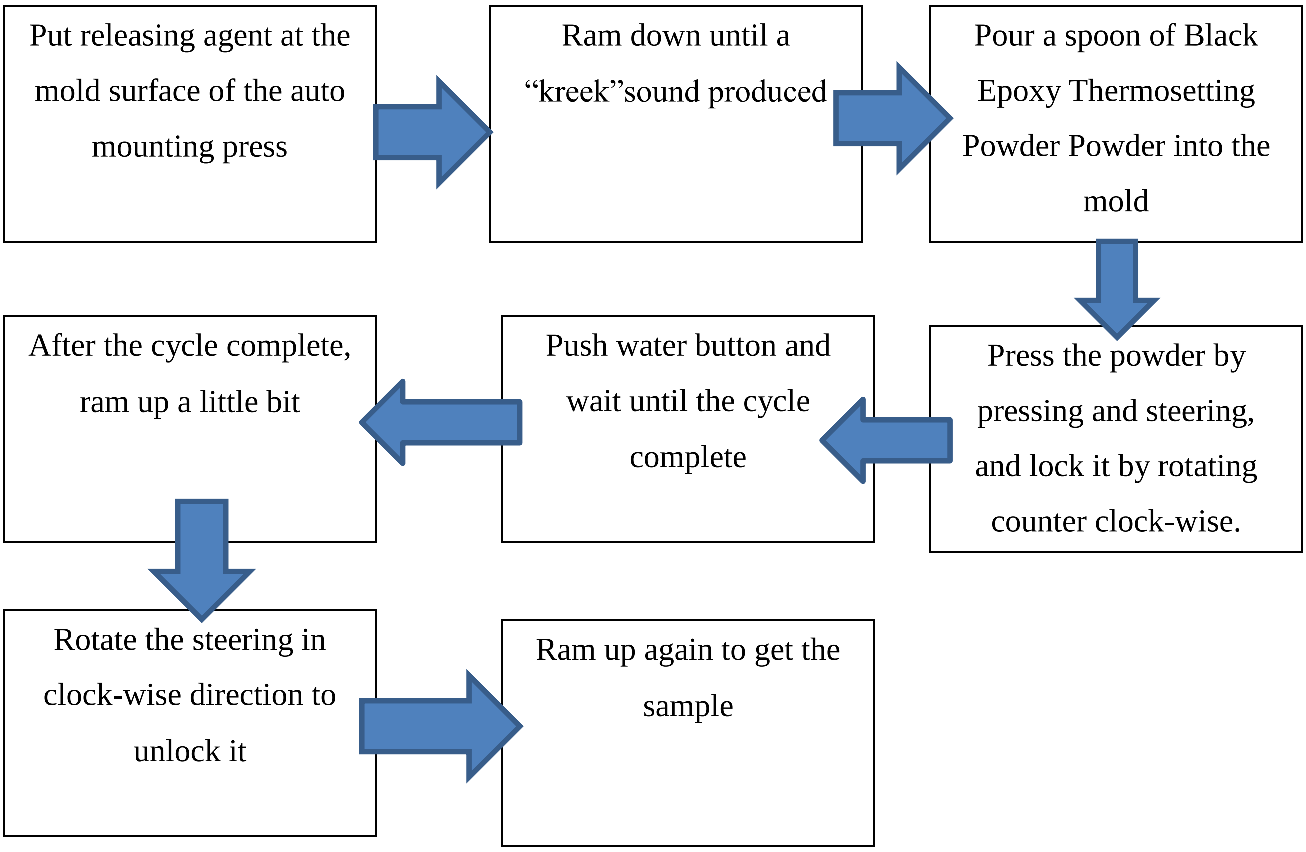


Figure 3.8 : Steps of mounting process

c) Grinding

Figure 3.9 : Grinder/polisher at Block 17

After mounting, the specimen is wet ground to reveal the surface of the metal. The specimen is successively ground with finer and finer abrasive media. Silicon carbide abrasive paper was the first of grinding and still used today including for this metallographic technique. The main aims of grinding are :-

- To remove material deformed during cutting(rough, plane grinding)
- To remove the superficial layer of specimen that covers the material destined for examination (rough, plane grinding)
- To prepare a flat surface while introducing only some residual or superficial deformation that can be eliminated during polishing (fine grinding)

The silicon carbide (SiC) abrasive papers are being used with vary grids. The table below shows the flow of grinding process for every sample.

Table 3.3 : The flow of grinding process for every sample

Step	Abrasive	Gradation	Lubricant	Rotational Speed (rpm)
1	SiC	120	H_2O	Vary
2	SiC	180	H_2O	Vary
3	SiC	240	H_2O	Vary
4	SiC	280	H_2O	Vary
5	SiC	320	H_2O	Vary
6	SiC	400	H_2O	Vary
7	SiC	600	H_2O	Vary
8	SiC	1200	H_2O	Vary
9	SiC	2400	H_2O	Vary

d) Polishing

After grinding the specimen, polishing is performed. The specimen is polished with a slurry of napless cloth to produce a scratch-free mirror finish, free from smear, drag, or pull-outs and with minimal deformation remaining from the preparation process. For this spot welding test, we use A Grade 3 Diamond Compounds (paste) with mesh 8000 is used for polishing.

e) Etching

Etching is used to reveal the microstructure of the metal through selective chemical attack. In alloys with more than one phase etching creates contrast between different regions through differences in topography or the reflectivity of the different phases.

The rate of etching is affected by crystallographic orientation, so contrast is formed between grains, for example in pure metals. The reagent will also preferentially etch high energy sites such as grain boundaries. This results in a surface relief that enables different crystal orientations, grain boundaries, phases, and precipitates to be easily distinguished.

The specimen is etched using a reagent. The etching reagents used for the microscopic examination are not yet determined.

