SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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EFFECT OF SPOT WELDING PROCESSING PARAMETERS ON FERROUS AND NON FERROUS METAL

By

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DECLARATION

I hereby declare that I have conducted, completed research project and written the dissertation entitled **“Effect of Spot Welding Processing Parameters on Ferrous and Non Ferrous Metal.”** I also declare that it has not been previously submitted for award of any degree or diploma or other similar title of this for any other examining body or University.

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Date : 25 June 2018

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LIST OF ABBREVIATIONS

RSW	Resistance Spot Welding
FZ	Fusion zone
HAZ	Heat affected zone
BZ	Base metal zone
DOE	Design of experiment
XRF	X-ray Fluorescence
GI	Galvanized Iron

LIST OF SYMBOLS

kA	Kiloampere
ms	Milisecond
mm	Milimeter
MPa	Megapascal
kN	Kilonewton
Q	Heat generation
I	Current supply
R	Resistance of materials and the contact interfaces
T	Time of current flow
$\tilde{x}$	Median
μ	Mean
σ	Standard deviation
z	Z score value

ABSTRAK

Kimpalan tempat rintangan adalah proses penggabungan logam yang telah digunakan secara meluas dalam industri sekarang ini terutamanya dalam industri aeroangkasa dan automotif. Kaedah RSW memberi tumpuan kepada gabungan kepingan logam kerana teknik terbatas kepada ketebalan tertentu sahaja. Terdapat banyak penyelidikan yang dilakukan untuk membincangkan tentang kesan parameter kimpalan terhadap sifat-sifat dan tingkah laku kawasan kimpalan bersama. Walau bagaimanapun, projek ini memberi tumpuan kepada parameter RSW terhadap kekuatan tegangan tempat bersama yang dikimpal. Parameter proses kimpalan yang dipilih adalah masa pemerasan, pada 50 ms dan 100ms, tekanan kimpalan, pada 0.37 kN dan 0.38 kN dan kimpalan arus, dalam 4kA dan 7kA . Eksperimen dijalankan dengan menggabungkan gabungan bahan-bahan yang sama untuk keluli, aluminium dan besi belgavanized dan kombinasi bahan yang berbeza untuk besi tembaga dan galvanis. Nilai skor Z untuk setiap kombinasi set dikira dan dilukis dalam graf berbentuk bel untuk memastikan semua nilai skor Z ditempatkan di antara julat -2 hingga 2. Terdapat beberapa masalah dalam kaedah RSW seperti tanda membakar pada tempat dikimpal bersama dan kerosakan permukaan disebabkan oleh tekanan semasa proses RSW.

ABSTRACT

Resistance Spot Welding (RSW) is the joining metal process that has been widely used in industry nowadays especially in aerospace and automotive industry. RSW method is focusing on the joining of sheet metal combination because of its limitation to the certain thickness only. There has many research has been done on discussing about the effect of welding parameters towards the properties and behaviour of spot welded joint. However, this project is focusing on resistance spot welding (RSW) parameters towards the tensile strength of the spot welded joint. The selected welding process parameters involved are squeeze time, of 50ms and 100ms, welding pressure, of 0.37kN and 0.38kN and also welding current of 4kA and 7kA. Experiments were conducted by joining the similar combination of materials for copper, aluminium and galvanized iron and dissimilar materials combination for copper and galvanized iron. The reliability of the data expressed in form of Z score value for each set combination. They are calculated and plotted in the bell shaped graph to make sure all the Z score value is placed between range of -2 to 2. There are some few problems in the RSW method such as burn marks on the spot welded joint and surface damage due to over pressure during RSW process.

CHAPTER 1

1.1 Research Background

Nowadays, Resistance Spot Welding (RSW) is one of the metal joining method that widely used in automotive and aerospace industries. RSW is a rapid process of joining method for sheet metal joining purposes in various application such as automotive parts, aerospace parts, and electric and electronic parts. Figure 1.0 shows the layout of the process in RSW process.

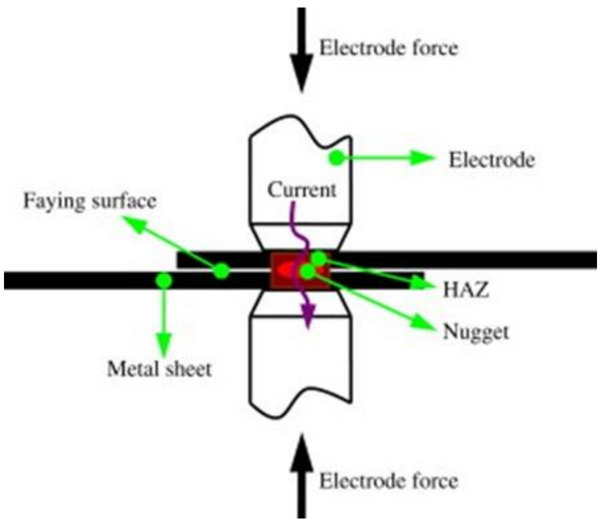

Figure 1.0 Resistance spot welding (RSW) process (http://mechtechroyal.blogspot.my)

RSW have advantages such as RSW method is it is a rapid joining process. There are no other things need consumable to assist the welding process as it is a clean and environmentally friendly welding process. Strength of the joint also is reliable by electro-mechanical joint process. During this RSW operation, a simple heat generation process will occur as the heat generated by the passage of current through resistance and it works similar as the heating coil. There are few parameters that need to be considered in RSW operation including weld current, squeeze time, and weld pressure. In nowadays industries, RSW process is performed using automated system of robot which needed minimum skill requirements. Besides that, the shortcoming of applying RSW technique is the capital cost for the equipment is high and the difficulty in disassembly the undesired welding joint.

