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STUDY THE EFFECT OF THE SPOTS DISTRIPUTION IN SPOT WELDING

دراسة تأثير توزيع البقع في لحام النقطة

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الآيه

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قال الله تعالي:

﴿قُلْ هُوَ اللَّهُ أَحَدٌ (1) اللَّهُ الصَّمَدُ (2) لَمْ يَلِدْ وَلَمْ يُولَدْ (3) وَلَمْ
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Dedication

This research is dedicated to my parents and brothers for them continues support, encouragement, and their understanding throughout the period of my studies.

To my colleagues and General family members who assisted and encouraged us in various ways.

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ABSTRACT

This research presented a study of tensile strength and toughness method of welding joints in spot welding of 0.5 mm thicknesses low carbon steel sheets (Grade 1.8969 S600MC). six specimens welding joints were subjected to tensile shear using a tensile test machine, and the effect of welding time, welding current and welding pitch was studies. Period of weld current, weld time, and welding pitch is 6 - 8 KA, 8 -10 cycle and 10 - 20 mm respectively was selected during the welding process. In this experiment increase in welding current and welding time, the joint strength and toughness of welding increase, and decrease in welding pitch, the joint of weld became strong against pullout failure mode. The optimum parameter for tensile shear test at welding current 8 KA, welding time 10 cycle and welding pitch 10 mm, the highest tensile strength and toughness 109.85 Mpa and 32.17 J respectively at weld current 8 KA, weld time 10 Cycle and weld pitch 20 mm. Finally, the comparison result shown the higher strength and toughness of joint spot welding sheet.

المستخلص

قدم هذا البحث طريقة دراسة مقاومة ومتانة الشد عن طريق توصيل شريحتين معدنيتين بواسطة استخدام لحام النقطة، سمك اللوح الحديدي 0.5 مليمتر من الصلب منخفض الكربون (نوع 1.8969 S600MC). حيث تم تعريض الوصلة اللحامية لشد قصي باستخدام آلية اختبار الشد لستة عينات اختبارية تحت تاثير التيار والزمن وكذلك طول الخطوة. يتراوح مدى التيار، والزمن وطول الخطوة 6-8 كيلو امبير، 8-10 دورة و 10-20 مليمتر على التوالي تم اختيارهم وفقا لعملية اللحام. في هذه التجربة بزيادة تيار ومدة اللحام فان مقاومة ومتانة اللحام للوصلة المركبة تزيد مع تقليل طول الخطوة، حيث تصبح الوصلة اللحامية مقاومة اكثر ضد عملية الخلع. وجد ان العومل المثلى بالنسبة لاختبار الشد القصي تكون تكون عند تيار 8 كيلو امبير وزمن 10 دورة بطول خطوة 10 مليمتر، اقصي مقاومة ومتانة شد عند 109.85 ميقا باسكال و 32.17 جول علي التوالي عند تيار لحام 8 كيلو امبير وزمن 10 دورة. اخيرا تم مقارنة النتائج المتحصلة لأقصي مقاومة ومتانة شد للشريحة الموصلة بواسطة لحام النقطة.

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LIST OF ABBREVIATION

Abbreviation	Name
RW	Resistance welding
RSW	Resistance Spot welding
AC	Alternating current
DC	Direct current
ST	Squeeze time
WT	Weld time
CCT	Continuous-Cooling Transformation
TTT	Time-temperature transformation
WPS	Welding Procedure Specifications
PQR	Procedure Qualification Record
WPQR	Welding Procedure Qualification Record
AWS	American Welding Society
ASME	American Society of Mechanical Engineers
AISI	American iron and steel institute
HAZ	Heat affected zone
FZ	Fusion zone
BM	Base metal
IF	Interfacial failure
PF	Pullout failure

LIST OF SYMBOLS

symbol	**Name**
H	Heat generated (J)
I	Current (A)
R	electrical resistance (Ω)
t_C	Time to current flow
e	Combined sheet thickness (mm)
Ω	Ohm
J	Joule
A	Ampere
t	The sample thickness (mm)
b	The sample width (mm)
L	The sample length (mm)
a	Welding pitch (mm)
P_{IF}	Failure load for interfacial fracture
A_{IF}	The weld interface area
t_w	The shear strength of the material at the weld interface
σ_{max}	The maximum tensile stress occurring at the loading line.
r	The weld nugget radius
σ_{haz}	The fracture tensile stress of the material
ε	Strain in the material
ε_R	Strain at rupture
U_T	Modulus of toughness ($J.m^3$)
σ	Shear Stress in the cylindrical area of the weld (Mpa)
σ_Y	Yield Strength (Mpa)
σ_U	Tensile Strength (Mpa)
P	Shear Force (KN)
A_C	Cylindrical Area of the Weld (mm^2)
I	Number of Welds
D	Spot Weld Diameter (mm)
T	Tensile toughness (J)
P_Y	Yield Shear Force (KN)
P_U	Ultimate Shear Force (KN)
V	Volume of the Weld (mm^3)
ΔL	Change in Length (mm)

