EFFECT OF WELDING NUGGET DIAMETER ON THE TENSILE STRENGTH OF THE RESISTANCE SPOT WELDING JOINTS OF SAME SHEETS METAL

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A report submitted in partial fulfillment of
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SUPERVISOR DECLARATION

I hereby declare that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT DECLARATION

I declare that this thesis entitled *"Effect of Welding Nugget Diameter On The Tensile Strength Of The Resistance Spot Welding Joints Of Same Sheets Metal"* is the result of my own research except as cited in the references. The thesis has not been accepted for my degree and is not concurrently candidature of any other degree.

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Dedicated:

To my Beloved Parent

Jenis Bagu

Jane Ranjah

To my Beloved Siblings

Ronnie

Edna Vianney

Onniel

Dick Colbert

Mc Ohlsen

To the person who supported me always

Nancy Lieu

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ABSTRACT

Resistance spot welding is commonly used in the automotive industry, because it has the advantage which is high speed, high-production assembly lines and suitability for automation. The welded joints are exposed to the variables of load and pressure, these conditions made the welded joint to rupture. The objective of this project is to study the effect of welding nugget diameter on the tensile strength of the resistance spot welded joints. Using the tensile test method to analyze the selected size of the nugget diameter to determine the maximum load that can be applied before the specimen is rupture or tears apart. By doing the analysis, the suitable size of the nugget diameter can be determined. The materials used in this study are Aluminum and Mild Steel sheet metal and the selected nugget diameter used 4 mm, 5mm and 6 mm because it is varied in the industrial applications.

ABSTRAK

Kimpalan rintangan bintik biasanya digunakan dalam industri automotif, ini kerana ianya mempunyai kelebihan dari segi kelajuan yang tinggi, hasil pemasangan yg tinggi dan sesuai dalam automasi. Sambungan hasil kimpalan biasanya terdedah dengan pelbagai beban dan tekanan, keadaan seperti itu boleh menyebabkan sambungan itu retak. Objektif projek ini ialah untuk mengkaji kesan saiz gumpalan kimpalan yang dikimpal menggunakan kaedah kimpalan rintangan bintik, terhadap kekuatan ketegangan sambungan kimpalan itu. Dengan menggunakan ujian kaedah ketegangan dalam menganalisa saiz gumpalan kimpalan yang terpilih, beban maksimum yang boleh dikenakan sebelum spesimen itu terpisah dua atau retak boleh ditentukan. Dengan melakukan analisa tersebut, saiz gumpalan kimpalan yang sesuai dapat di tentukan. Jenis bahan yang digunakan dalam kajian ini adalah kepingan besi Aluminium dan Besi Halus.dan saiz gumpalan kimpalan yang terpilih ialah 4.0 mm, 5.0 mm dan 6.0 mm kerana ianya digunakan dalam pelbagai industri.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION OF RESISTANCE SPOT WELDING (RSW)

Resistance spot welding (RSW) is a process in which metal surfaces are joined in one or more spots by resistance to the flow of electric current through work pieces that are held together under force by electrodes [2]. The weld is made by a combination of heat, pressure, and time. The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the work piece. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal. The resistance spot welding has the advantage which is high speed and suitability for automation.

Mechanical testing is an important aspect of weld ability study. Such testing is either for revealing important welds characteristics, such as weld nugget diameter or weld button size, or for obtaining and evaluating the quantitative measures of weld's strength [2]. Mechanical testing of a weldment can be static or dynamic test and among the static test, tension shear or tensile shear testing is commonly used in determining weld strength or the tensile strength of the welded joints because it is easy to conduct the test and the specimens for the test is simple in fabrication.

1.2 IMPORTANCE OF RESEARCH

- To study the effects of the nugget diameter on the tensile strength of the resistance spot welded joints on the sheets metal.
- To estimate the amount of load that could be apply to each different nugget diameter size before the welded joints is fails or rupture.

1.3 PROBLEM STATEMENT

Nugget diameter is one of the important parameters to determine the weld strength of the spot weld before rupture. Different material may show the different effects to the nugget diameter. Aluminum and Mild Steel may have different suitable nugget diameter size for tensile strength endurance limits.

1.4 OBJECTIVE

- To analyze the tensile strength welded joints of aluminum-aluminum sheets metal and mild steel-mild steel sheets metal with the different nugget diameter.

1.5 SCOPE OF RESEARCH

This research is focusing on the effects of welding nugget diameter due to tensile strength of the welded joints of sheets metal. Using tensile test analysis, the tensile strength of the welded joint of sheets metal being evaluated in terms of the maximum load (N) and the displacement of the welded specimens (mm).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed the literatures of the resistance spot welding and the information's about the tensile test analysis.

2.2 RESISTANCE SPOT WELDING

Resistance spot welding is one of the oldest of the electric welding processes in use by industry today, especially in the automotive industry. The weld is made by a combination of heat, pressure, and time. As the name resistance welding implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part. The pressure exerted by the tongs and electrode tips, through which the current flows, holds the parts to be welded in intimate contact before, during, and after the welding current time cycle. The required amount of time current flows in the joint is determined by material thickness and type, the amount of current flowing, and the cross-sectional area of the welding tip contact surfaces [1].

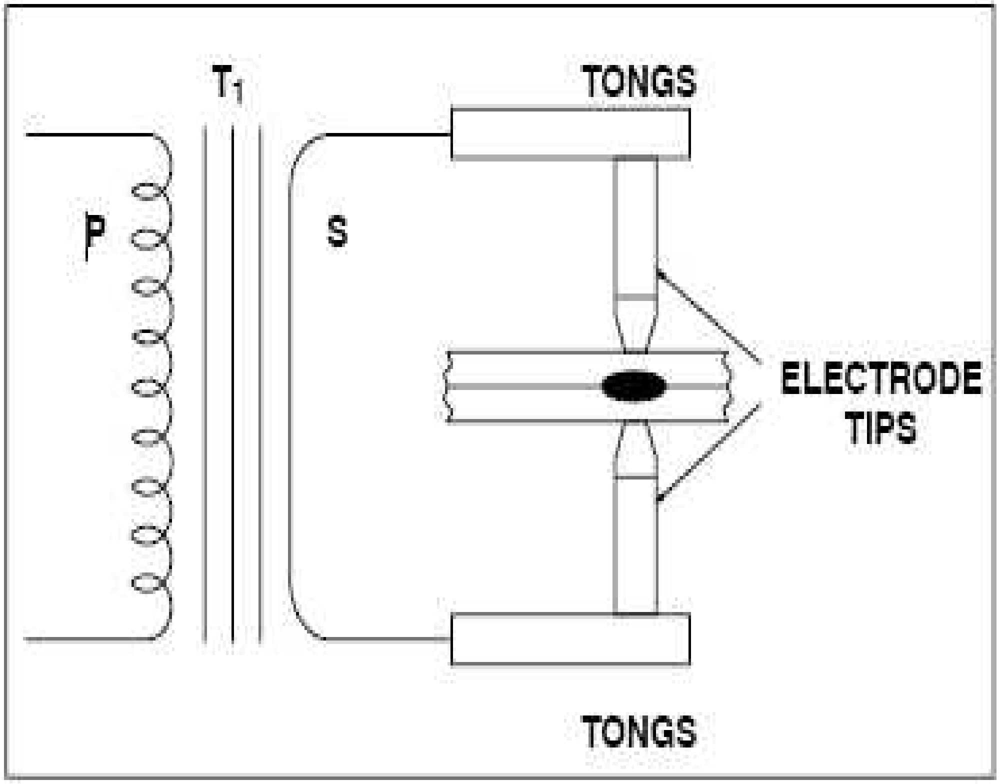

Figure 1: Resistance Spot Welding Machine with Work

The size and shape of the individually formed welds are limited primarily by the size and contour of the electrode faces. The weld nugget forms at the laying surfaces, as shown in **Figure 1**, but does not extend completely to the outer surfaces. In section, the nugget in a properly formed spot weld is round or oval in shape. Spacing between adjacent spot welds or rows of spot welds must be enough to prevent shunting or to limit it to an acceptable amount [1].

2.3 PRINCIPLES OF THE RESISTANCE SPOT WELDING

Resistance Spot Welding is done when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The operation of spot welding involves a coordinated application of current of the proper magnitude for the correct length of time. This current must pass through a closed circuit. The resistance of the base metal to electrical current flow causes localized heating in the joint, and the weld is made.

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 so the weld can 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 [1].