RSW is typically used whenever welding process is done on certain particular types of welded wire mesh, sheet metal or wire mesh. Work pieces with thicker thickness are more difficult to spot weld because the heat flows into the surrounding metal more easily compared to the thinner work pieces. Aluminium alloys can be easily spotted welded, but as they have higher thermal conductivity and electrical conductivity, they require higher welding currents as well as larger and powerful welding transformers to undergoes the process. One of the most common applications of spot welding is in the automobile manufacturing industry, as it is used universally to weld the sheet metal in order to put in parts to produce a fabrication of car. To producing the best weld quality, some requirements need to be considered during welding process. First requirement is a good design practice must always allow adequate accessibility. Besides that, connecting surfaces should be free of contaminants such as scale, oil, and dirt, in order to ensure the quality of welds produced. However, metal thickness generally is not a factor in determining good welds. Figure 1.1 shows the configuration process involved in RSW. The typical configuration of the weld joint is lap joint between two sheets metal. Spot welding (SW) is the overlapping pieces of sheet metals at a spot by the application of pressure and electric current. Copper alloy is the common material used as the electrode of the spot welder machine. Pressure will be applied to the work pieces through the copper electrode and passed the electric current through it. The resistance between the upper electrode and lower electrode will generate heat at the work piece and the heat will develop at the interface between the two sheet metals at the sheets metal interface, weld pool is developed and with the assist of pressure by the electrodes the weld pool then cooled and form a joint called weld nugget between the work pieces' material (Aravinthan 2011).

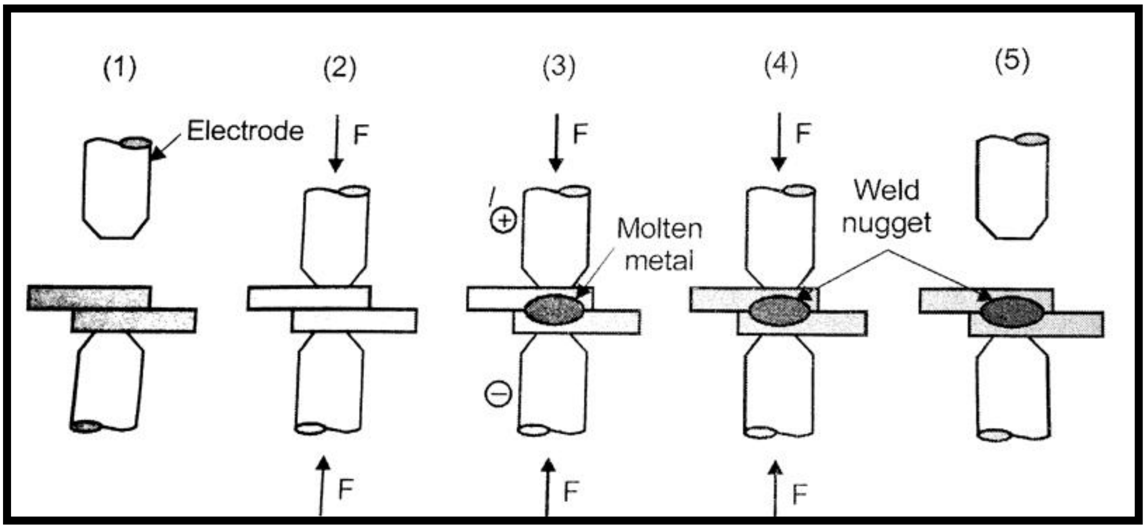

Figure 1.1 Configuration process involved in RSW (Aravinthan 2011)

In RSW, the weld nugget starts to form when there is sufficient heat generated at work piece interface. The formation of nugget is largely depending on the RSW process parameters including weld current, squeeze time, and pressure. These parameters need to be control in order to prevent any weld discontinuities. It is vital to choose and control the spot welding process parameters for obtaining optimal weld strength (Aravinthan 2011).

1.2 Problem Statement

Resistance spot welding (RSW) are the cheapest and efficient welding method among all of the welding technique in industry. Due to that, RSW is often being selected as the welding method for the continuous mass production process. Besides of efficient welding method, RSW also provide good strength and this strength is likely depend on the quality of the weld nugget formed between two sheets of the material. RSW is used primarily in various industries such as aerospace and automotive. The significant of choosing RSW method compared to other type of welding method in industry, for the reason that RSW process does not cause any damage to the work piece.