CHAPTER ONE

INTRODUCTION

Introduction

1.1 Background

Spot welding is one of the oldest welding processes. It’s one form of resistance welding, which is a method of welding two or more metal sheets together without using any filler material by applying pressure and heat to the area to be welded. Resistance spot welding is a widely used joining process for fabricating sheet metal assemblies such as automobiles, truck cabins, rail vehicles and home applications due to its advantages in welding efficiency and suitability for automation. For example, a modern auto-body assembly needs 7000 to 12,000 spots of welding according to the size of a car, so the spot welding is an important process in auto-body assembly. Spot welding is an economical and primarily method for joining metals because its speed ,precision, efficiency, and resulting cost reductions afforded by automated resistance spot welding are well documented and accepted, actually in automotive industry. The method is adaptable to high speed automation and is under strict cycle times.

The spot welding process is used to join sheet materials and uses shaped copper alloy electrode to apply pressure and convey the electrical current through the work pieces. In all forms of resistance welding, the parts are locally heated. The material between the electrodes yields and is squeezed together. It then melts, destroying the interface between the parts. The current is switched off and the "nugget" of molten materials solidifies forming the joint. The material has a higher electrical resistivity and lower thermal conductivity than the electrode used is suitable to choose such as steel because it making welding relatively easy.

For another material, such as aluminum, it’s electrical resistivity and thermal conductivity is closer to copper but the melting point for this material is lower than copper, make a welded is possible [1].

In the spot welding, it has some parameter to be considered. These parameters will affect the quality of the welds. The suitable combination of the spot welding parameter will produce strong joining and have a good quality of weld. Spot welding parameters include:

- Electrode force
- Diameter of the electrode contact surface
- Squeeze time
- Weld time
- Hold time
- Weld current

The strength of the joint in this process depends on the number and size of spot welded structure of the welds. The diameters size for spot weld is range from 3 mm to 12.5 mm. To investigate the strength of spot welds in terms of the specimen geometry, welding parameter, welding schedule, base metal strength, testing speed and testing configuration the tensile test method also can use to investigate the strength of the spot weld [1].

Due to the applied pressure by the electrodes during the welding, the thickness of the nugget is usually less than the thickness of the two metal sheets. This nugget indentation is not significant for plate thickness up to 1 mm, but is more feasible when thick plates are assembled. When a change of thickness takes, place stress the concentration may occur at the edges, which may result in crack initiation. Also, the transient heating and cooling results in hardening of the material, and a pre-stress may remain after cooling [2].

1.2 Problem Statement

1. Failure in spot weld joining parts because of un suitable setup of welding parameter which causes a low strength of joint.
2. The best design in term of orientation using spot weld joining need to be considered.

1.3 Research Objectives

The objectives of the research are:

1. To check the toughness of the joined by parts spot welding.
2. To compare the quality joining with different weld time and different weld current.

1.4 Project Scope

This research is focus in spot welding method. This focus area is done based on the following aspect:

1. Only one material, one thickness and one orientations that will be use in this research.
2. Base on mild steel material.

1.5 Dissertation layouts

In addition to chapter one this dissertation consists of five chapters. Chapter two gives the literature review of resistance welding, power source, classification of resistance welding processes, the principle of spot welding, parameters and material selection. Chapter three gives methodology. Chapter four discuses the results. Finally, chapter five gives conclusions and recommendations of the work.

CHAPTER TWO

LITERATURE REVIEW

Literature Review

2.1 Resistance Welding

Resistance welding (RW) is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence, the heat being generated by electrical resistance to current flow at the junction to be welded. The principal components in resistance welding are shown in Figure (2.1) for a resistance spot-welding operation, the most widely used process in the group. The components include work parts to be welded (usually sheet metal parts), two opposing electrodes, a means of applying pressure to squeeze the parts between the electrodes, and an AC power supply from which a controlled current can be applied. The operation results in a fused zone between the two parts, called a weld nugget in spot welding [3].