2.4 ELECTROTHERMAL PROCESS OF WELDING

In resistance welding, the heat are required to create the coherence is generated by applying an electric current through the stack- up of sheets between the electrodes. So, the formation of a welded joint, including the nugget diameter and the heat- affected zone (HAZ), are definitely depends on the electrical and thermal properties of the sheets and coating materials. The general expression of heat generated in an electric circuit can be expressed as

$$Q = I^2 Rt \quad \text{(modification of the Ohm's Law)} \qquad [2]$$

where **Q** is heat (Joule), **I** is current (Ampere) , **R** is electrical resistance of the circuit (ohm,Ω) and **t** is time (second) which is allowed to flow in the circuit. For resistance welding, the heat generation at all location in a weldment is more relevant than, rather than the total heat generated, as heating is not and should not be uniform in the weldment. That means, consideration should more on the heat rate than the total heat, as it will determines the temperature history, and, in turn, the microstructure [2].

For example, considering an aluminum welding, melting may not be happen if the welding current applied is low, due to the low electrical resistivity of aluminum. In general, the electric and thermal process should be considered together in welding.

2.5 SPOT WELDS PARAMETERS

2.5.1 The Parameters

1) Electrode Force

The electrode force is required to squeeze the metal sheets to be weld and joint together. This requires a large electrode force because the weld quality would not be good enough. However, the force must not be too large as it might cause other problems. When the electrode force is increased the heat energy will decrease. So, the higher electrode force needed a higher weld current. When weld current becomes too high, spatter will occur between electrodes and sheets. This will cause the electrodes to get stuck to the sheet.

2) Squeeze Time

Squeeze Time is the time interval between the initial application of the electrode force on the work and the first application of current. Squeeze time is necessary to delay the weld current until the electrode force has attained the desired level [3].

3) Weld or Heat Time

Weld time is the time during which welding current is applied to the metal sheets. The weld time is measured and adjusted in cycles of line voltage as with all timing functions. As the weld time is, more or less, related to what is required for the weld spot, it is difficult to give an exact value of the optimum weld time. For instance:

- Weld time should be as short as possible.
- The weld parameters should be chosen to give as little wearing of the electrodes as possible. (short weld time.).
- The weld time shall cause the nugget diameter to be big when welding thick sheets.
- The weld time might have to be adjusted to fit the welding equipment in case it does not fulfil the requirements for the weld current and the electrode force. (A longer weld time might be needed.).
- The weld time shall cause the indentation due to the electrode to be as small as possible. (a short weld time.).
- The weld time shall be adjusted to welding with automatic tip-dressing, where the size of the electrode contact surface can be kept at a constant value. (a shorter welding time.) [3].

4) Hold Time (cooling-time)

Hold time is the time, after the welding and occurred when the electrodes are still applied to the sheet to chill the weld (time that pressure is maintained after weld is made.). Hold time is necessary to allow the weld nugget to solidify before releasing the welded parts, but it must not be to long as this may cause the heat in the weld spot to spread to the electrode and heat it. The electrode will then get more exposed to wear. Further, if the hold time is too long and the carbon content of the material is high (more than 0.1%), there is a risk the weld will become brittle [3].

5) Weld Current

The weld current is used during welding is being made. The amount of weld current is controlled by two things; first, the setting of the transformer tap switch determines the maximum amount of weld current available; second the percentage of current control determines the percentage of the available current to be used for making the weld. Low percentage of current settings is not normally recommended because it might affect the quality of the weld. Proper welding current can be obtained with the percentage current set between seventy and ninety percent by adjust the tap switch.

The weld current should be kept as low as possible. When determining the current to be used, the current is gradually increased until weld spatter occurs between the metal sheets. This indicates that the correct weld current has been reached. Weld current also influences the value of nugget diameter. Different value of current, it will produce different dimension of the nugget diameter [3].

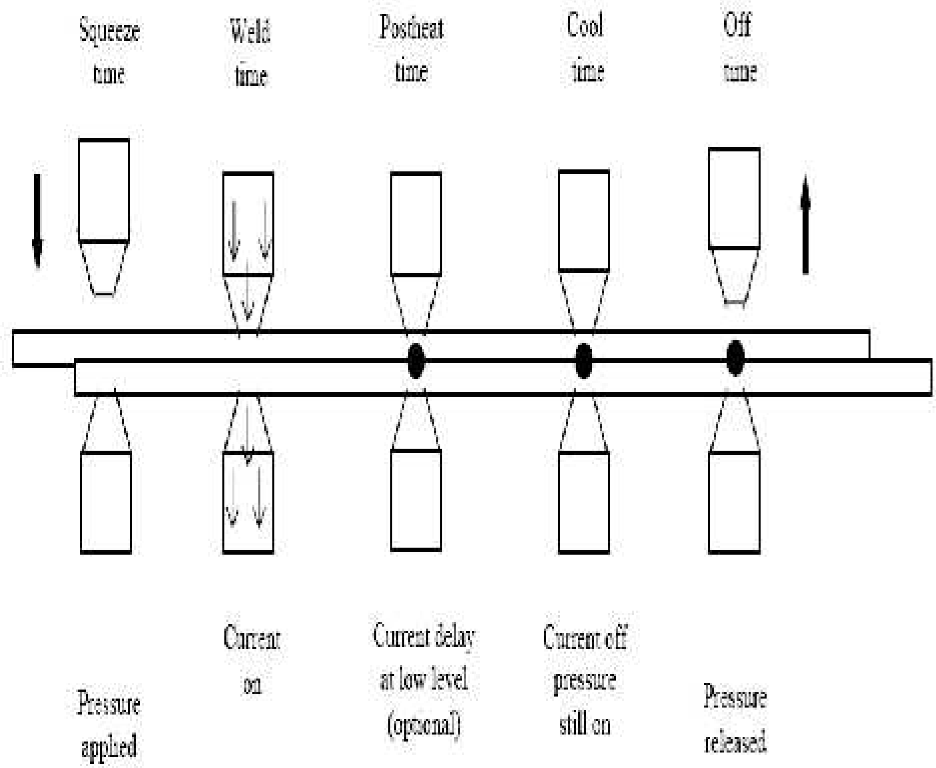

Figure 2: Welding Cycle

The welding processes in resistance spot welding have 5 cycle process as shown in the **Figure 2**. The first cycle is the squeeze time, where pressure from the electrode force is applied to the workpiece. The second cycle is weld time, this process where the current is on and the welding current is applied in the metal sheets to melt the sheet metal for the welding process. Then, postheat time, the current delay at the low level. The fourth cycle is cool time. This cycle allow the melt nugget diameter to solidify before the releasing the welded parts and lastly the off time cycle, the electrode force applied on the sheets metal is released the welding process is done.

2.6 TENSILE TEST

The strength of the welded joints will be analyzed using tensile test method. This method is suitable and simple to test the strength of the welded joint of sheet metal in terms of the tensile strength of the joint before fail or tear apart.

2.6.1 The Tensile Testing

Among statics test, tensile test is commonly used in determining weld strength because of its simplicity in specimen fabrication and testing.

This test consists of pulling in tension to destruction, on a standard testing machine, a test specimen obtained by lapping two strips of metal and joining them by single weld. The ultimate strength of the test specimen and the nature of the fracture, whether by shear of the weld material or by tear of the parent material, and whether a ductile or brittle fracture is obtained, should be recorded.

The most commonly monitored variable in tensile testing is the peak load. However, the displacement at the peak load (maximum displacement) and the corresponding energy should also be monitored, in addition to the peak load. The maximum displacement indicates the ductility and the energy to the energy-absorbing capacity of a weldment. The displacement and energy should be calculated only to the peak load because the failure of the specimen is largely determined at such moments. After the load reaches its peak value, the displacement and energy are generally not unique because of the uncertainty in subsequently tearing the specimens [4].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the steps in welding the joints and the type of data that would be used to evaluate the tensile strength of the specimens using tensile test method.

3.2 JUSTIFICATION

In this research, the Mild Steel and Aluminum sheet metal are the material that would be used in the resistance spot welding experiment. Both materials are chosen in term of its thermal conductivity and melting points and these properties would affect the tensile strength.