However, RSW may also has some shortcomings including lower strength at the spot welded joint. Besides that, the disadvantages could be the formation of undersized weld nugget and burn mark on the spot welded joint. Undersized weld nugget problem might occur once the current applied is too low and the weld time for welding process is too short. Meanwhile the burn marks on the spot welded joint occurs when the welding current used is too high and over of squeeze time uses during welding process. This study is done purposely to investigate the factor of resistance spot welding parameters towards the result of tensile shear strength. Undersized nugget and burn marks problems will eventually lower the strength of the weld. Other welding surface problems such as damage surface due to inadequate current, deep indentation mark as too high weld pressure is applied as well as weld splash that may form during welding process on the surface of the test piece due to high resistance between the joined materials. In performing RSW process, several parameters need to be considered in order to produce high quality weld. Hence, parameters of RSW used in this study are welding current, welding time, welding pressure and electrode tip diameter. Above and beyond, different materials with different composition may result in different electrical conductivity and thermal conductivity. Additionally, properties of electrical conductivity and thermal conductivity may play important role in determining the value of parameters used.

A study by Kahraman (2007) described that the formation of weld nugget size is important in determining the tensile shear strength of the spot welded joint Different size of nugget will contribute different values in terms of strength and toughness. Size of the resistance spot welding nugget can be controlled by adjusting the parameters of RSW process. By providing different set of parameters, different set size of weld nugget will be produced. By optimizing several parameters, we may have the chance to manufacture good welding joint with good tensile shear strength by using RSW machine.

1.3 Objectives

The objectives of the research are:

1. To study Resistance Spot Welding (RSW) ability of Ferrous metal and Non Ferrous Metal.
2. To investigate the different parameters of Resistance Spot Welding (RSW) towards various samples.
3. To observe the microstructure correlations of materials towards the load of the spot welded joint of the samples.

1.4 Scope of Works

In order to conduct this study, several types of materials such as copper, aluminium, and galvanized iron sheet metal with 0.5 mm thickness were used. As the initial procedure for this experiment, material characterization such as X-ray fluorescence (XRF) was used to determine the chemical composition of cooper, aluminium, and galvanized iron. Several parameters were considered for this experiment such as weld current, electrode tip diameter, weld time, squeeze time and pressure. All the parameters have been studied and optimized before choosing the best parameters which affect spot welded joint properties the most. The RSW parameters selected for this project were weld current, squeeze time and weld pressure in order to understand the relationship of the parameters chosen with the tensile shear strength of the spot welded joint. The tensile shear strength of the spot welded joint was investigated by using Instron Universal Testing machine. It was performed three times for a set of parameter.

Next, the sample was prepared for the microstructural observation. Sample has been moulded with the mixture of the resin polymer. Before the samples can be observed under optical microscope (OM), the samples must be grinded with silicon carbide paper and polished using diamond paste. Sample were prepared by grinding the surface of the cross section welding parts. Grinding process started with the lowest grid of silica carbide paper until highest grid of silica carbide paper. This grinding process was done purposely to remove the scratch on the surface. The process continued with the polishing process for the sample until the sample surface looked shiny and alike mirror. Lastly, microstructure evaluation on three zones (fusion zone, heat affected zone and base metal zone) was observed by using optical microscope (OM) to investigate the behaviour of the weld morphology. Various of magnification was used starting from 50X until 200X. Different set of etchants were used to evaluate the grains during the optical observation process. For galvanized iron materials, nital was used as the etchant meanwhile for aluminium materials, Keller’s etch was used. As for copper materials, combination of distilled water, hydrochloric acid and ferric chloride with certain amount was used as the etchant. The main purpose of using etchant was to expose and enhance the microstructure evaluation.

CHAPTER 2

2.1 Introduction

Resistance spot welding (RSW) is a welding process wherein combination is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by electrodes (Sahota et al. 2013). Larry (2002) mentioned that RSW is a combining process of two metal surface joint together by the heat produced from the resistance between two copper electrodes. The process is used extensively for joining low and mild carbon steel sheet metal components in automobiles, steel cabinets, aluminium furniture and similar products. In RSW, the weld nugget of the welded part is not clearly visible outside the work piece or the product. The work pieces are held together by the force from both electrodes. The process of RSW involving the thermal, mechanical, electrical and metallurgical factors (Li & Lin et al. 2007). The interaction between mechanical, electrical, thermal and metallurgical is important in determining the process parameters of the resistance spot welding. Copper electrode is usually used as the electrodes for RSW setup. Two copper electrodes are usually used to concentrate the welding into a small spot on the work pieces and to simultaneously clamp two work pieces together. RSW joint sheet metal together by overlapping two sheet metal and heat generated from the resistance between two copper electrodes will form a fused nugget between the work pieces. The amount of heat deliver to the materials is depending on the resistance between the electrodes and magnitude and duration of the applied current. There are several parameters need to be measured in the RSW process such as weld current, squeeze time, and pressure. The required amount of time current flows in the joint is determined by thickness and type of materials, the amount of current flowing, and the cross-sectional area of the welding tip contact surfaces. Joining two work piece of metal can be quick and efficient throughout SW process. The advantages of RSW are the process is comparatively low cost compared to other welding processes. Handling a spot welder machine does not need highly skilled worker, thus, it can actually reduce the labour cost. The process of RSW can be done in two ways; automatic or semi-automatic. Furthermore, the range of thickness of the work piece can be thin up to 0.5 mm sheet thickness and this characteristic made RSW has been used widely in automotive sector. Besides, RSW is capable to join multiple sheets metal join once at a time. However, RSW may cost an initial cost equipment of spot welder machine which is higher than other conventional arc welding machine (Pires & Loureiro et al. 2006). RSW on the other hand is able to create localized joint, which the welded zone is only at one spot. However, the joint of resistance spot welding (RSW) might not be particularly strong compared to other welding technique. The spot welded joint is highly depended on the parameters of the spot welding machine and the cleanliness of both the work piece and the electrodes.