Below are the lab procedures for etching specimens:

1. The specimen is placed on the table under the Fume Hood with the polished surface up.
2. The Fume Hood is turned on.
3. Without touching the specimen surface, the surface is cleaned with alcohol and let it dry using the drier machine. NOTE: Do not let anything but the alcohol touch the specimen surface
4. Using the Eye-Dropper, a few drops of etchant is applied to the specimen surface covering the entire metallic surface of the specimen.
5. After about 20 to 30 seconds, the etchant is rinsed into the sink with water and the specimen is then rinsed quickly with alcohol without touching the surface.
6. The drier machine is used to dry the sample.
7. Next is the microscopic examination. If further etching is required, step 1 through 6 should be repeated by varying the time in step 5 depending on the results.
8. If the specimen has many scratches and marks, or the microstructure cannot be seen after several etches, fine grinding and other necessary steps should be repeated.

3.2.8. Microhardness Test

Principle of any hardness test method is forcing an indenter into the sample surface followed by measuring dimension of the indentation (depth or actual surface area of the indentation). Hardness is not fundamental property and its value depends on the combination of yield strength, tensile strength and modulus of elasticity.

Depending on the loading force and indentation dimensions, hardness is defined as a macro-, micro-, or nano-hardness. In this experiment, we will use micro hardness test to analyze the welding sample. Micro hardness test are applicable when hardness of coatings, surface hardness, or hardness of different phases in the multi-phase material is measured. Small diamond pyramid is used as indenter loaded with a small force of 10 to 1000gf.[6]

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force of between 1gf and 100kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surfaces of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.[7]

F	Load in kgf
d	Arithmetic mean of the two diagonals, *d1* and *d2* in mm
HV	Vickers hardness

$$HV = \frac{2F\sin\frac{136^{o}}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf test force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. The Vickers method is capable of testing the softest and hardest of materials, under varying loads.

CHAPTER 4 : RESULT AND DISCUSSION

4.1. Tensile Test Result

The figure below shows the result of spot weld joint from the Resistance Spot Welding. For this experiment, three different combinations of materials were being used. However, the combination of mild steel with stainless steel was not determined yet. For each of the combination, the welding current supplied were varied started from 4 kA to 16 kA.

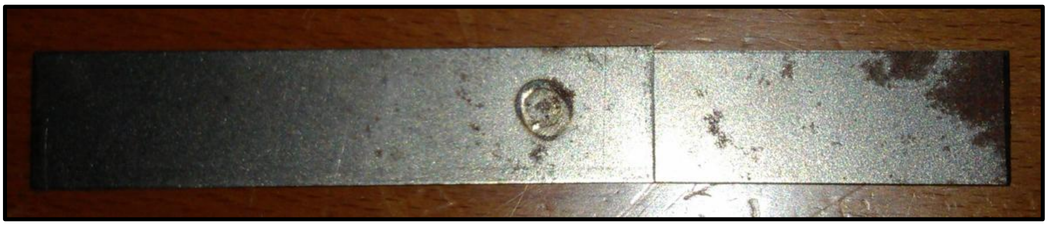


Figure 4.1 : Lap Shear Resistance Spot Weld specimen of Mild Steel sheet

Figure 4.2 : Lap Shear Resistance Spot Weld specimen of Stainless Steel sheet

In this result section, the tensile strength of the specimen were determined by doing the tensile test on different set of welding current and also cycle time. The table below shows the parameter related to the tensile strength test:-

Table 4.1 : Tensile Test Condition

TEMPERATURE IN (degree C)	22.6
TEMPERATURE OUT (degree C)	22.7
HUMIDITY (%)	64
AVERAGE PULLING SPEED (mm/s)	0.02
THICKNESS OF SAMPLE (mm)	2

The tested samples were recorded accordingly by referring the table below:-

Table 4.2 : Welding Parameter for Each Sample of Tensile Test

Material	Sample	Welding Current (kA)	Welding Cycle	Speed Rate (mm/s)	Time Required to break the sample (minutes)
Mild Steel	A	16	15	0.001	360
Mild Steel	B	13	15	0.005	240
Mild Steel	C	10	15	0.02	45
Mild Steel	D	16	10	0.02	45
Mild Steel	E	13	10	0.02	45
Mild Steel	F	10	10	0.02	45
Stainless Steel	G	4	15	0.02	30
Stainless Steel	H	4	10	0.02	30
Stainless Steel	I	6	10	0.02	30
Stainless Steel	J	8	10	0.02	30

However, there were some missing graph for Sample E, F, and H due to some technical error in the computer.

Below are the graph of Load versus Strain for each recorded sample and also the figure of the sample after it break :-