3.3 METHODOLOGY

Below shows the flow chart of the research being made:

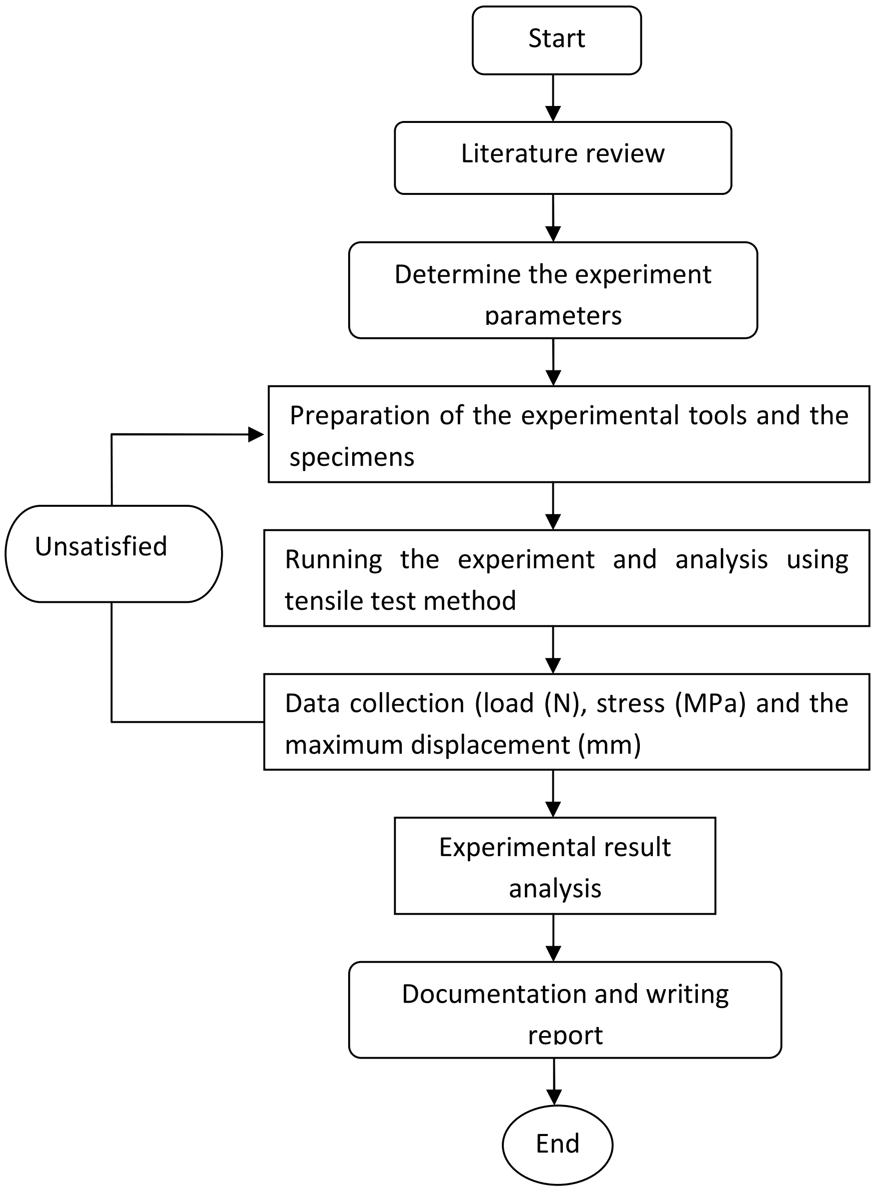

Figure 3: The Flow Chart of the Project

3.4 NUGGET DIAMETER

The main parameter in the experiment is the nugget diameters. This is because different diameter of nugget would shows different tensile strength.

In order to obtain the desired nugget diameter, pre-test would be implemented in resistance spot welding to obtain the correct value of welding current (kA). This is because different welding current would give different value of nugget diameter in spot welding joints.

In this project the desired nugget diameter is 4.0 mm, 5.0 mm and 6.0 mm. Hence, the second parameter is the current welding which affects the value of the nugget diameters.

The 4.0 mm, 5.0 mm and 6.0 mm nugget diameter have being selected because it is suitable for the thickness of the sheet metal. The selected nugget diameter would give better results of tensile strength compares with the nugget diameter of 1.0 mm, 2.0 mm and 3.0 mm. This size is not suitable because the area of joint is too small. The nugget diameter of 4.0, 5.0 and 6.0 mm also varied in industrial applications [7].

Table 1: Welding Currents in Pre-test

Metal Sheet combination	Nugget diameter (± 0.5mm)	Welding current (kA)	Welding Current (second)
Mild-steel with mild-steel	4		
	5		
	6		
Aluminum with aluminum	4		
	5		
	6		

The data during the Pre-test experiment would be record using the table as shown in **Table 1** above.

3.5 WORK PIECE AND MATERIALS

The analysis is uses 2 different materials, which are Aluminum sheets metal and Mild-Steel sheets metal. Each of the specimens dimension is 2.0 cm (width) and 10.0 cm (length). The thickness for both materials is 1.2 mm. The sheets metal will be joint using resistance spot welding. The specimens is combination of same sheets metal which is Aluminum joints with Aluminum sheet metal and Mild Steel joints with Mild Steel sheet metal with the selected nugget diameter of 4.0 mm, 5.0 mm and 6.0 mm.

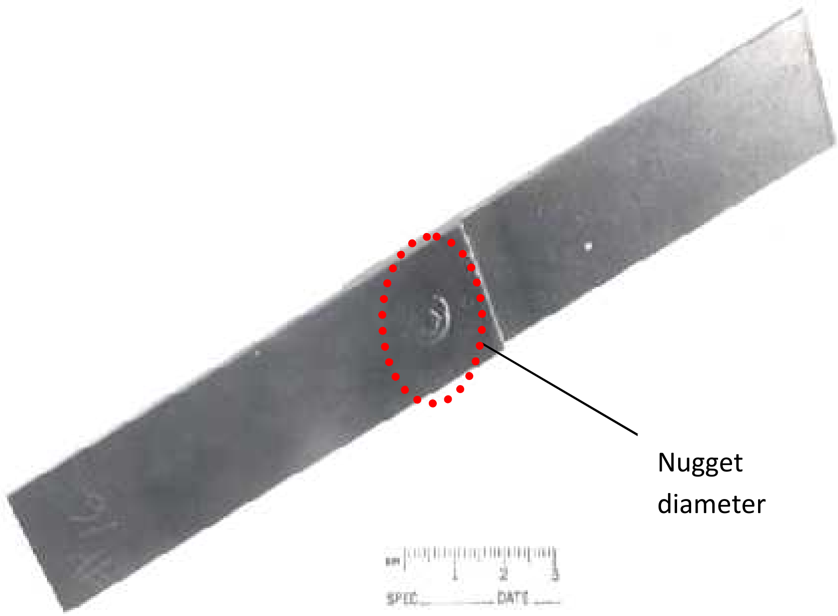

Figure 4: Specimens of Sheets Metal which is Joints Using the Resistance Spot Welding Machine

3.6 DATA COLLECTIONS

Several tables are being used to record the reading during tensile test analysis. The selected data are maximum load (Newton) and the maximum displacement (mm).

Table 2: Data of Load and Displacement at the Maximum Load

Number of specimens	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1		
2		
3		
4		
5		
6		
mean		

Data is taken for each difference sizes of the nugget diameter. Aluminum specimen and Mild Steel specimens would have 3 tables respectively according to the nugget diameter. It means that the analysis of 4 mm nugget diameter will use 1 table as 5.0 mm and 6.0 mm. The example of the table used in this project is shown in **Table 2**.

The mean data for each type of material will be calculated and the table of this data is being recorded on the **Table 3**.

Table 3: The Mean Data for 4mm, 5mm and 6mm Nugget Diameter of Welded Sheets Metal

Nugget diameter (mm)	Load at Max. Load (kN)	Displacement at Max. Load (mm)
4		
5		
6		

From the data, the graph is being plotting to make the tensile strength comparison of each nugget diameter. The graph for this analysis is Load Versus the nugget diameter. This graph can be used to analyze and make a comparison for each nugget diameter. The examples of the graphs are shown in **Figure 5** and **Figure 6**.