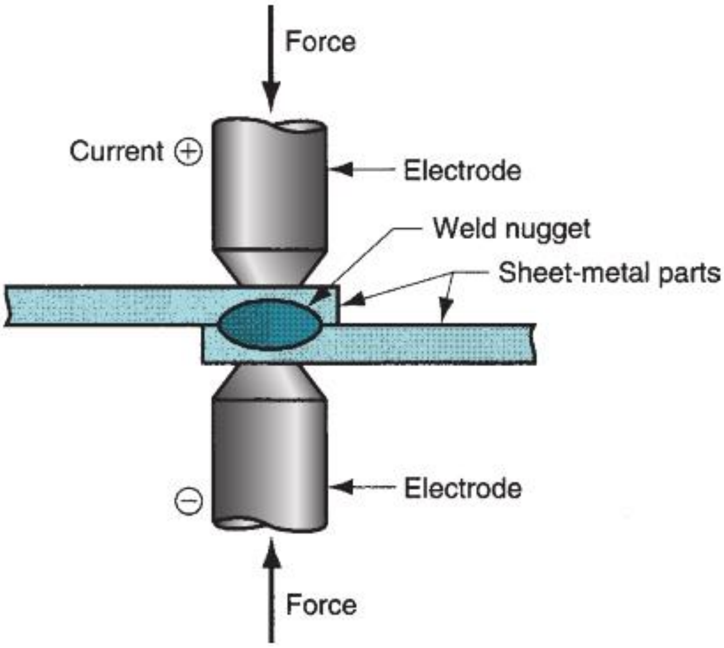

Figure 2.1: Components in Spot Welding [3]

Resistance welding is classified as fusion welding because the applied heat almost always causes melting of the faying surfaces. However, there are exceptions. Some welding operations based on resistance heating use temperatures below the melting points of the base metals, so fusion does not occur.

2.2 Power Source in Resistance Welding

The heat energy supplied to the welding operation depends on current flow, resistance of the circuit, and length of time the current is applied. This can be expressed by the equation:

$H = I^2 R t_c$ ……………………………………………………. (2.1)

Where:

H = heat generated (J)

I = current (KA)

R = electrical resistance (Ω)

t_c = time to current flow (s)

The current used in resistance welding operations is very high (50 to 20 KA, typically), although voltage is relatively low (usually below 10 Ω). The duration t of the current is short in most processes, perhaps lasting (0.1 to 0.4 s) in a typical spot welding operation.

Success in resistance welding depends on pressure as well as heat. The principal functions of pressure in resistance welding are to:

- force contact between the electrodes and the work parts and between the two work surfaces prior to applying current.
- press the faying surfaces together to accomplish coalescence when the proper welding temperature has been reached [3].

2.3 Advantages of Resistance Welding

- No filler metal is required,
- high production rates are possible
- lends itself to mechanization and automation,
- operator skill level is lower than that required for arc welding
- good repeatability and reliability

2.4 Drawbacks of Resistance Welding

- equipment cost is high
- types of joints that can be welded are limited to lap joints for most resistance welding processes.

2.5 Classification of Resistance Welding Processes

The resistance welding processes of most commercial importance are spot, seam, and projection welding.

2.5.1 Resistance Seam Welding

Resistance Seam Welding is a welding process is shown in Figure (2.2) it is of continuous joining of overlapping sheets by passing them between two electrode wheels. Heat generated from the electric current flowing through the contact area and pressure provided by the wheels is sufficient to produce a leak tight weld.

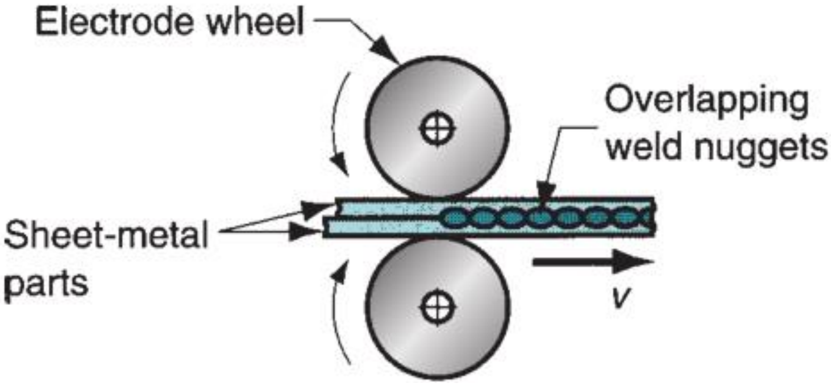

Figure 2.2: Resistance Seam Welding [3]