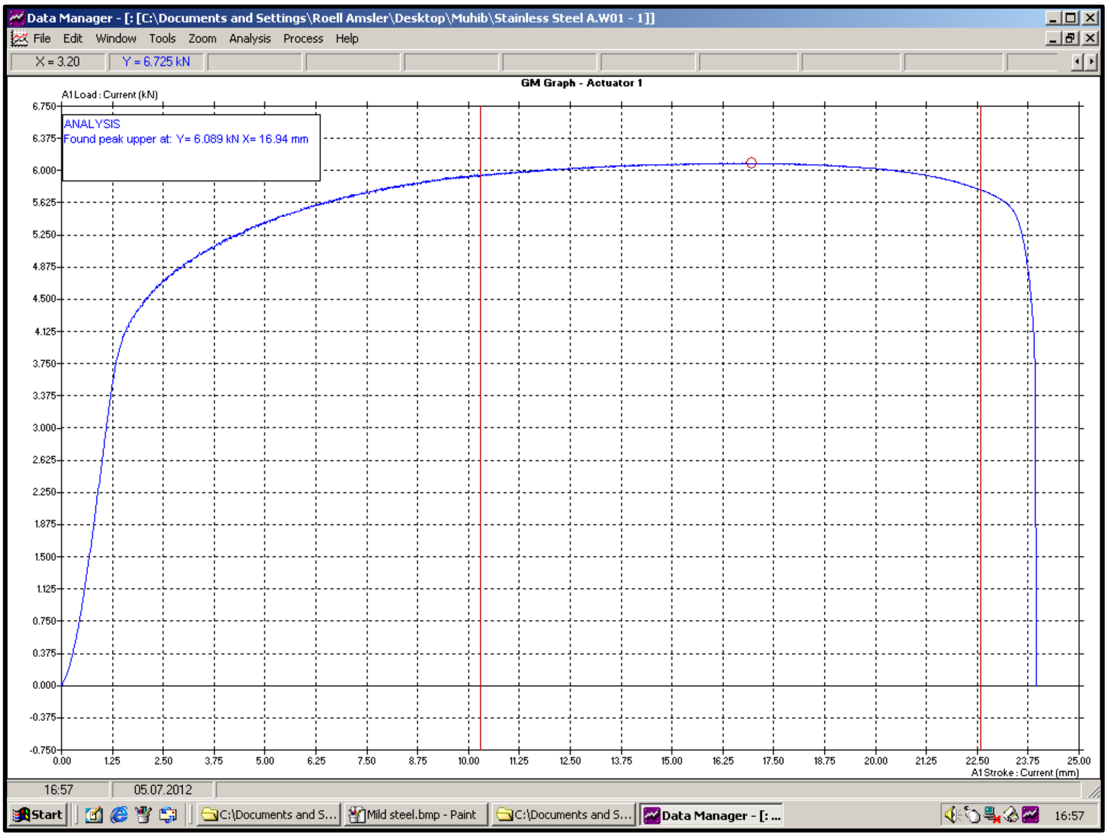


Figure 4.3 : Graph for Sample A

Figure 4.4 : Sample A after it break

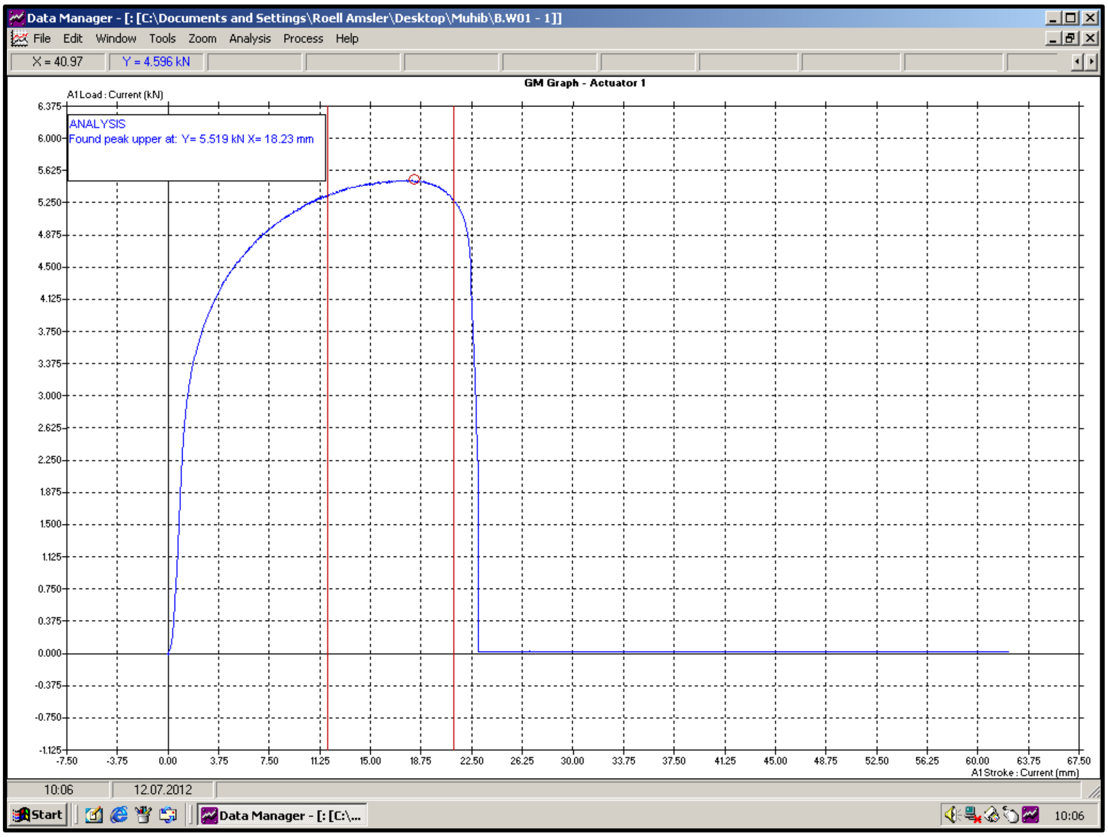


Figure 4.5 : Graph for Sample B

Figure 4.6 : Sample B after it break

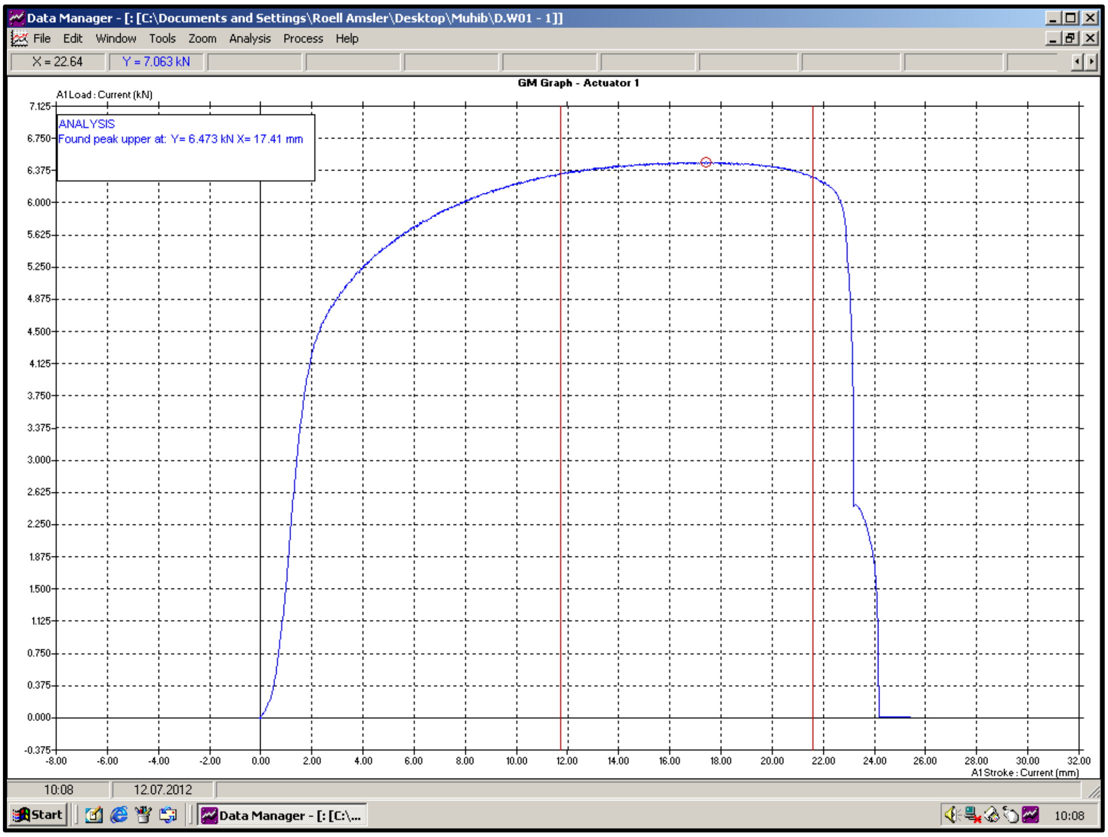


Figure 4.9 : Graph for Sample D

Figure 4.10 : Sample D after it break

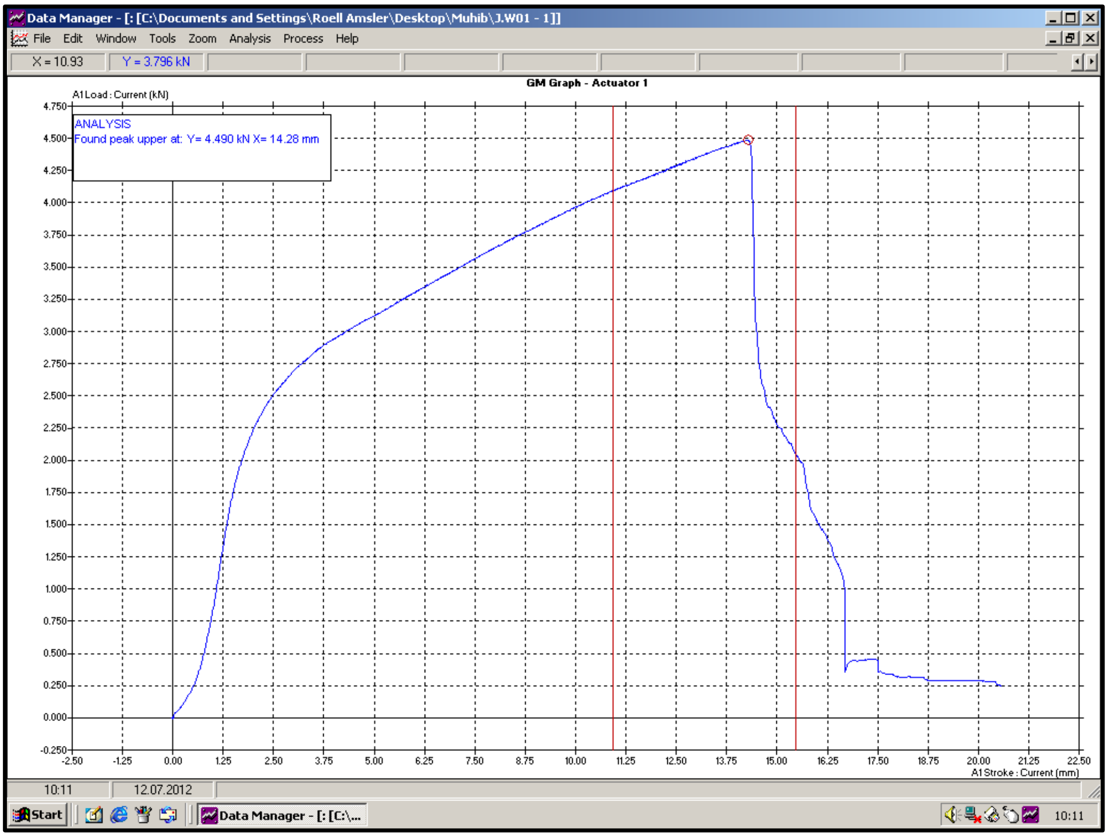


Figure 4.15 : Graph for Sample J

Figure 4.16 : Sample J after it break

The table below summarized the maximum load the sample can withstand before it breaks :-

Table 4.3 : Maximum Load and Nugget's Diameter for each sample

SAMPLE	MAXIMUM LOAD (kN)	AVERAGE DIAMETER OF NUGGET (mm)
A	6.089	5.17
B	5.519	5.57
C	6.221	4.43
D	6.437	5.00
G	4.431	8.50
I	4.372	8.17
J	4.490	7.00

To find the Ultimate Tensile Strength of the sample, we can perform that by using this formula:-

Tensile Strength = Maximum Load/ Area of nugget (MPa)

The table below shows the tensile strength value :-

Table 4.4 : The Tensile Strength of the Sample

SAMPLE	MAXIMUM BREAKING LOAD (kN)	AVERAGE DIAMETER OF NUGGET (mm)	UTS (MPa)
A	6.089	5.57	250
B	5.519	5.17	263
C	6.221	4.43	418
D	6.437	5.00	328
G	4.431	8.50	79
I	4.372	8.17	83
J	4.490	7.00	115

From the result of the tensile strength, only 7 samples were able to be tested. It is shown that Resistance Spot Welding with high welding current resulted to bigger diameter of the sample. The tensile strength for mild steel with 16 kA is lower than the sample with 13 kA welding current, which is 250 MPa to 263 MPa. The higher welding cycle also resulted in higher tensile strength since the more welding time applied, the more strength the weld joint that will be produced.

From this result, it can be concluded that Sample C, which is mild steel specimen with weld current of 16 kA and welding cycle of 15 has the highest tensile strength compared to other samples.