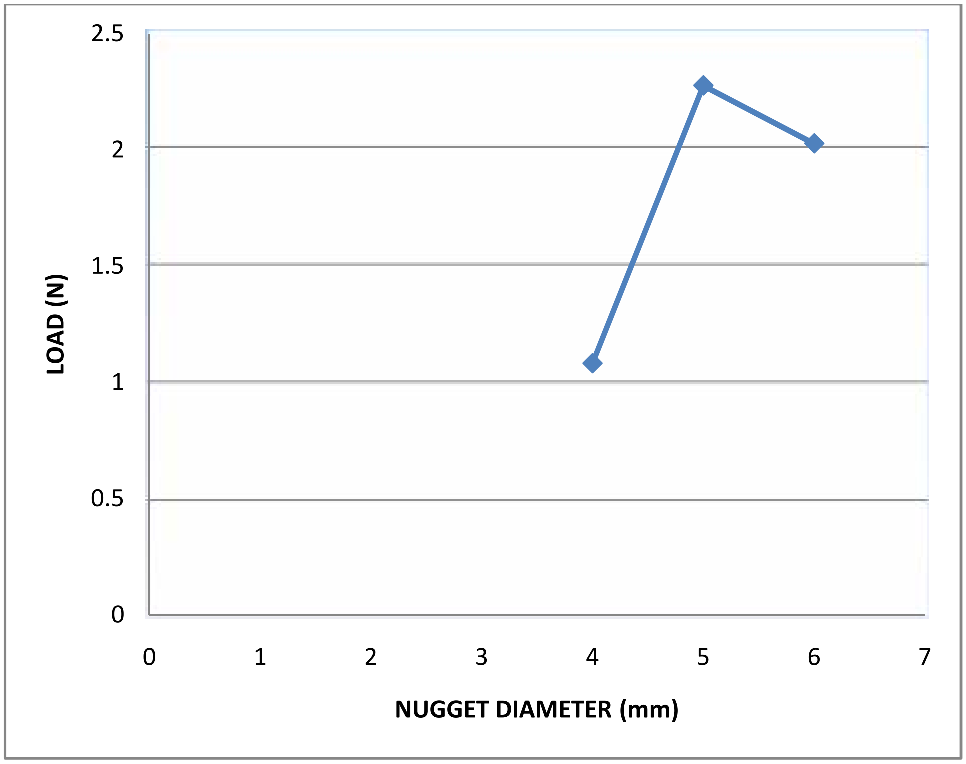

Figure 5: Load (N) Versus Nugget Diameter(mm)

Figure 5 shows the example graph of load versus the nugget diameter of the welded joint. The loads in the graph represent the maximum load (N) that can be applied in the tensile test before the joint of two welded sheet metal is fail or tear apart in each of the different nugget diameter (mm) of the analysis.

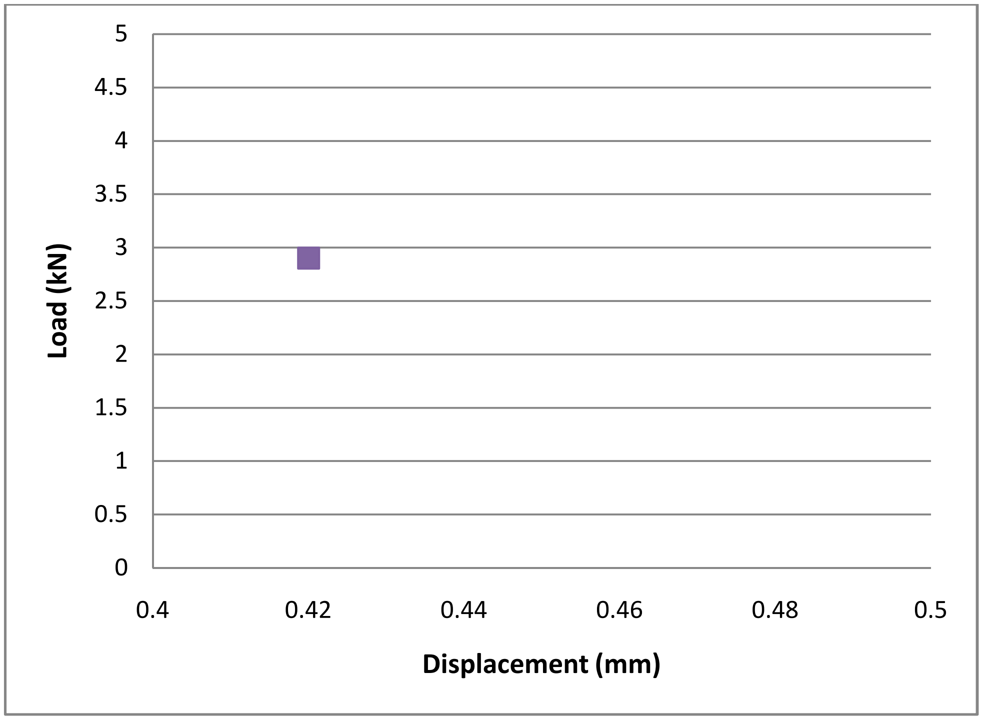

Figure 6: Loads versus Displacement

Figure 6 shows the example of the graph of Load versus Displacement. During the tensile test analysis, the load and the displacement of the welded joint will increase until at the maximum load, the joint will reach its limits and fail. The rupture occurred in the weld nugget of the spot weld. This graph could be obtained during the tensile test analysis are done and the data especially the maximum load of the tensile strength could be taken and recorded in the selected table.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discussed about the result and analysis obtained in the experiment and the effect of the tensile strength on the Aluminum-Aluminum and Mild steel-Mild steel welded joints specimens is discussed.

4.2 THE EFFECT OF THE WELDING CURRENT AND WELDING TIME TO THE NUGGET DIAMETER

The welding current and welding time is the main parameter in setting up the size of the nugget diameter in the resistance spot welding process. It is based on the equation

$$Q = I^2 R t \qquad [1]$$

where Q is the heat (Joule) input (Joule), I is welding current (Ampere), R is electrical resistance (ohm, Ω) and t is welding time (second). From the equation, as the I, the welding current and t, welding time is increases, hence the Q, heat input will also increase. Heat input during the welding process will verify the size of the nugget diameter. But, the parameter which most affects the heat, Q in this analysis is, the welding current I. Commonly, the value of the welding currents is in terms of kiloAmpere, (kA).Which is $1x10^3$ Ampere. For the welding time, mostly less than 10 second and the values of electrical resistance, R is usually is in μΩ, which is $1x10^{-6}$. Hence, the welding current is the most effect parameter to the nugget diameter size.

4.2.1 The Welding Current and Welding Time of Welded Aluminum-Aluminum Sheets Metal

Table 4 shows the applied of welding current and welding time to the Aluminum-Aluminum metal combination with the thickness of the sheet metal is 1.2 mm joint by using Resistance spot welding method.

Table 4: The Apply Current, I (kA) and Time (s) to Form the Required Nugget Size of Welded Aluminum-Aluminum

Nugget Diameter (±0.5mm)	Welding Current (kA)	Welding Time (s)
4.0	4.0	2
5.0	5.0	1
6.0	6.0	1

As the welding current is increased, the nugget diameter sizes also increased. 4.0 mm nugget diameter required 4.0 kA welding current. For 5.0 mm and 6.0 mm nugget diameter, both required 5.0 kA and 6.0 kA welding current respectively as shown in **Table 4**.

4.2.2 Welding Current and Welding Time of Welded Mild Steel-Mild Steel Sheets Metal

Table 5 shows the applied of welding current and welding time of Mild Steel-Mild Steel sheets metal.

Table 5: The Apply Current, I (kA) and Time (s) to Form the Required Nugget Size of Welded Mild Steel-Mild Steel

Nugget Diameter (±0.5mm)	Welding Current (kA)	Welding Time (s)
4.0	2.0	4
5.0	3.0	3
6.0	4.0	2

From the data shows in **Table 5**, the nugget diameter is direct proportional to the values of welding current. As the nugget diameter increased from 4.0 mm to 6.0 mm, the welding currents are also increased from 2 kA to 4 kA.

4.2.3 Effects of the Welding Current On The Nugget Diameter

Based on the result on **Table 4** and **Table 5**, the graph of welding current Versus the nugget diameter size is being plotted. The graph shown in **Figure 7** shows the effect of the welding current would affect the size of the nugget welded joints.