2.5.2 Resistance Projection Welding

Resistance projection welding is an RW process in which coalescence occurs at one or more relatively small contact points on the parts. These contact points are determined by the design of the parts to be joined, and may consist of projections, embossments, or localized intersections of the parts. A typical case in which two sheet-metal parts are welded together is described in Figure (2.3) The part on top has been fabricated with two embossed points to contact the other part at the start of the process. It might be argued that the embossing operation increases the cost of the part, but this increase may be more than offset by savings in welding cost.

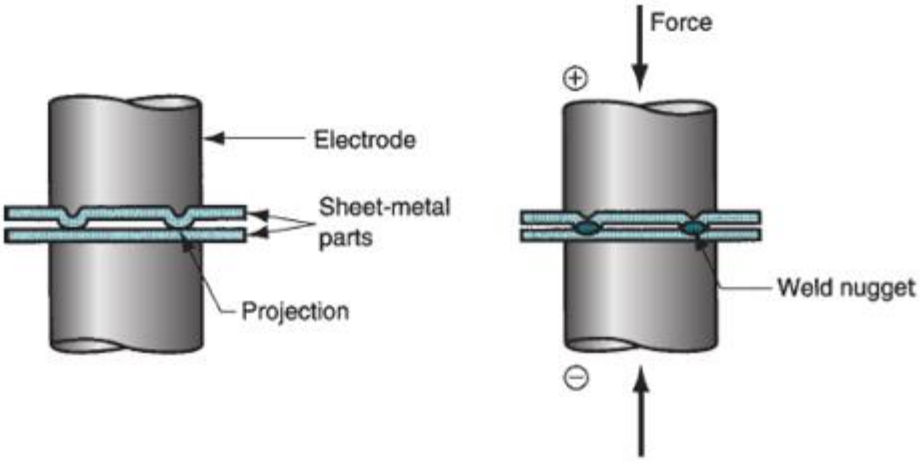

Figure 2.3: Resistance Projection Welding Operation [3]

2.5.3 Resistance Spot Welding

Resistance spot welding (RSW) is an RW process in which fusion of the faying surfaces of a lap joint is achieved at one location by opposing electrodes. The process is used to join sheet-metal parts of thickness 3 mm (0.125 in) or less, using a series of spot welds, in situations where an airtight assembly is not required. The size and shape of the weld spot is determined by the electrode tip, the most common electrode shape being around, but hexagonal, square, and other shapes are also used. The resulting weld nugget is typically 5 to 10 mm in diameter, with a heat-affected zone extending slightly beyond the nugget into the base metals. If the weld is made properly, its strength will be comparable to that of the surrounding metal. The steps in a spot welding cycle are depicted in Figure (2.1) [3].

2.6 Principle of Spot Welding

Spot welding operations involve a co-ordinate application of electric current and mechanical pressure of the proper magnitudes and durations. The welding current must pass from the electrodes through the work. Its continuity is assured by forces applied to the electrodes. The sequence of operation must first develop sufficient heat to raise a confined volume of metal to the molten state. This metal is then allowed to cool while under pressure until it is adequate strength to hold the parts together. The current density and pressure must be such that a nugget is formed, but not so high that molten metal is expelled from the weld zone. The duration of weld current must be sufficiently short to prevent excessive heating of the electrode faces. Such heating may bond the electrodes to the work and greatly reduce their life [4].

2.6.1 Physical Phenomena in Resistance Spot Welding

The heat required for these resistance welding processes is produced by the resistance of the work pieces to an electric current passing through the material. Because of the short electric current path in the work and limited weld time, relatively high welding currents are required to develop the necessary welding heat. The amount of heat generated depends upon three factors:

- The amperage
- The resistance of the conductor
- The duration of current.

These three factors affect the heat generated as expressed in the formula 2.1.

When the current or resistance is not constant, integrating the above expression will result in the heat generated in a time interval t_c. For resistance welding, the heat generation at all locations in a weldment, rather than the total heat generated, is more relevant, as heating is not and should not be uniform in the weldment. In addition, the heating rate is more important than the total heat, as how fast the heat is applied during welding determines the temperature history and, in turn, the microstructure. This can be easily understood by considering an aluminum welding. If the welding current is low, melting may not be possible no matter how long the heating is, due to the low electrical resistivity of aluminum, and the fact that the heat generated is conducted out quickly through the water-cooled electrodes and the sheets due to the high thermal conductivity of aluminum. In general, the electric and thermal processes should be considered together in welding.