4.2. Microstructure Test Result

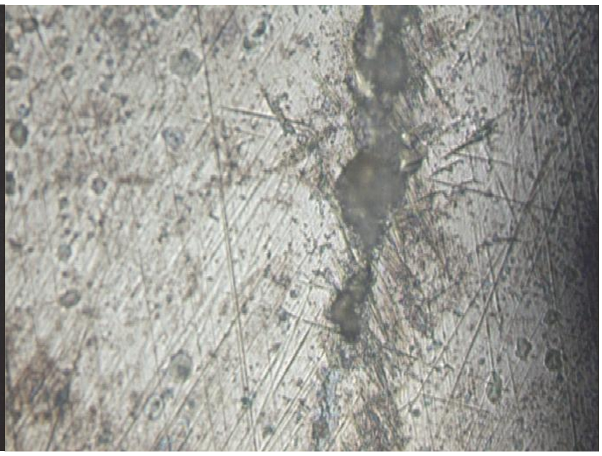
Cross sections for the microstructural investigations were taken from the spot welded joints. The microstructure studies of weld nuggets and the heat affected zones (HAZ) were carried out using an optical microscope.

The welded samples for mild steel were etched in a Nital solution, while the welded samples for stainless steel were etched by Glyceregia***.[http://www.metallographic.com/Etchants/Stainless%20steel%20etchants.htm]***

The Nital solution will reveal alpha grain boundaries and its constituents to the welded samples.

4.2.1. Weld Microstructure of Sample A

(a)



(b)

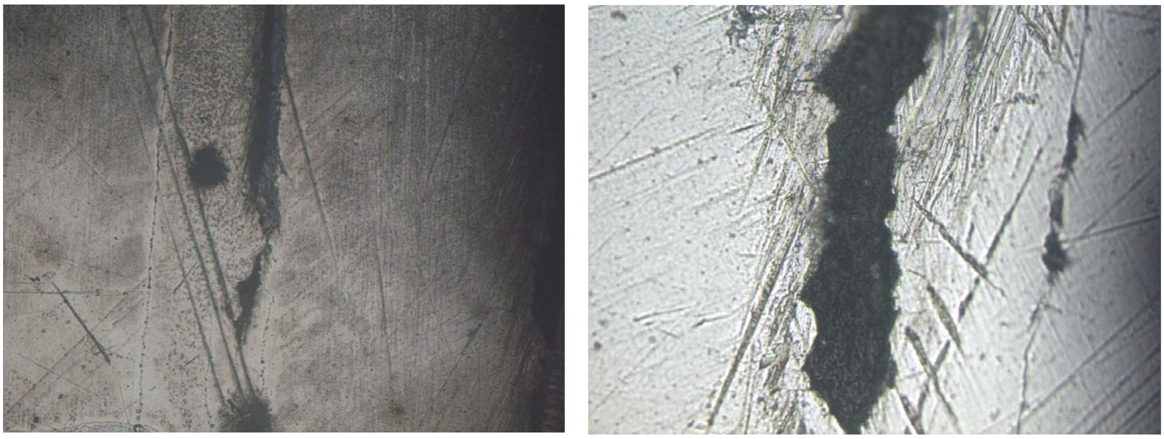
(c)

Figure 4.17 : Microstructure of Sample A of magnification (a) x10 (b) x50

The microstructure of Sample A which is Stainless Steel at 6kA and 15 cycle are shown in above figure.

We can see the welding nugget formation in the middle of the picture and it is not too clear maybe due to wrong technique of etching process. It was recognized that the grain structure around the welding nugget was finer and separation of the sheets was also small.

4.2.2. Weld Microstructure of Sample C



(a) (b)

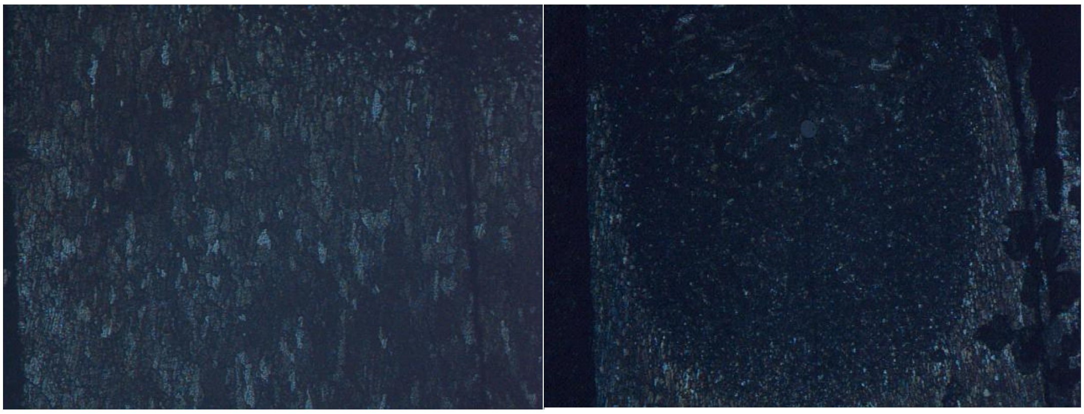
Figure 4.18 : Microstructure of Sample C of (a) x10 (b) x50 magnification

The microstructure of Sample C which is Stainless Steel at 8kA and 15 cycles are shown in above figure.

The grain structure of Sample C is slightly finer than grain structure compared to Sample A, which is 6kA and 15 cycles welded material. There are some scratches at the (b) image maybe due to indentation of electrode during the welding process.

Therefore, we can analyse that welding current doesn’t effects much on the microstructure of the cross section of the spot welds.