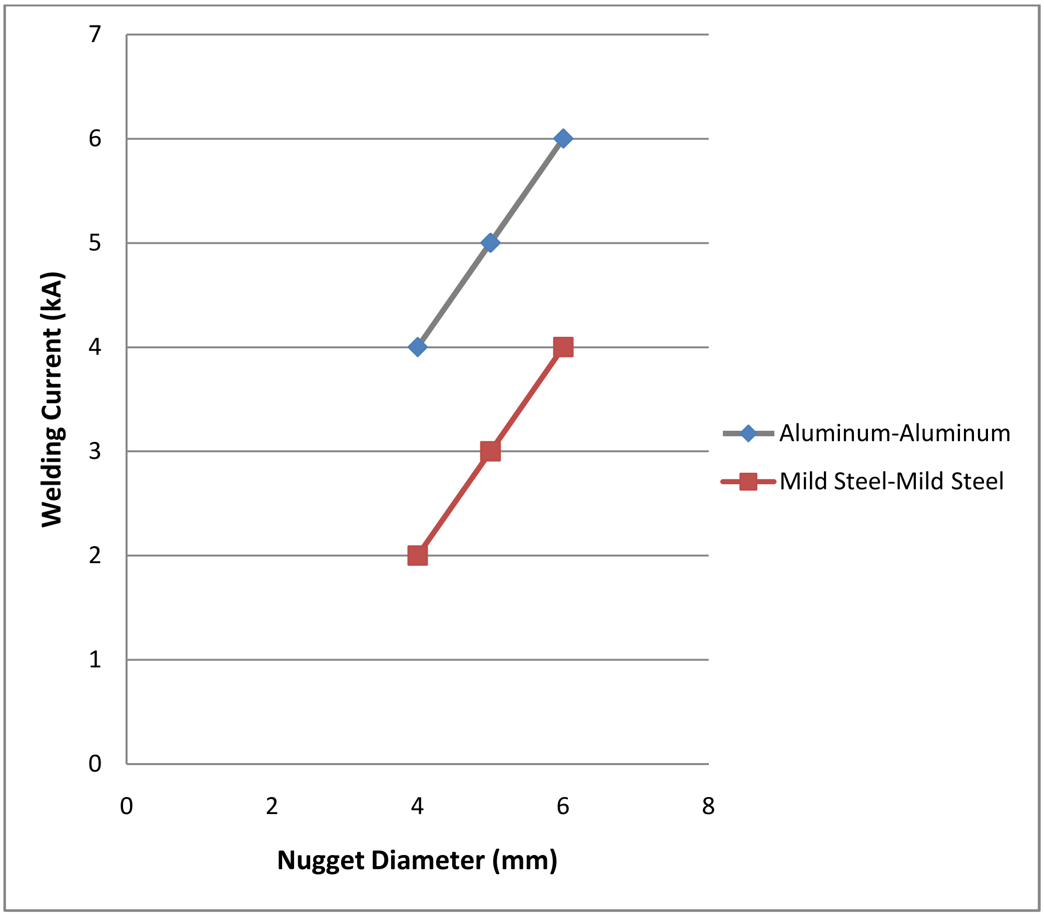

Figure 7: Welding Current Versus Nugget Diameter

To form the required nugget diameter, Pre-test is required to obtain the values of welding currents and welding times needed. Based on the Pre-test, as the welding current increase, the nugget diameter size will also increase. The graph of the data shows on **Figure 7**.

Nugget diameter size is increase when the energy input is increase, which is cause essentially by the enhancement of weld current. Based on the equation below

$$\mathbf{Q= I^2 Rt} \quad \textbf{(modification of the Ohm's Law)} \qquad \textbf{[1]}$$

it shows that increased the welding current, I (Ampere) and welding times, t (second) would increased the heat generated, Q (Joule). Hence, increasing the welding current and welding time would increase the nugget diameter size of the welded joint; but when the certain value is reach to the limit, the nugget diameter decrease because excessive melting and splashing [7]

Aluminum requires higher welding current than the mild steel to weld because the electrical conductivity for Aluminum is high [2]. It required 4 kA to weld the Aluminum sheets metal with nugget diameter is 4.0 mm, and for Mild Steel, the weld of 4.0 mm nugget diameter only required 2 kA to weld the joints of mild steel sheets metal.

4.3 TENSILE STRENGTH TEST ANALYSIS RESULTS

4.3.1 Tensile Strength Test Results for the Welded Joints between Aluminum-Aluminum Sheet Metal

1. 6 specimens of welded Aluminum-Aluminum sheets metal with nugget diameter is 4.0 mm is tested using the tensile test machine. The results are shown in the **Figure 8** below.

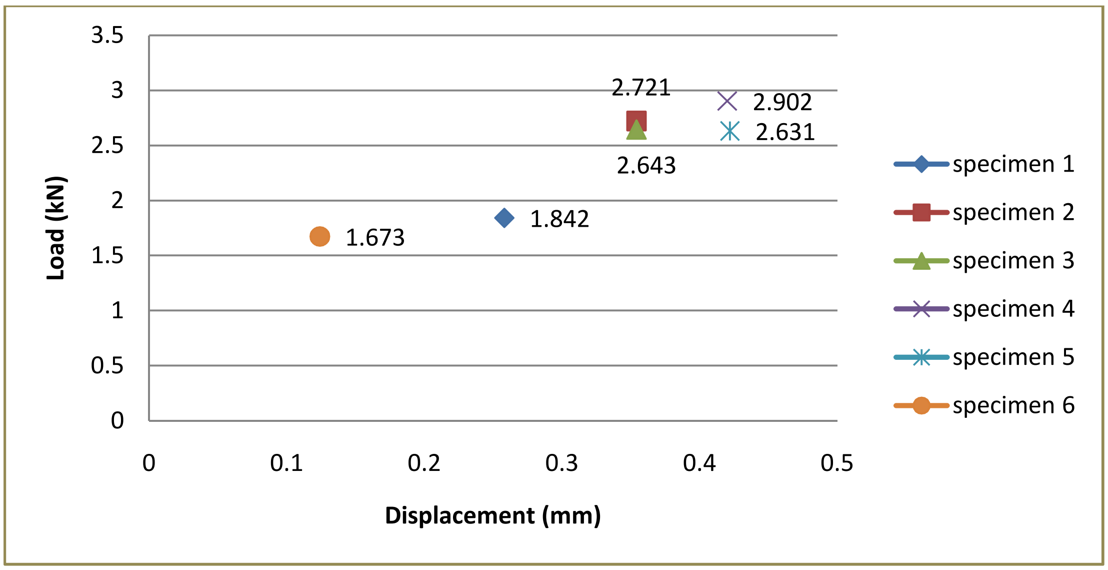

Figure 8: The Load (kN) Versus Displacement (mm) for 4.0 mm Nugget Diameter

The graph as shown in **Figure 8** is constructed based on data from **Table 6 (Appendix)**. The graph shows each specimen of the 4.0 mm nugget diameter its endurance limits to the tensile strength test. Each specimen is ruptured and tears apart when the specimens reached its maximum load which is applied on the welded joints during the tensile test. The mean data for tensile strength of 4.0 mm nugget diameter is 2.402 kN of maximum load with 0.322 mm displacement.

2. 6 specimens of welded Aluminum-Aluminum sheets metal with nugget diameter is 5.0 mm is tested using the tensile test machine. The results are shown in the **Figure 9** below.

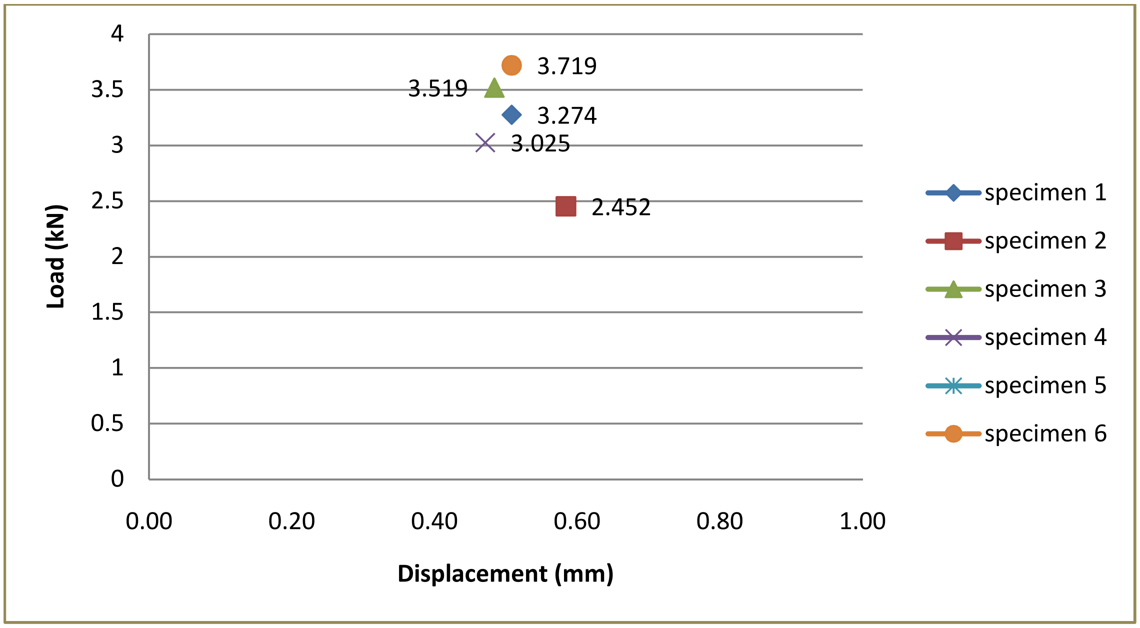

Figure 9: The Load (kN) Versus Displacement (mm) for 5.0 mm Nugget Diameter

From the **Table 7 (Appendix)**, the mean data for the tensile test analysis with the nugget diameter size is 5mm is 3.415 kN for maximum load and 0.525 mm for the maximum displacement of the welded joints. Each specimen results took from the analysis is plotted in the graph as shown in **Figure 9**, which is graph of the load (kN) versus the maximum displacement for 5.0 mm nugget diameter of welded Aluminum-Aluminum sheets metal.