2.1.1 History and Background

Resistance Spot Welding (RSW) are of the optimized method in various welding process. The effectiveness of RSW in performing good welding combination are proven by the uses of RSW method in various production industry in the world. RSW process is largely optimized to join assemblies with similar steel sheets; nevertheless, difficulties still exist with heterogeneous assemblies combining different steel sheets. The dissymmetry may be due to the differences in thicknesses, grades, and coatings between the steel sheets. This work deals with the understanding of the mechanisms that influence the development of the nugget in a specific combination of three steel sheets. Most RSW mainly used in manufacturing of various vehicles. This technology is applied to assembly sheet metal parts such as car body, aerospace, electronics and electrical appliances parts. Furthermore, RSW is one of the cost saving welding process as the process is simple without the need of any highly skilled workers as it is able to be handled by almost everyone. Most of the spot welders are automated operation, thus, it may promote the accuracy and the consistency of the welding process (Geslain et al. 2018).

2.1.2 Resistance Spot Welding (RSW) Overview

Resistance Spot Welding (RSW) is made up by allowing current to flow for certain period of time, throughout the work piece from upper electrodes to lower electrodes which may cause the welding force to join them. In RSW, the weld nugget of the welded part is not visible outside the work piece or the product. The force holds the work pieces together from both electrodes. The process of RSW involving the thermal, mechanical, electrical and metallurgical factors (Li & Lin et al. 2007). The interaction between mechanical, electrical, thermal and metallurgical is vital in determining the processed parameters of RSW. Typically, the metal sheets thickness is ranging from 0.5 mm up to 3.0 mm. Copper alloy electrode is used as the electrodes. Two copper alloy electrodes are usually used to penetrate the welding into a small spot on the work pieces and the materials are clamped in dies connected to the secondary of the resistance welding transformer. RSW joint sheet metals together by overlapping the metals, then, heat generated from the resistance between two copper electrodes will form a fused nugget between the work pieces. By forcing a large current input through, the spot will melt the metal faster and forming the result called weld formation. Between two copper electrodes inside or between the two sheet metal interfaces, the formation of weld nugget will form from the resistance. The amount of heat deliver to the materials is depending on the resistance between the electrodes and magnitude and duration of the applied current. Usually, the amount of heat applied during welding process is chosen by matching the material properties, materials composition and materials thickness.

Application of RSW is widely used in various industries especially in welding particular types of sheet metal, welded wire mesh and wire mesh. In contrast, thinner materials are more suitable to be used for RSW application but thicker materials are more difficult to be spot weld as the tendency to lose the heat is higher and heat is more likely to flow into surrounding metal.

There are several parameters considered in RSW process such as weld current, pressure, electrodes tip diameter, material thickness, squeeze time and hold time. The required amount of time current flows in the joint is determined by material thickness and type of materials, the amount of current flowing, and the cross-sectional area of the welding tip contact surfaces. Figure 2.0 shows the schematic of RSW and the weld nugget form as a result after RSW process.

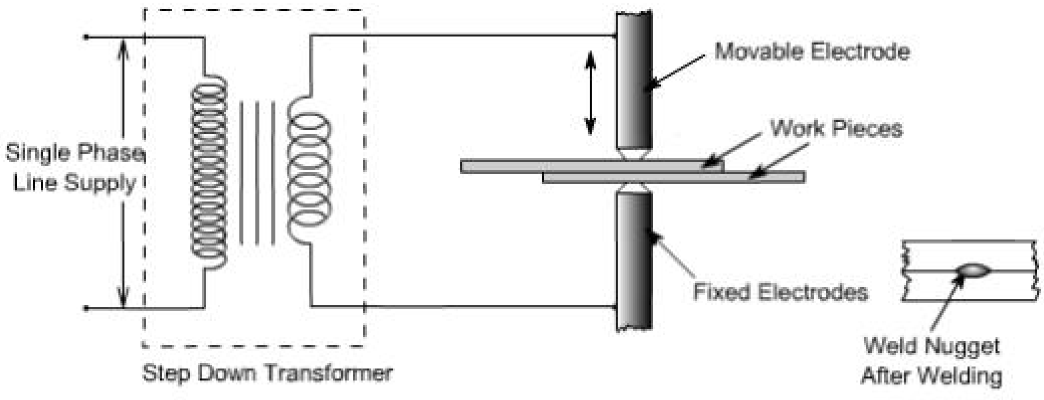

Figure 2.0 Schematic of resistance spot welding (Millers ,2010)

2.2 Types of Materials

2.2.1 Copper

Copper (Cu) is a shiny, reddish element which available adequately inside minerals of earth, and it is considered as one of the most important metal in industry these days. Copper is found as native metal and in the minerals cuprite, malachite, azurite, chalcopyrite and bornite. Copper ranks as third-most-consumed industrial metal in the world, after iron and aluminium. Copper is notorious for its habit of developing a green oxidation tarnish on exposed surfaces, which is caused by exposure to weathering. As it is kept away from water and moisture, it will not tarnish. The green tarnish is sometimes known as patina, especially when referring to historic statues and objects where the antique nature is enhanced by tarnish.