The heat generated is proportional to the square of the welding current and directly proportional to the resistance and the time. Part of the heat generated is used to make the weld and part is lost to the surrounding metal.

The welding current required to produce a given weld is approximately inversely proportional to the square root of the time. Thus, if the time is extremely short, the current required will be very high. A combination of high current and insufficiently short time may produce an undesirable distribution of heat in the weld zone, resulting in severe surface melting and rapid electrode deterioration [4].

The temperature will decrease again and the joined sheets form a solid nugget, joining the sheets. The outline of the spot welding process is illustrated in Figure (2.4).

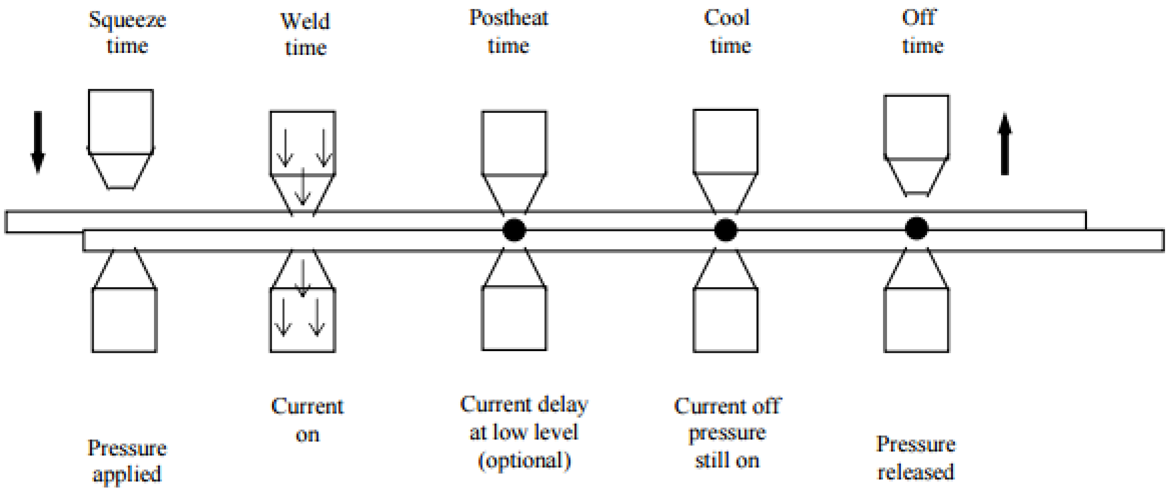

Figure 2.4: The RSW Process Timeline [1]

2.6.2 Thermo-Electrical Processes of Resistance Spot Welding

The secondary circuit of a resistance welding machine and the work being welded constitute a series of resistances. The total resistance of the current path affects the current magnitude. The current will be the same in all parts of the circuit regardless of the instantaneous resistance at any location in the circuit, but the heat generated at any location in the circuit will be directly proportional to the resistance at that point.

The heat generated due to the electrical current is defined through Joule's law, equation 3.1. The resistances, and thus heat generation, of the circuit are located at four major sources, see Figure (2.5), Typical values of resistances of materials used in RSW can be seen in Figure (2.6).

An importance characteristic of resistance welding is the rapidity with which welding heat can be produced. The temperature distribution in the work and electrodes, in the case of spot welding at least seven resistances connected in series in a weld that account for the temperature distribution. For a two-thickness joint, these are the following:

1. 1 and 7, the electrical resistance of the electrode material.
2. 2 and 6, the contact resistance between the electrode and the base metal.

The magnitude of this resistance depends upon the surface condition of the base metal and electrode force. This is a point of high heat generation, but the surface of the base metal does not reach its fusion temperature during the current passage, due to the high thermal conductivity of the electrodes (1 and 7) and the fact that they are usually water cooled.