3. 6 specimens of welded Aluminum-Aluminum sheets metal with nugget diameter is 6.0 mm is tested using the tensile test machine. The results are shown in the **Figure 10** below.

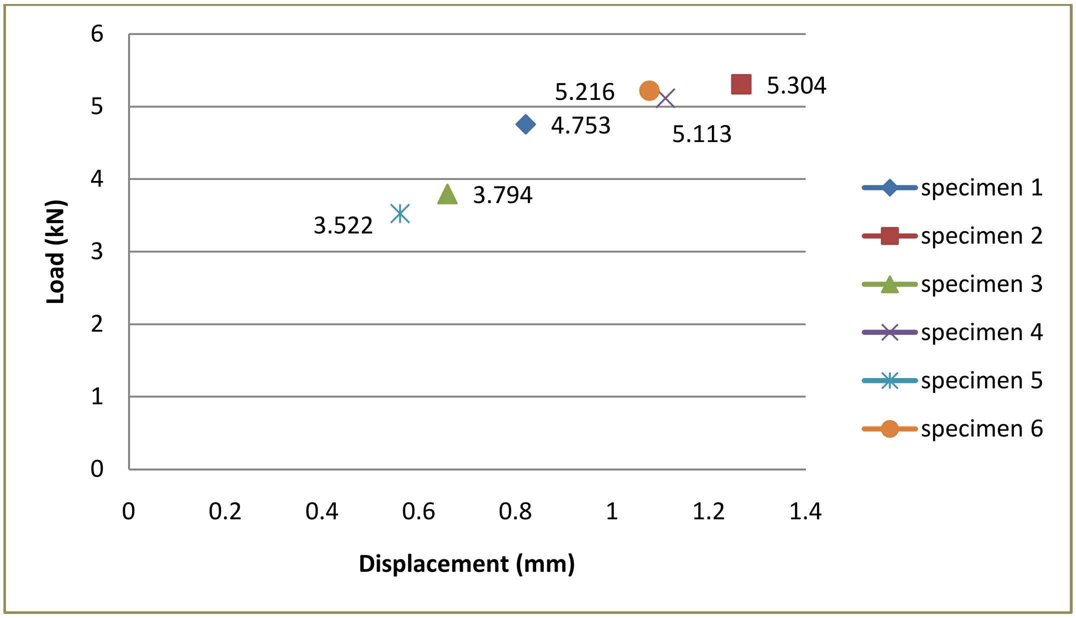

Figure 10: The Load (kN) Versus Displacement (mm) for 6.0 mm Nugget Diameter

The mean data for the graph shows in **Figure 10** is 4.617 kN for maximum load and 0.916 mm of maximum displacement. The data of each specimen is on the **Table 8 (Appendix)**.

4.3.2 Tensile Strength Test Results For the Welded Joints Between Mild Steel-Mild Steel Sheets Metal

1 6 specimens of welded Mild Steel-Mild Steel sheets metal with nugget diameter is 4.0 mm is tested using the tensile test machine. The results are shown on the **Figure 11** below.

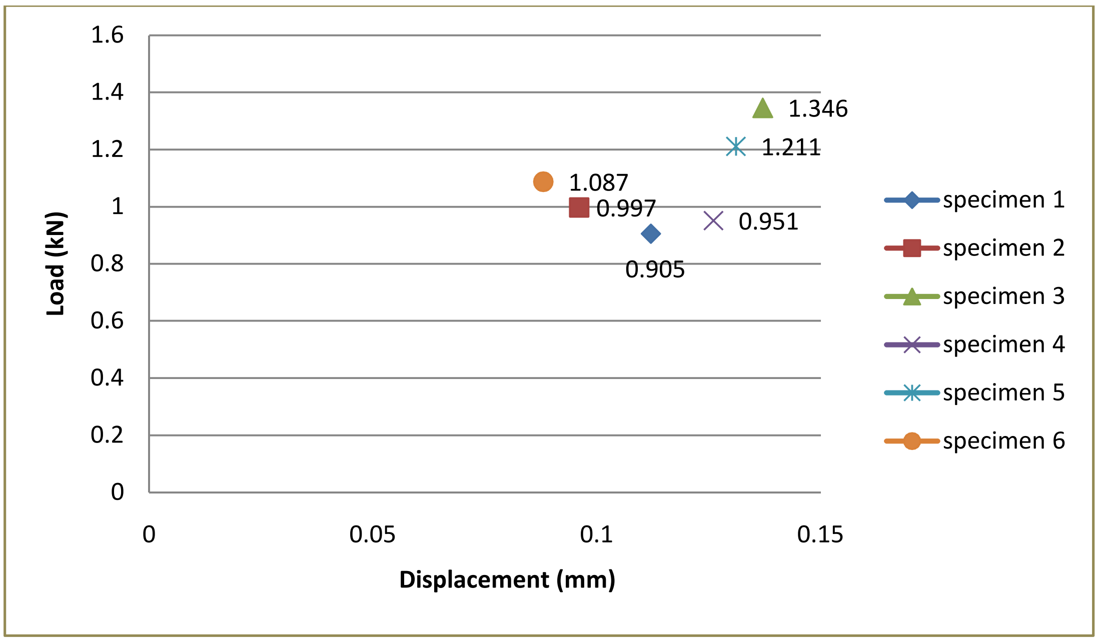

Figure 11: The Load (kN) Versus Displacement (mm) for 4.0 mm Nugget Diameter of Mild Steel-Mild Steel Welded Joint

Based on the result on the **Table 9 (Appendix)**, the graph as shown on **Figure 11** is constructed. The specimens shows the differences of the maximum load values applied in the tensile test before the specimens are tears apart. The mean data for 4.0 mm nugget diameter is 1.083 kN of maximum load and 0.115 mm of maximum joint displacement.

2. 6 specimens of welded Mild Steel-Mild Steel sheets metal with nugget diameter is 5.0 mm is tested using the tensile test machine. The results are shown on the **Figure 12** below.

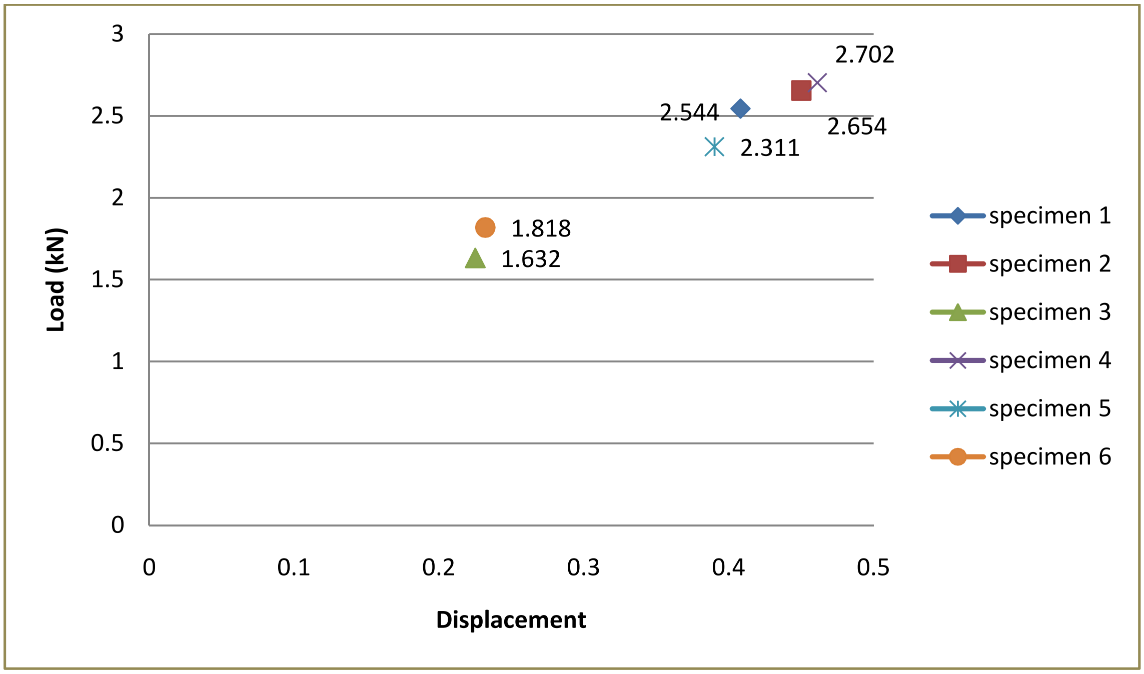

Figure 12: The Load (kN) Versus Displacement (mm) for 5.0 mm Nugget Diameter of Mild Steel-Mild Steel Welded Joint

The graph shown on **Figure 12** is based on the data of **Table 10 (Appendix)**.The mean data for 5.0 mm nugget diameter of welded Mild Steel-Mild Steel welded joint is 2.277 kN and 0.361 mm of maximum load and displacement respectively.