Copper is a tough, ductile and malleable material. These properties make copper extremely suitable for tube forming, wire drawing, spinning and deep drawing. The other key properties exhibited by copper and its alloys include as excellent heat conductivity, excellent electrical conductivity, good corrosion resistance, good machinability and good biofouling resistance. About three-quarters of the amount of copper used to make electrical wires, telecommunication cables and electronics. Almost all mined copper goes towards electrical and plumbing use. Copper has always been significant in coin minting, and continues to remain a standard in coins. Copper, as well as brass and bronze, are fashioned into utensils, ornaments, and statues, but rarely used in jewellery. In order to manufacture copper, care must be exerted with copper ornaments to prevent oxidization. They should be stored away from humid areas, and if they are washed they should be dried immediately.

2.2.2 Aluminium

Metal called Aluminium (Al) is the most abundant metal in the Earth's which is hardly and rarely found uncombined in nature. Mostly all ofaluminium mostly found in minerals such as bauxite and cryolite. Most commercially produced aluminium is extracted by the Hall–Héroult process. In this process, aluminium oxide is dissolved in molten cryolite and then electrolytically reduced to pure aluminium. Process of making aluminium is very energy intensive. However, properties of aluminium once it has been made it does not readily corrode and can be easily recycled.

Type of aluminium which is aluminium alloys is a family of aluminium which has been classified in series of it. Aluminium alloys is the alloys which the predominant metal is aluminium. In aluminium alloys, there are several alloying elements need to be added into the original metal to either increase the properties of the original metal or to lower its properties depends on purposed of the aluminium alloys used. The main alloying elements in aluminium alloys family are magnesium, tin, copper, zinc and manganese. Aluminium also used in a huge variety of products including cans, foils, kitchen utensils, window frames, beer kegs and aeroplane parts production. This is because of its particular properties as it has low density, non-toxic, has a high thermal conductivity, excellent corrosion resistance and can be easily cast, machined and formed.

Aluminium alloys is also non-magnetic and non-sparking materials. It is often used as an alloy because aluminium itself is not particularly strong. Alloys with combination of copper, manganese, magnesium and silicon are lightweight but strong in use. Those materials are very important in the construction of aeroplanes and other forms of transport. Besides that, aluminium is a good electrical conductor and is often used in electrical transmission lines in construction. It is because aluminium alloys cheaper than copper and weigh almost twice as good as conductor. When aluminium alloys is evaporated in a vacuum, aluminium forms a highly reflective coating for both light and heat. It does not deteriorate, like a silver coating would. These aluminium coatings have many usages, including telescope mirrors, decorative paper, packages and toys.

The high level composition of silicon in cast aluminium alloys is one of the important alloying system (Al-Si) which give the excellent casting characteristics. In industries of engineering component or structure, light weight metal and a good corrosion resistance metal are desirable (Polmear 1995). Accordingly, aluminium alloys has becoming one of the popular choice as they are having significant characteristics and properties.

2.2.3 Galvanized Iron

Galvanization is the process of applying a protective zinc coating to steel or iron in order to prevent it from rusting. Galvanized iron (GI) sheets are steel sheets which are basically coated with zinc through the process of hot dip galvanized and electro-galvanized steel sheets. Zinc weathers at a very slow rate, so the coating generally has a long life. Zinc has a greater electro-negativity than iron and hence provides cathodic or also called as sacrificial protection to the steel. This results in the zinc corroding in preference to the steel if the coating is chipped or damaged to expose the base metal. Galvanized steel consists of a thin sheet or strip of steel coated with a zinc layer to protect against rusting. Zinc has a low electrical resistance and a high thermal conductivity. Thus, in RSW processing, the resistance heat generation rate is low, while the heat transfer rate at the electrode-sheet and faying interfaces is high(Lin et al. 2018)

GI sheet also being widely used in automobile sector such as used for making car, bus and truck bodies, undercarriage work, air and oil filters, fuel and oil tanks and exhaust pipes. Besides that, GI sheet also being used in construction such as roofing element, side walls, partitions, panels, valley gutters, false ceiling, rolling shutters, highway bumpers and slotted angles. Purpose of GI widely used in construction and automotive industry are because GI can provide good strength during its application and can present corrosion due the absence of zinc at the outer layer of steel.

Advantages of GI sheets such as low cost because galvanizing process is lower in first cost than many other commonly specified protective coating for steel. GI sheet can be used in any weather and workplaces and GI sheets do not need regularly maintenance thus reducing the maintenance cost. Besides that, advantages of GI sheets also providing long life service. The life expectancy of GI sheets is quite high in rural, urban and coastal environment. Besides than that, GI sheets has a toughest coating, a galvanized coating has a unique metallurgical structure which gives excellent resistance to mechanical damage in transport, erection and service. Lastly galvanized coating is easily to inspect just by using sight and simply non-destructive thickness testing methods can be used.