4.2.3. Weld Microstructure of Sample D



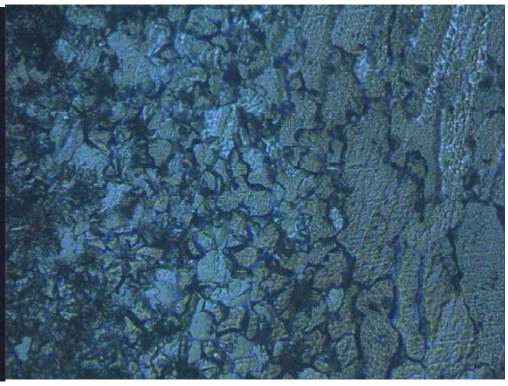
(a) (b)

Figure 4.19 : Microstructure of Sample D of (a) Welding region around the HAZ and welding nugget (b) Welding nugget formation view

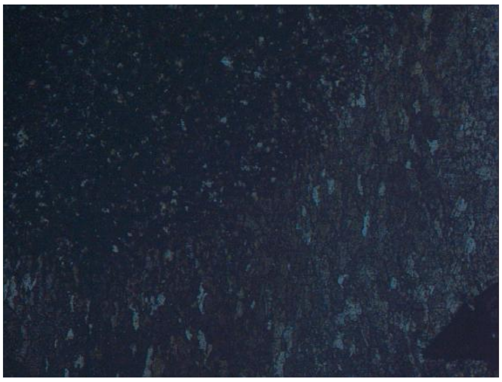
The microstructure of Sample D which is Mild Steel at 13kA and 10 cycles are shown in above figure.

The welding region far from the welding nugget shows the equal distribution of the grain structure. The region is slightly blue in colour because the water remains at the samples even after the drying process. In the image (b), we can observe clearly the welding nugget, which is at the centre of the picture. The grain size of the nugget is much bigger compared to HAZ and base metal.

4.2.4. Welding Microstructure of Sample E

(a) (b)



(c)

Figure 4.20 : Microstructure of Sample E of (a) x10 near weld nugget region (b) x50 near HAZ (c) Welding region near the nugget

The microstructure of Sample E which is Mild Steel at 10 kA and 10 cycles are shown in above figure.

The microstructure of Sample E shows the similar pattern from Sample D, which is small sheet separation and clear view of welding nugget.

4.3. Micro hardness Test Result

The Vickers micro hardness measurement across the weld nugget, HAZ and base metal was carried out with a load of 500 g. Hardness profiles have been evaluated in both the longitudinal and in the transverse directions of the cross-section of the weld nuggets.

Dwell time = 20s

Base metal hardness for stainless steel = 194 HV

Base metal hardness for mild steel = 250 HV

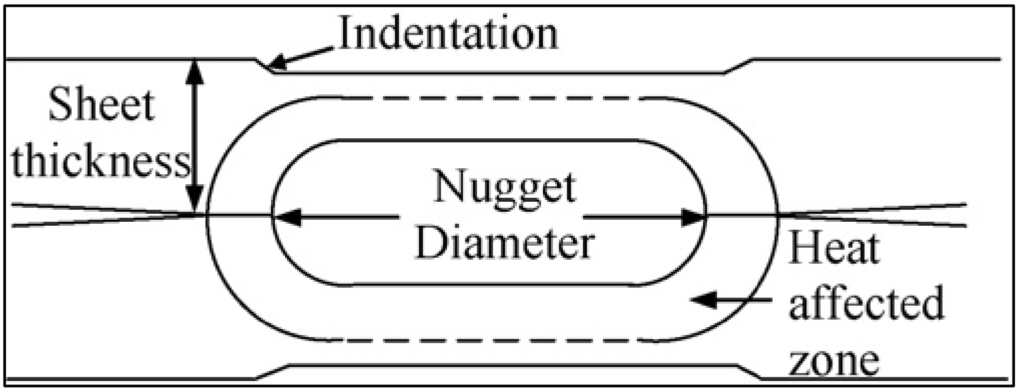


Figure 4.21: Schematic cross-section of a spot-weld.

The table below shows the hardness value for Sample A, Sample B, Sample D, and Sample E.

Table 4.5: Sample A, 6 kA, 15 cycle of Stainless Steel

Distance from center (mm)	Vickers Hardness, HV of 500g
5	341
4	333
3	347
2	335
1	353
1	340
2	321
3	320
4	315
5	313

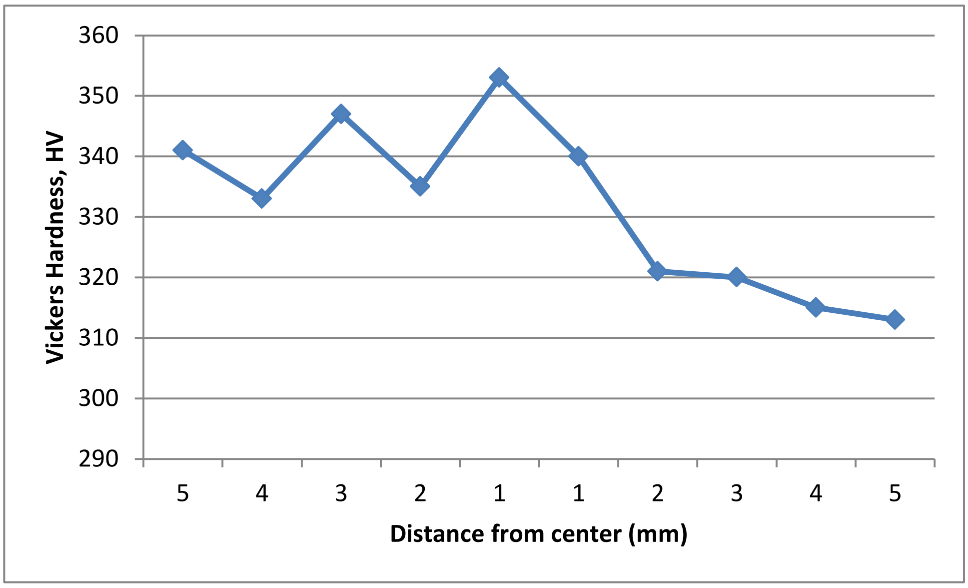


Figure 4.22: Hardness profile across the welds of Sample A

Table 4.6: Sample B, 4 kA, 15 cycle of Stainless Steel

Distance from center (mm)	Vickers Hardness, HV of 500g
5	330
4	333
3	335
2	349
1	359
1	360
2	343
3	344
4	325
5	320