3 6 specimens of welded Mild Steel-Mild Steel sheets metal with nugget diameter is 6.0 mm is tested using the tensile test machine. The results are shown on the **Figure 13** below.

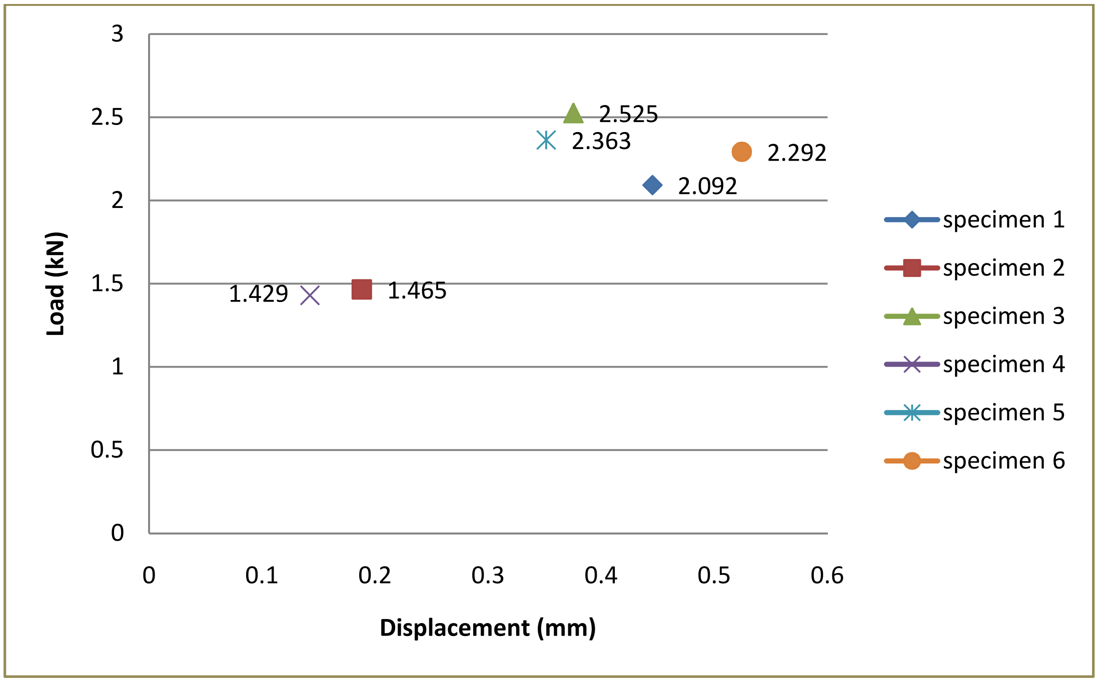

Figure 13: The Load (kN) Versus Displacement (mm) for 6.0 mm Nugget Diameter of Mild Steel-Mild Steel Welded Joint

Figure 13 shows the graph of the load (kN) versus displacement (mm) of the welded joint of Mild Steel-Mild Steel with nugget diameter size is 6.0 mm. The mean data of overall data of the specimen is 2.028 kN for the maximum load applied in the tensile test analysis and maximum displacement of the welded joint is 0.339 mm. The graph constructed based on the result **Table 11 (Appendix)**.

4.4 MEAN DATA

Each nugget diameter got 6 specimens to be tested. The selected nugget diameter is 4.0 mm, 5.0 mm and 6.0 mm because the range of 4.0 to6.0 mm nugget diameter is varied in the industrial application. From the 6 specimen, the mean data can be calculated. **Table 12 and Table 13 (Appendix)** shows the result of the mean data of each nugget diameter for both materials, which is Aluminum and Mild Steel. From the both table, the graph of Load (kN) versus the Nugget Diameter for the Aluminum-Aluminum and Mild Steel-Mild Steel welded joints are constructed. The graph is shows on **Figure 14**.

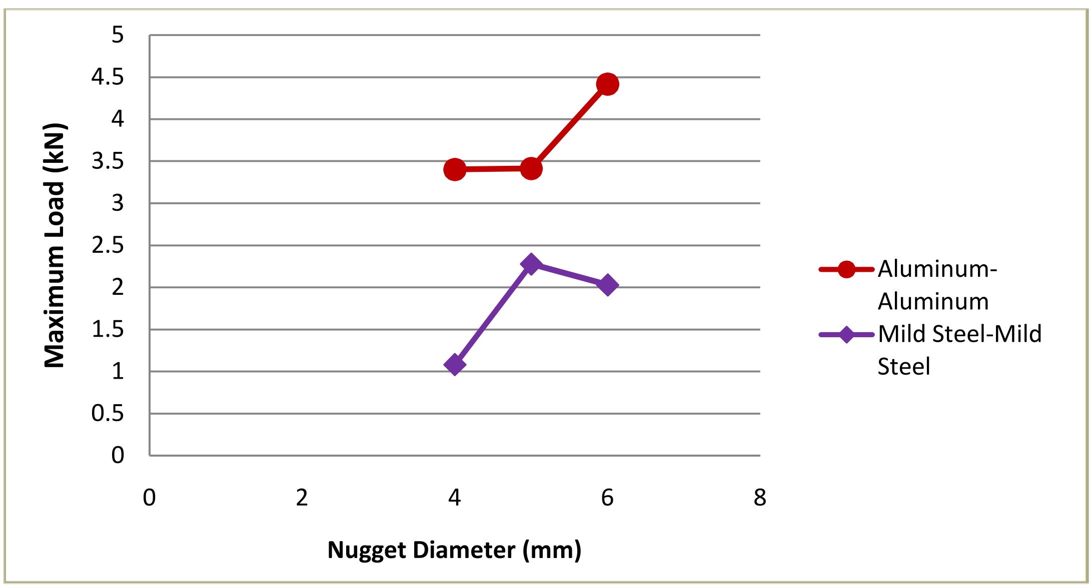

Figure 14: Load (kN) Versus Nugget Diameter

4.4.1 Tensile Strength for Aluminum-Aluminum Sheets Metal

From the graph on **Figure 14**, as the nugget diameter increase from 4.0 mm, 5.0 mm and 6.0 mm, the maximum load of the tensile strength before the specimen fail is also increase. The maximum load values increase from 3.402 kN, 3.415 kN to 4.417 kN as the nugget diameter increase. This is because the effect of the area that had been joints. As the area of welded joints increase, the strength of the tensile to hold the specimen from fail also increases. The greater the area of the joints, the strength to prevent the rupture of the welded joints will also greater. As the nugget diameter increase, the tensile strength for the welded Aluminum applied until it is tears apart also increase.

4.4.2 Tensile Strength for Mild Steel-Mild Steel Sheets Metal

The graph on **Figure 14** shows that as the nugget diameter increase from 4.0 mm to 5.0 mm, the maximum load apply to the tensile test also increase, that is from 1.083 kN to 2.277 kN. But, at the nugget diameter of 6.0 mm, the maximum load drop to 2.028 kN. As the nugget diameter increase, the maximum loads also increase for 4.0 mm and 5.0 mm nugget diameter. The effect is similar with the Aluminum-Aluminum welded joints tested by tensile test machine. Until the nugget diameter is 6.0 mm, the mild steel reaches its limits and the maximum load is lower than 5.0 mm nugget diameter maximum load value.

The tensile strength supposedly increases as the nugget diameter size is increase [7]. The nugget diameter size is the area of the welded joint in of the sheets metal. From the result on **Figure 14**, the tensile strength value dropped from 2.277 kN to 2.028 kN, 10.94 % differences. Weld quality and the Mild Steel properties might cause the lower tensile strength for 6.0 mm nugget diameter.