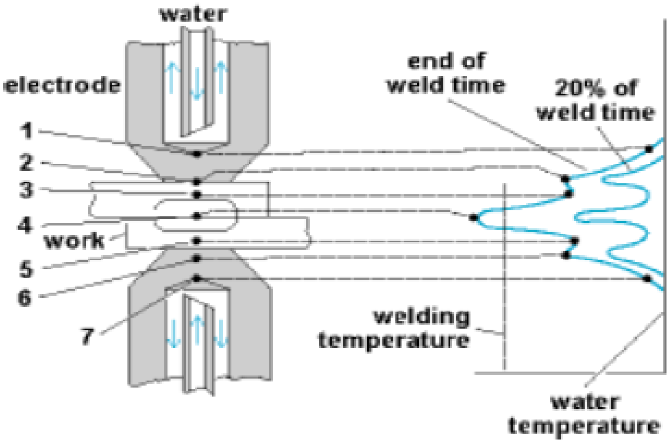

Figure 2.5: Showing the Resistance and Temperature Distribution [4]

3. 3 and 5, the total resistance of the base metal itself, which is directly proportional to the cross-sectional area of the current path.
4. 4, the base metal interface at the location where the weld is to be formed. This is the point of highest resistance and,

therefore the point of greatest heat generation. Since heat is also generated at points 2 and 6, the heat generated at interface 4 is not readily lost to the electrodes.

For stack-ups with more than two sheets, bulk resistances and contact resistances are added accordingly [4].

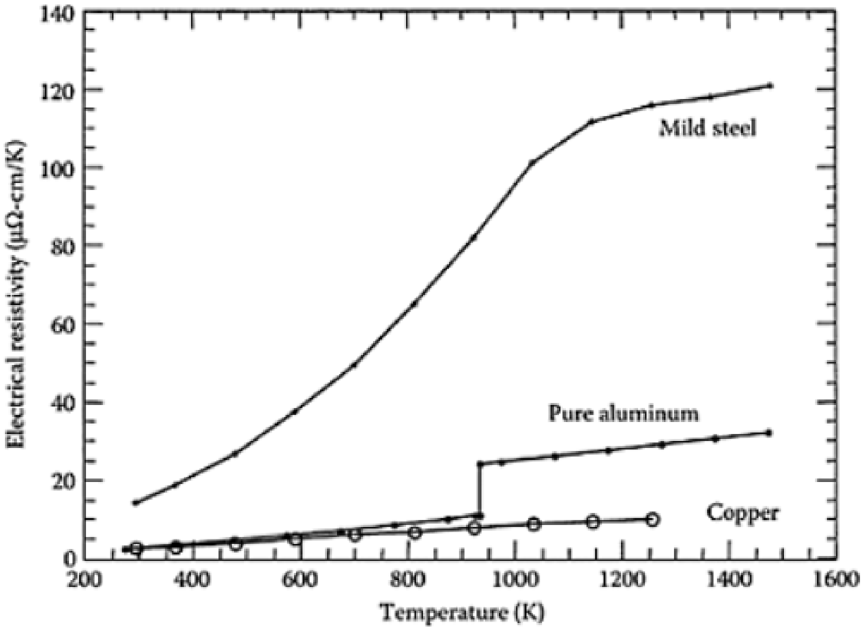

Figure 2.6: Electrical Resistivity of RSW Materials [4]

Since the resistances are connected in a series electrical circuit they will all retard current flow. However, the resistance is a highly temperature dependent variable and will change significantly during the weld process. It can be noted that the resistivity of both aluminum and steel is larger than that of copper of the electrodes. Thus, the heat generated in the work piece is greater than that in the electrodes, which enables welding. This also explains the difficulties to weld aluminum sheets compared to steel, due to the smaller heat generation. However, the contact resistances between the materials are significantly larger and thus, determine the heat generation more, than the bulk resistances of the materials.

To assure electrode contact with the work piece, the electrodes are clamped to the sheets with a mechanical force. The electrodes are most commonly made of a copper alloy. When the electrodes and work piece are in full contact, the electrodes are charged and high amperage current is flowing through the circuit. After the current flow stops the electrodes are squeezing the sheets during a further period, called cool time, to improve controlled nugget formation.

For non-constant current or resistance, which is often the case in RSW, the expression in Equation 1 must be integrated to find the correct heat energy. The formula gives a basic understanding of the circuit but is not detailed enough for full understanding. Firstly, in resistance spot welding the local heat generation at each resistance is of more interest than the total heat energy of Joule's law. Secondly, the heating rate is a more indicative parameter of weld development than total heat energy since it has a significant effect on the microstructures of the weld.

Although the Joule effect is the most prominent thermo-electrical effect in resistance spot welding in terms of weld generation, other electro-thermal effects do take place. The Peltier effect, see beck effect and Thomson effect all take place during RSW but have a minor effect on weld size and are not treated in detail in the present thesis.