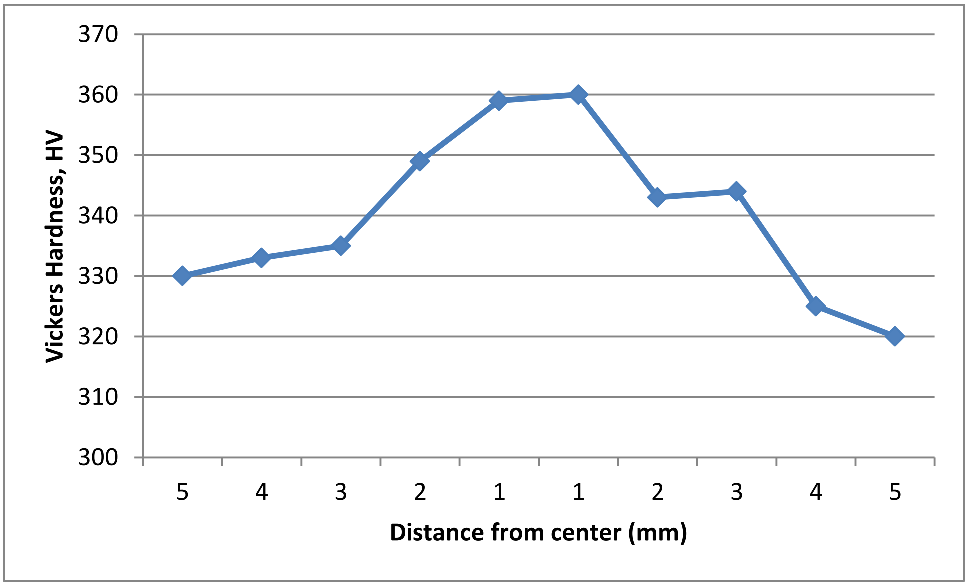


Figure 4.23: Hardness profile across the welds of Sample B

Table 4.7: Sample D, 13 kA, 10 cycle of Mild Steel

Distance from center (mm)	Vickers Hardness, HV of 500g
5	434
4	432
3	446
2	456
1	450
1	459
2	449
3	431
4	430
5	427

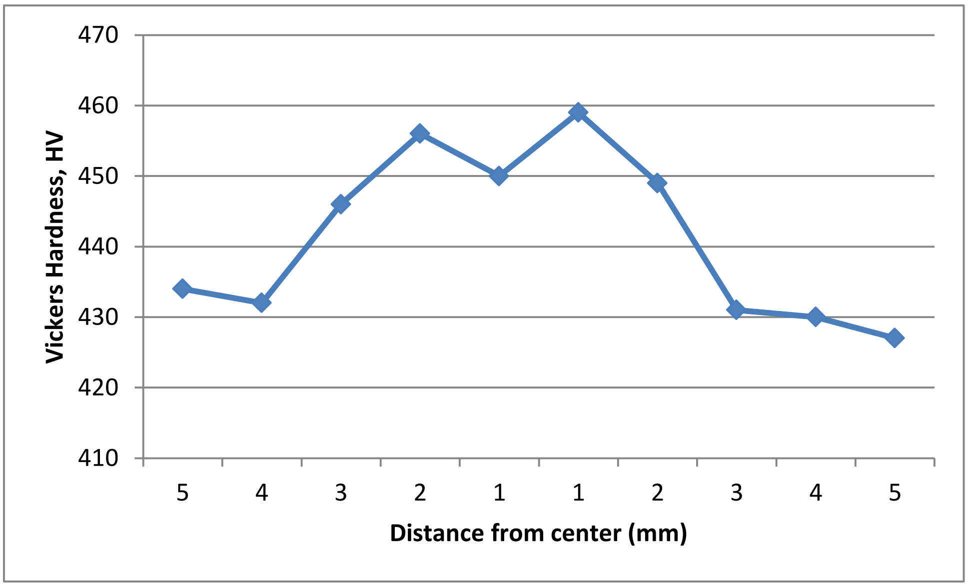


Figure 4.24: Hardness profile across the welds of Sample D

Table 4.8: Sample E, 10 kA, 10 cycle of Mild Steel

Distance from center (mm)	Vickers Hardness, HV of 500g
5	392
4	399
3	407
2	427
1	430
1	435
2	433
3	421
4	402
5	401

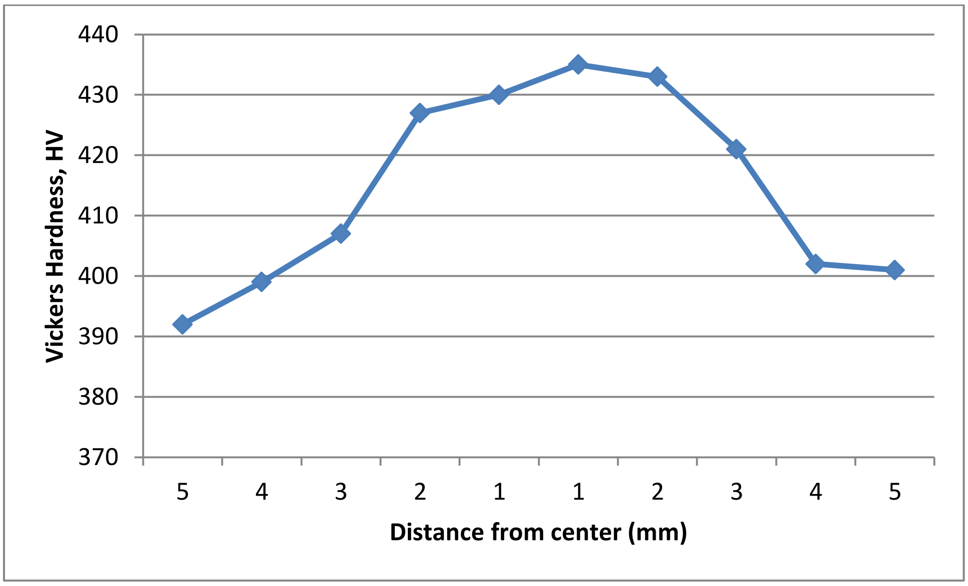


Figure 4.25: Hardness profile across the welds of Sample E

Typical distributions of microhardness across the spot-welds of stainless steel and mild steel sheets along the longitudinal direction are shown in in the graph above.