Mild steel is one of the low carbon steel types and it is easy to corrode. The rusty or the corrosions might affect the quality of the weld interrupt the flows of the current during the welding process.

The corrosion would cause the internal cracking of the welded joint which is contributed to the weakest tensile strength of the joint. Even the base metal itself would have low tensile strength if the sheet metal surface is corrode badly. The nugget diameter of 6.0 mm might have the higher value of tensile strength than 5.0 mm nugget, but the weld quality and the material conditions made the possibility for that result.

Mild steel is containing the carbon element. The carbon steels have a tendency to develop hard, brittle welds as the carbon content increases if proper postheating procedures are not used [9]. Hence, as the welding current increase, the possibility for the welded Mild Steel to develop hard and brittle also increase.

By evaluate the data for specimens with nugget diameter 5.0 mm and 6.0 mm, the range of the tensile strength load are so close. Referred to the data on **Table 10 and Table 11 (Appendix)**, the highest maximum load for nugget diameter 5.0 mm is specimen number 4, 2.702 kN and for 6.0 mm nugget diameter is, 2.525 kN, which is specimen number 3.

The values of maximum load are still in the range of 2.50-2.70 kN and it is possible for the tensile strength of 6.0 mm nugget diameter is higher than 5.0 mm if improvement are made to get the better weld quality and reduce the Mild Steel properties weaknesses.

Knowing that conditions, there are more parameters should be concern to get the better quality of the nugget diameter. Mild Steel sheet metal use for the test should clean and free from corrosion so these unnecessary parameters could be neglect.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter is the last chapter of this thesis. In this chapter, the conclusion of the project have been made and discussed about the whole result of the project.

5.2 CONCLUSION

Spot welding is the most simplest and it is commonly used is resistance spot welding process. Spot welding is used widely for fabricating sheets metal parts

The nugget diameter is one of the main parameter to determine the quality of the welded joint. The suitable nugget diameter size will result the higher endurance limits of the tensile strength. This is shows for Aluminum welded joint and mild steel welded joint.

From the analysis, for the welded joint of Aluminum-Aluminum, as the nugget diameter increasing from 4 mm to 6 mm, the loads in the tensile test also increase. The nugget diameter of 6 mm shows the higher of load value, which is 4.417 kN. The Aluminum welded joint; it can be concluding that 6mm nugget diameter is better than 4mm and 5mm because the maximum load (N) for nugget diameter of 6mm is greater than 4mm and 5mm. As the nugget diameter increase, the maximum loads also increase.

For the welded joint of Mild Steel-Mild Steel, the higher maximum load of tensile strength is 2.277 kN, which is tested using 5 mm nugget diameter specimen. As the nugget diameter increase from 4 mm to 5 mm, the tensile strength also increase from 1.083 kN to 2.277 kN, then the load is drop to 2.028 kN when using the specimen of 6 mm nugget diameter of the welded joint.

5.3 RECOMMENDATIONS FOR FUTURE WORK

To improve the tensile strength of the welded joint of the sheet metal, the suitable nugget diameter should be considered. The biggest size of the nugget diameter would not promise the better quality of the tensile strength of the joint. Some of the material, for example, low carbon steel, heat from welding process could change the origin properties of the metal; the consequences of the process made the metal weakest and bigger load could not be applied because the metal would fail early.

From the heating and melting process during the welding process, the others parameter also have to be considered not only the nugget diameter. Others parameters that effects weld quality are:

- Surface appearance
- Strength and Ductility
- Weld Penetration
- Sheets Separation
- Internal Discontinuities

Other parameter should be give attention too is heat affected zone. It is because as nugget diameter increase, the heat affected zone will also increase.

Heat affected zone (HAZ) is where the microstructure is changes and different from the original microstructure which is prior to welding. It is happens because the base metal has been subjected temporarily to elevated temperature during welding process. This conditions cause the grains will grow in size (grain growth), and the region of grain growth will be softer and have lower strength. The joint will weakest and the tensile strength will also weak [5].

Hence, for the future work of this project, the analysis should consider the HAZ and using microscopic to analysis and evaluate the surface of the HAZ. The sheet metal use in the analysis should be clean and free from any corrosion especially the Mild Steel. This would help to get the better data regarding the effects of the nugget diameter to the welded joint.

REFERENCES:

[1].Miller Electric Mfg Co, 2005. *Handbook For Resistance Spot Welding*

http://www.miller.com

[2]. Hong Yan Zhang, Jacek Senkara, *Resistance Welding*, 2006, Taylor & Francis Group.

[3]. Rotech Tooling Sweden, 2001. *Spot Welding Parameters*.

http://www.Robot-welding.com

[4]. Yung-Lee Dee, Jwo-Pan, Richard Hathaway, Mark Barkey, *Fatigue Testing and Analysis*, 2005, Elsevier Butterworth-Heinemann.

[5]. Serope Kalpakjian, Steven Schmid, *Manufacturing Engineering and Technology*, 2006, Pearson Education South Asia Pte Ltd.

[6]. M. Vural, A. Akkus, *Effect of Welding Nugget Diameter on the Fatigue Strength of the Resistance Spot Welding Welded Joints of Same Steel Sheets*, 2006, Journal of Materials Processing Technology 176 (2006) 127-132

[7]. Hatsuhiko Oikawa, Tatsuya Sakiyama, Tadashi Ishikawa, Gen Muruyama, Yasuo Takashi, *Resistance Spot Weldability Of High Strength Steel (HSS) Sheets for Automobile,* Nippon Steel Technical Report January 2007 no 95.

[8]. ATI Allegheny Ludlum, 2006. Stainless Steel

http://www.alleghenytechnologies.com

[9]. Ahmad Aziz Tahar, Ahmad Latiffi, *The influence of welding parameters and corrosive environment on the joint strength of resistance spot-welded mild steel sheets,* Universiti Malaysia Perlis. Apr-2008

[10]. William F. Smith, *Foundations Of Materials Science And Engineering*, 2004 McGraw Hill.

APPENDIX A

Table 6: Tensile Test Data Obtained for 4.0 mm Nugget Diameter of Welded Aluminum-Aluminum Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	1.842	0.258
2	2.721	0.354
3	2.643	0.354
4	2.902	0.420
5	2.631	0.422
6	1.673	0.124
mean	**2.402**	**0.322**

Table 7: Tensile Test Data Obtained for 5 mm Nugget Diameter of Welded Aluminum-Aluminum Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	3.274	0.508
2	2.452	0.584
3	3.519	0.484
4	3.025	0.471
5	3.501	0.596
6	3.719	0.508
mean	**3.415**	**0.525**

APPENDIX B

Table 8: The Tensile Test Data Obtained for 6.0 mm Nugget Diameter of Welded Aluminum-Aluminum Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	4.753	0.821
2	5.304	1.267
3	3.794	0.659
4	5.113	1.110
5	3.522	0.561
6	5.216	1.077
mean	**4.617**	**0.916**

Table 9: The Tensile Test Data Obtained for 4.0 mm Nugget Diameter of Welded Mild Steel-Mild Steel Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	0.905	0.112
2	0.997	0.096
3	1.346	0.137
4	0.951	0.126
5	1.211	0.131
6	1.087	0.088
mean	**1.083**	**0.115**

APPENDIX C

Table 10: The Tensile Test Data Obtained for 5.0 mm Nugget Diameter of Welded Mild Steel-Mild Steel Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	2.544	0.408
2	2.654	0.450
3	1.632	0.225
4	2.702	0.461
5	2.311	0.390
6	1.818	0.232
mean	**2.277**	**0.361**

Table 11: The Tensile Test Data Obtained for 6.0 mm Nugget Diameter of Welded Mild Steel-Mild Steel Sheets Metal

Number of specimen	Load at Max. Load (kN)	Displacement at Max. Load (mm)
1	2.092	0.445
2	1.465	0.188
3	2.525	0.375
4	1.429	0.142
5	2.363	0.351
6	2.292	0.524
mean	**2.028**	**0.339**

APPENDIX D

Table 12: The Mean Data for Aluminum-Aluminum Welded Sheets Metal

Nugget diameter (mm)	Load at Maximum Load (kN)	Displacement at Maximum Load (mm)
4	3.402	0.322
5	3.415	0.525
6	4.417	0.916

Table 13: The Mean Data for Aluminum-Aluminum Welded Sheets Metal

Nugget diameter (mm)	Load at Maximum Load (kN)	Displacement at Maximum Load (mm)
4	1.083	0.115
5	2.277	0.361
6	2.028	0.339