All metals involved in the resistance spot welding process increases in electrical resistance with temperature. Steel is very sensitive to temperature changes, the difference between steel and copper explain the excessive heat in the steel sheets compared to the heat in the electrodes. In addition, the electrodes are water-cooled Which decreases their temperature increase, and resistance.

Another electrical phenomenon that must be taken into account is shunting currents. Such currents occur when a weld is made in close relation to previously made welds. The adjacent welds create a current path which distorts the intended welding by lowering the effective welding current or current density [1].

2.6.3 Thermal Parameters of Resistance Spot Welding

To create a good weld, it is crucial to maintain a low temperature in the electrodes. It will also help in maintaining electrode life. If the electrodes are sufficiently cooled the heat will dissipate effectively through the electrodes due to the high conductivity of copper.

Another important phenomenon observed during welding is thermal expansion. Figure (2.7) below shows the coefficient of thermal expansion for copper, steel and aluminum at different temperatures. The figure shows the drastic difference between steel and aluminum, which explains the different behavior of the materials during welding.

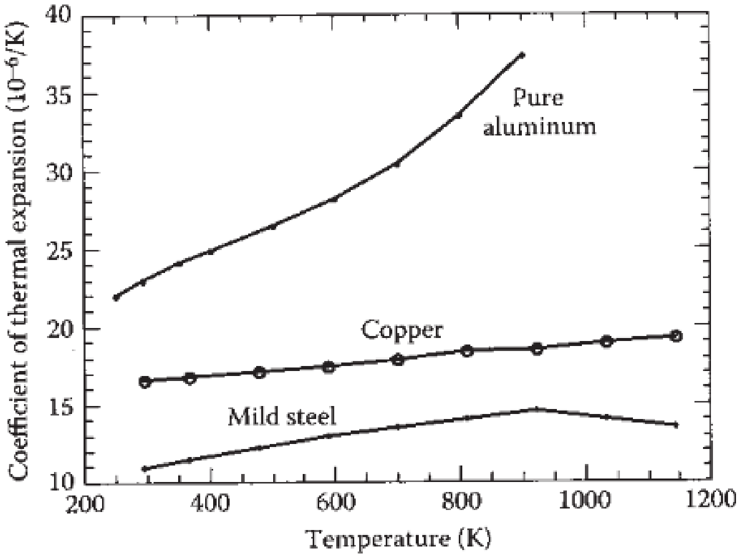

Figure 2.7: Coefficient of Thermal Expansion for RSW Materials [4]

The thermal expansion is also the reason why electrode displacement can be used as a parameter for welding monitoring. Heat gain in the nugget will expand the material and try to push the electrodes apart while heat loss works in opposite [1].

2.7 Spot Welding Parameters

According to Joule's law the welding parameter is time, pressure, current and electric resistances. In the electric resistance, there are several parameters such as electrical receptivity of materials, quality of material surface to be weld and welding force. The parameters that can be controlled in the welding machine are current, time and force.

Generally, have a six-important parameter in spot weld that is:

- Electrode force
- Diameter of the electrode contact surface
- Squeeze time (ST)
- Weld time (WT)
- Hold time
- Weld current.

2.7.1 Weld Time (WT)

The thicker the material, the longer it will take to heat it up to the required temperature. In general, therefore, weld times increase in proportion to the thickness of the components as shown in Figure (2.8).

2.7.2 Hold Time

Hold time is the time after the welding when electrodes are still applied to the sheet to chill the weld.

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.

If the hold time is too long and the carbon content of the material is high (more than 0.1%), there is a risk that the weld become brittle [1].

2.7.3 Squeeze Time (ST)

Squeeze time is the time interval between the initial application of the electrode force on the work and the first application of current as shown in Figure (2.9).

Squeeze time is necessary to delay the weld current until the electrode force has attained the desired level.

2.7.4 Weld Current

The weld current is the current in the welding circuit during the making of a weld. The amount of weld current is controlled by two things:

- The setting of the transformer tap switch determines the maximum amount of weld current available.
- The percent of current control determines the percent of the available current to be used for making the weld.

2.7.5 Electrode Force

The purpose of the electrode force is to squeeze the metal sheets to be joined together. This requires a large electrode force else the weld quality will not be good enough.

When the electrode force is increased the heat energy will decrease, this means that the higher electrodes force requires a higher weld current.

When weld current becomes too high spatter will occur between electrodes and sheets. This will cause the electrodes to get struck to the sheet.