From the result and graph that have been produced before, we can analyse that the microhardness profile of welding sample is not change much regardless of welding current of the sample, except for Stainless steel sample which the variation is slightly bigger than mild steel.

The base metal, HAZ and the fusion zone of the spot welds are considered to exhibit some characteristic average hardness value; as we can see the hardness value did not change much from different region of weld. The mean hardness of the fusion zone is the highest, while that of the base metal is the lowest. The microhardness of HAZ exhibits considerable increase in its magnitude from the base metal side to the fusion zone side, and microhardness of center of the nugget produce the biggest hardness value. Thus the observed order of increase in the estimated hardness values of the fusion zone and the HAZ over that of the base metal for the selected steels is similar to that reported in the literature.

CHAPTER 5 : CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

From the experiment of the tensile strength of Resistance Spot Weld, it can be concluded that the size of the weld nugget increases steadily with increasing welding current, but too high current will result in expulsion and electrode deteriorations.

However, as the welding current increases, the tensile strength of the specimen become lower, maybe due to failure occurred at the specimen. The welding cycle also affect the specimen. The longer the welding time, the more heat will be generated. It resulted in lower tensile strength produced by the sample.

The lap shear strength of the welding sample joints also depended on the strength and thickness of the material. Besides, the nugget diameter is also an important critical parameter in determination of spot weld quality [8]. The quality and approximate strength of the weld can be estimated by measuring its diameter and depth of fusion [9].

The microstructure of the cross section of the welded samples were clearly seen the difference between the welding nugget, heat affected zone and base metal. The grain structure of the welding nugget is much coarse than base metal and HAZ. The increasing heat input and welding cycle caused slightly coarsening of the microstructure of weld nugget and HAZ.

For the hardness distribution of the sample, increasing welding current does not much increase the hardness distribution. The base metal, HAZ and the fusion zone of the spot welds are considered to exhibit some characteristic average hardness value; as we can see the hardness value did not change much from different region of weld. The mean hardness of the fusion zone is the highest, while that of the base metal is the lowest.

As conclusion, Resistance Spot Welding is the most popular and important process that is implemented in automotive industries. Spot welders can also be completely automated, and many of the industrial robots found on assembly lines are spot welders. More study and research should be done so that the sheet metal with much higher thermal conductivity and electrical conductivity can be welded properly.

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 of spot weld joint is needed to obtain a good microstructure samples.

4) The weld sample is made from more thicker materials, such as with thickness of 5 mm to 10 mm to make the analysis process much easier and precise.

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APPENDIX I: PROJECT TIMELINE FOR FYP I

NO.	ACTIVITY / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Selection of Project Title															
2.	Preliminary Research Work															
3.	Submission of Extended Proposal															
4.	Preparation for Oral Proposal Defence															
5.	Oral Proposal Defence Presentation															
6.	Detailed Literature Review															
7.	Learn The Laboratory Test Procedure															
8.	Preparation of Interim Report															
9.	Submission of Interim Draft Report															
10.	Submission of Interim Final Report															

APPENDIX II: WELDING PARAMETERS FOR COLD ROLLED AND COATED SHEETS

Welding parameters for cold rolled and coated sheets

Sheet thickness, t, mm	Weld diameter D, mm	Electrode tip Ø d, mm	Force F, kN	Weld time, cycles	Effective welding current I, kA	Minimum distance between welds, mm 	Minimum acceptable overlapping, mm 
0.6	4	5	1.4 - 1.7	5 - 8	6	20	12
0.8	4	5	1.6 - 2.3	6 - 10	7	20	12
0.9	5	6	1.7 - 2.5	8 - 11	8	25	14
1.0	5	6	2.1 - 2.9	9 - 12	9	25	14
1.2	5	6	2.5 - 3.4	10 - 13	9.5	35	15
1.5	6	7	3.3 - 4.3	12 - 16	10	35	16
2.0	6	7	3.9 - 5.4	16 - 20	11	40	18
2.5	7	8	5.4 - 7.0	22 - 26	12.5	45	20
3.0	7	8	6.3 - 8.5	24 - 30	14	50	22

APPENDIX III: WELDING PARAMETERS FOR COLD ROLLED SHEETS

Welding parameters for cold rolled sheets

Sheet thickness t, mm	Electrode tip Ø d, mm	Hot-dip galvanised sheet, Z275			Hot-dip galvanised sheet, Z100		
		Force, kN	Weld time cycles	Welding current, kA	Force, kN	Weld time cycles	Welding current, kA
0.4 - 0.6	4	1.5 - 2.0	6 - 8	7 - 9	1.5 - 2.0	6 - 8	6 - 8
0.6 - 0.8	4	1.9 - 2.2	8 - 10	8 - 10	1.9 - 2.2	8 - 10	7 - 9
0.8 - 1.0	5	2.2 - 2.9	9 - 12	9 - 11	2.2 - 2.9	9 - 12	8 - 10
1.0 - 1.2	5	2.8 - 3.6	10 - 13	10 - 13	2.8 - 3.6	10 - 13	9 - 13
1.2 - 1.6	6	3.4 - 4.5	11 - 15	14 - 16	3.4 - 4.5	11 - 15	12 - 15
1.6 - 2.0	7	4.4 - 5.5	12 - 16	18 - 21	4.4 - 5.5	12 - 16	14 - 17
2.0 - 2.5	8	5.4 - 6.8	14 - 18	22 - 26	5.4 - 6.8	14 - 18	17 - 22
2.5 - 3.0	9	6.6 - 8.0	17 - 21	26 - 30	6.6 - 8.0	17 - 21	19 - 24

Welding parameters for hot-dip galvanised sheets using two coatings: Z275 and Z100. The recommended welding current slope adjustment is 2–4 cycles.

APPENDIX IV: PROJECT TIMELINE FOR FYP II

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■					Mid-Semester Break							
2	Submission of Progress Report 1				●											
3	Project Work Continue				■	■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)										■	■	■			
5	Project work continue									■	■	■	■			
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone

■ Process