2.3 Welding Morphology

During Resistance Spot Welding (RSW) process, the work piece will receive certain amount of the current which will be converted into heat and with sufficient amount of time and pressure, weld nugget will be formed between the interface of the work pieces. This process happened due to the flow of current through inside part of the material and melt the joining area of the work pieces. The RSW process involving the changes of microstructure of the material and the enhancement of the mechanical properties of the material. In RSW, there are three different welding zones that can be observed by using the metallography testing. Figure 2.1 shows separation of zone between fusion zone (FZ), heat affected zone (HAZ) and base metal zone (BM) (Aravinthan and Nachimani 2011). The observation of microstructural changing can be done by using optical microscope with magnification range between 50X to 200X. The metallographic samples were produced using standard procedure of resistance spot welding (RSW) and being observed with an optical microscope.

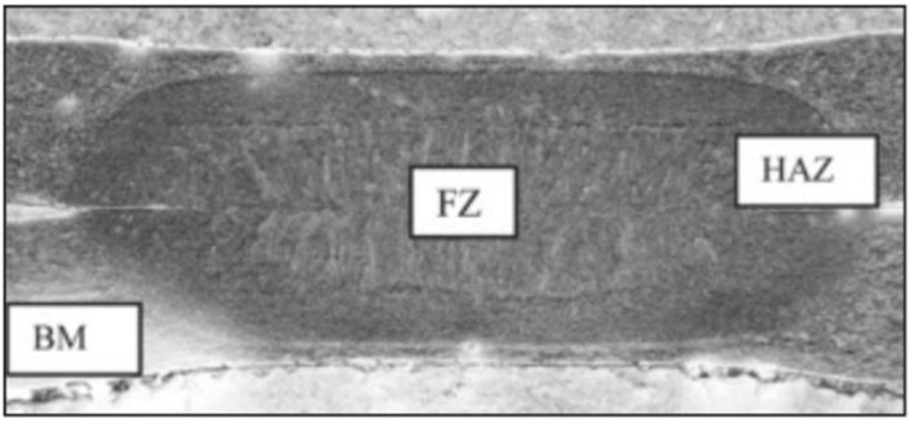

Figure 2.1 Separation zone of fusion zone (FZ), heat affected zone (HAZ) and base metal (BM) (Aravinthan and Nachimani, 2011).

2.3.1 Fusion Zone

The fusion zone (FZ) also called as weld zone is the melted zone between the interface of the work pieces which is melted during the welding process. This zone plays critical parts in determining the mechanical properties and strength of the joint. FZ undergoes process of microstructure changing and few of mechanical properties changing. The melted FZ then undergoes process of re-solidified and form microstructure which later give different microstructure from the base metal (BM), likely the combination of two work piece. Columnar grains at the FZ can be observed clearly in the Figure 2.1. The fusion zone will result in differences of mechanical properties from the heat affected zone and the base metal zone.

2.3.2 Heat Affected Zone (HAZ)

The heat affected zone (HAZ) is highly located between the fusion zone (FZ) and base metal (BM). HAZ is commonly not involved in melting but still undergoes microstructural changes as it receives sufficient amount of heat energy for the microstructure to have the ability to change. HAZ has the same chemical composition as the base metal but the microstructural and the properties of this zone is different from base metal due to the zone has been heat treated. Typically, the results on mechanical properties of heat affected zone is lower compared to fusion zone. The amount of alteration from the heat treatment of HAZ depends on several factors such as the time of the metal being exposed to welding temperature, the cooling rate of the process, the distance of the HAZ from FZ and the metal's thermal conductivity.

2.3.3 Base Metal Zone

The base metal zone (BM) is the original of microstructure and mechanical properties of the materials welded. It has no microstructural or properties changes. Usually BM zone located far from FZ, where the heat is supplied and microstructural changing occurred. The BM is mainly located at the outer layer of the weld nugget area. Microstructure at the BM does not face any different changing from the welding process happened because of its position, thus it does not change the mechanical properties and strength of the material. Microstructure at BM can be used to compared microstructural change occurred at FZ and HAZ.

2.4 Resistance Spot Welding Parameters

In the Resistance Spot Welding (RSW), the parameters of the welding process are important in determining the weld nugget formation and weld quality. There are few parameters that need to be considered during the welding process. Parameters in RSW process will determine the strength and quality of the welded work piece. The three main parameters in RSW are welding current, welding time and electrode force which also known as the welding pressure. Other parameters such as squeeze time, hold time and diameter of the electrode contact surface only plays minor role in the resistance spot welding process. All these parameters can be controlled on the RSW machine (Williams & Parker 2004). Determination of optimized welding parameters is a complex issue. In RSW, a change of one parameter might affect other parameters as well as affect the product.

2.4.1 Weld current

In Resistance Spot Welding (RSW), welding current is one of the most important parameter in determining the quality of the weld. The weld current is the current that are used during welding process and usually the unit used is Kilo-Ampere (kA). Weld current determine the heat generation during the welding. The principle of resistance spot welding is the Joule heating law. The heat generated is highly depending on the current (I), resistance (R) and time (t). Equation 2.1 shows the Joule heating law is expressed in the formula below.

$$Q = I^2Rt$$

Q: Heat generation

I: Current supply

R: Resistance of materials and the contact interfaces

T: Time of current flow

Equation 2.1 Formula of Joule heating law

The amount of weld current can be controlled by adjusting the value or percentage that are given to complete the welding process. The value of weld current is different for each material. Each material has different electrical conductivity and thermal conductivity. Thus, different amount of current is needed to generate sufficient heat to complete the welding process. In RSW, low amount or percentage of current are not recommended as it might reduce the quality of the weld (Aslanlar & Ogur et al. 2008). The weld nugget size is increasing rapidly by the increment of weld current during welding process. Large weld nugget size will give a significant strength to the welded zone but too much current supply might result in deterioration of the electrode and other type of undesired welding defects such as burn marks, spatter and expulsion. Thus, constant current control usually used in welding production to control the size of weld nugget formation and the to obtain a stable process (Zhou & Cai 2013). The typical types of welding current used in resistance spot welding are alternate current (AC), condensator discharge (CD) and middle frequency inverter DC. The most current supply used in the production is alternate current (AC). Mostly for the welding current in a body shop environment has a range of 2000 to 7000 amperes (A).

2.4.2 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 towards the work pieces. The squeeze time is necessary to delay the weld current until the electrode force has attained the desired level. Parameters squeeze time used are usually between 50ms-100ms. Squeeze time is allowing the weld head to settle prior to the application of weld current. Suitable squeeze time produces the best quality weld at the highest production rate of welding.

2.4.3 Pressure

The effect of pressure on the RSW should carefully being considered. The main major purpose of pressure is to hold the parts to be welded in close contact at the joint interface. Pressure used between range 0.3 kN-0.4 kN. High pressures exerted on the weld joint will decrease the resistance at the point of contact between the electrode tip and the work piece surface. Proper pressures, with close contact of the electrode tip and the base metal, tend to conduct heat away from the weld. Higher currents are necessary with greater pressures and, conversely, lower pressures require less amperage from the resistance spot welding machine. This fact should be carefully noted, particularly when using a heat control with the various resistance spot welding machines.

2.4.4 Advantages and Disadvantages of RSW

Resistance spot welding (RSW) is one of the metal joining process which used resistance between two electrodes to form weld nugget between the work pieces. Joining two work piece of metal can be quick and efficient by spot welding process. The advantages of RSW process is it is comparatively low cost compare to other welding processes. Handling a spot welder machine does not need highly skilled worker. Thus, it can actually lower the labour cost. The process of RSW can be done either automatic or semi-automatic. In a car body assembly factory, spot welder machines can produce up to 200 spot in six seconds. Furthermore, the range of thickness of the work piece can be as thin up to 0.5mm sheet thickness. Multiple sheets metal can be join at one time.

Besides that, RSW also can be done in quick succession. It just needs a few seconds to make the join. Lastly the joint made is clean and highly uniform. However, the equipment cost is high so it can has an effect on the initial cost and RSW initial equipment cost of spot welder machine is higher than others conventional arc welding machine (Pires & Loureiro et al. 2006). RSW is used specifically to create localized joint, which the welded zone is only at one spot. The joint might not be particularly strong. The spot welded joint is highly depended on the parameters of the spot welding machine and the cleanliness of both the work piece and the electrodes. The maximum sheet metal can be spot welded is around 5 mm. Thus, RSW is not suitable to be used on thick materials.

Other than that, some metals need special surface preparations for making joint success and in some case skilled welders or technicians are needed for the maintenance and controlling. Besides than that, as the number of welds made with a pair of electrodes increases, damage to the electrodes occurs as a consequence of the high pressures and current densities acting on the electrode face. The thermal and mechanical cycles developed causes the electrode to deform leading to electrode tip growth. Lastly setup process for implement resistance spot welding is difficult compared to others arc welding (Williams & Parker 2004). Figure 2.2 shows the examples of faults that might occur in RSW.

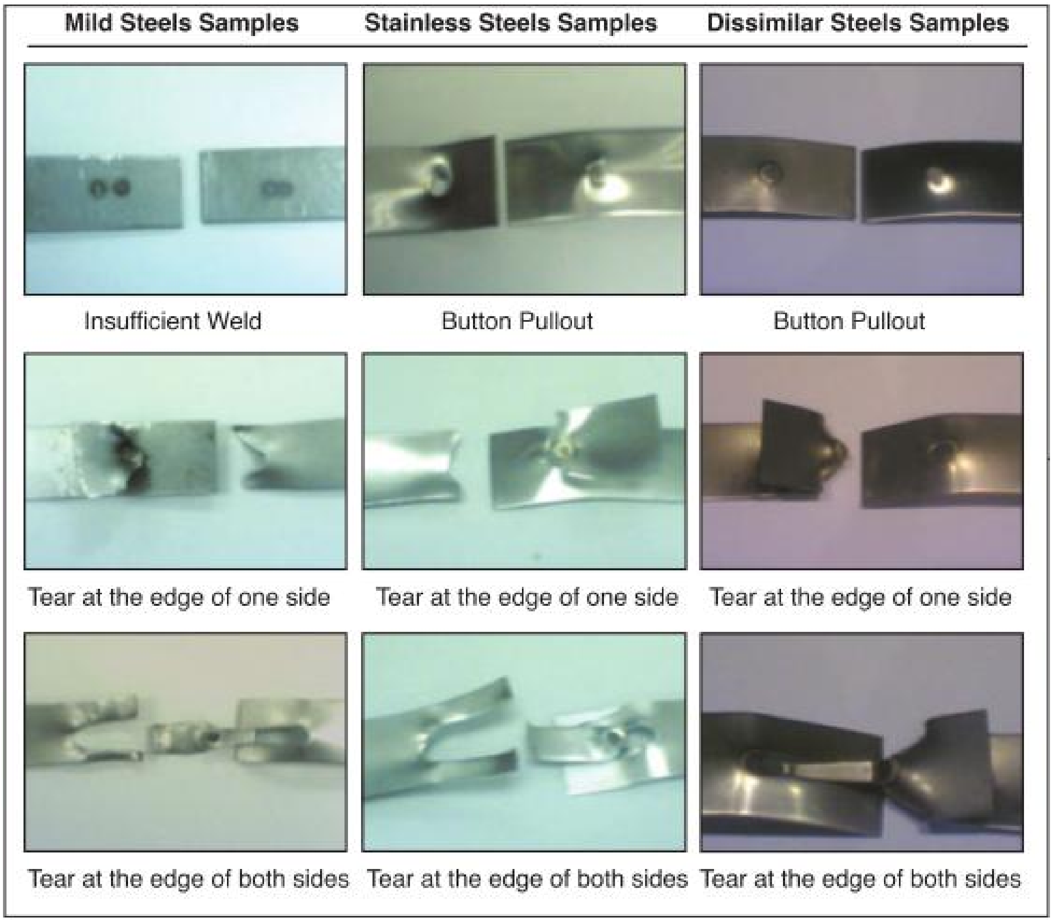

Figure 2.2 Faults in RSW

2.5 Properties of Welded metal

The solidification or phase transformation during the thermal cycle is the most important parts in determining the final microstructure of the weld metal and also will give greatly influence towards the properties of welding material. Process of welding will determine the weld geometry, weld size and usually composition of the melt as influenced by the filler material, the base material, fluxes, gas, pressure, moisture ad how the clean the joint was. Factor of speed can contribute to the strength properties of welded parts. The speed of welding and its effect on solidification speeds, crystal growth and segregation. Extremely high welding speeds in the present work, produced very poor metallic bonding and were ignored. As we know, heat input is proportional with inverse of welding speed. Therefore, with increasing the welding speed, a lot type of defect is more likely to occur. As a matter of fact, decreasing the welding speed gives effective influence on the plastic flow and consequently increasing the heat input (Saeid, Abdollah-zadeh & Sazgari 2010).

Controls over cooling rate in a particular fabrication is therefore achieved by varying heat input and preheat temperatures. The cooling rate has an influence on the mechanical properties of the weld and heat affected zone (HAZ). The cooling rate that is necessary to reach for the weld depends on the composition of the filler material used and the amount of hydrogen in the weld metal. Thickness of the welding structures will greatly influence towards the mechanical properties of structure. Welding the structure with small thickness usually will give slow cooling rate, which mean will decrease the mechanical properties such as decrease 0.2% proof strength and impact properties (Hakansson 2002).

Heat treatment process during welding is often very helpful in maintaining weld joint strength because it softens or tempers any martensite or bainite that has formed inside HAZ and also avoid stresses that can lead to cracking. During heat treatment can change grain size, modify the hardness, ductility, toughness and tensile strength. Besides that, good heat treatment process during welding can improves electrical, magnetic and machinability of materials. Good heat treatment during welding also modify the chemical composition and properties of metal surface.

It is well known that the micro structure of base metal as well as HAZ are somewhat different with respect to distributions of pearlite, ferrite, and grain size depending on the weld condition adopted. In a pass of the welding touch, the material is rapidly heated to the maximum temperature and allowed to cool more slowly by conduction of heat into the bulk of the parent metal. Phase changes can occur depending on the temperature reached. Sufficiently far from the weld pool, the material remains unaffected. The region next to the fusion zone where microstructure changes have occurred but no melting of base metal has affected is known as heat affected zone HAZ. Such microstructure changes can affect the mechanical properties of the weld and need to be controlled. The weld metal microstructure is controlled mainly by the cooling cycle. At lower energy input towards the materials means the time for solidification is less. The rapid cooling promotes smaller grains. With higher energy input, the time required for solidification decrease, and therefore cooling rate slows down which yields coarse grain. Coarse grain in the microstructure indicates lower hardness and low tensile strength (Asibeluo & Emifoniye 2015).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the experimental procedure and the materials used for completing this research study. Figure 3.0 shows the flow chart of summarized procedure from the beginning of the research. The flow chart included the summarized of methodology, testing and analysis that have been completed. The chemical composition of the starting materials was determined by X-ray fluorescence (XRF) spectrometer. The microstructural studied was performed by using optical microscope (OM) to investigate the relationship of microstructure towards strength properties of spot welded joint. Tensile shear testing is conducted to study the strength and mechanical properties of the welded work pieces. The weld nugget diameter of each of the experiments were taken by using stereo zoom microscope. Analysis of variance on the tensile shear test results were performed to determine the significant factors of resistance spot welding parameters for cooper, aluminium and galvanized iron with thickness 0.5mm. Confirmation tests were performed and analysed to validate the developed model. The confirmation test samples undergo mechanical test and microstructural observation to study the effect of the significant factor.