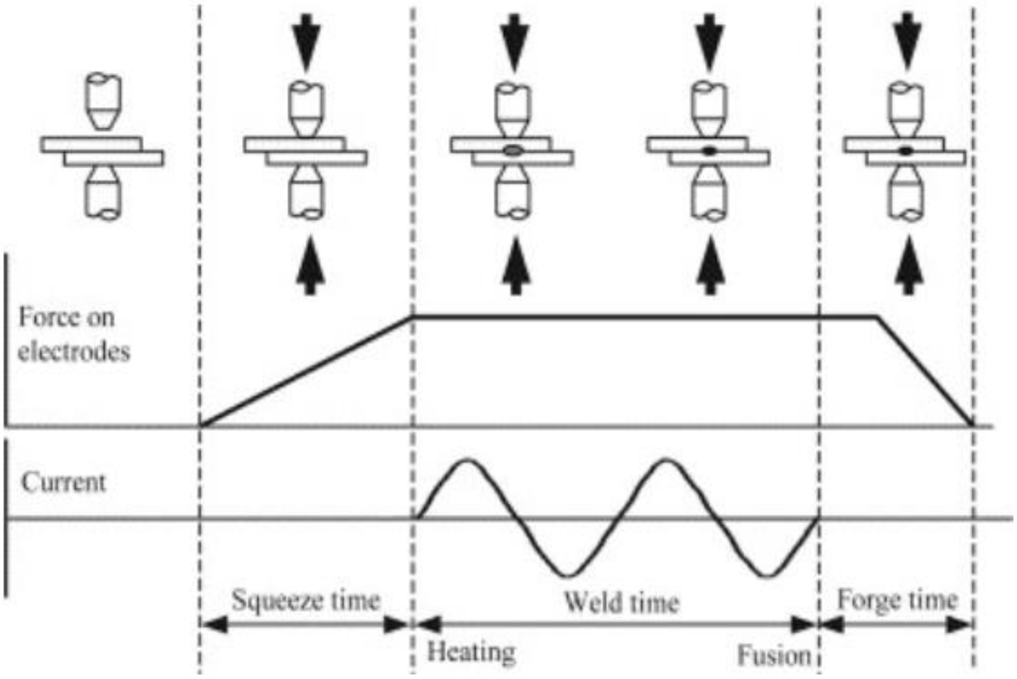

Figure 2.8: Basic Single Impulse Welding Cycle for Spot Welding [1]

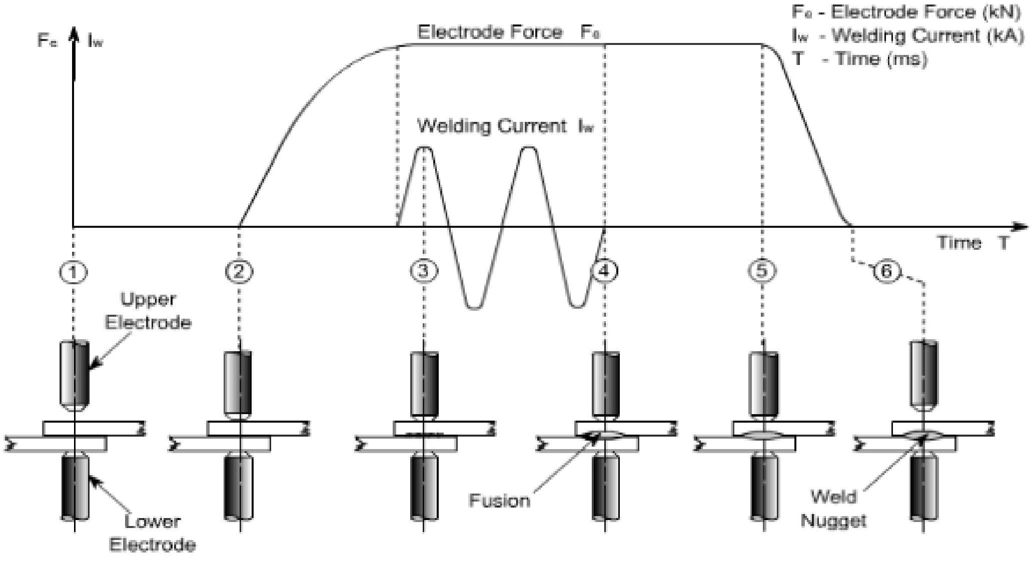

Figure 2.9: Sequence of Resistance Spot Welding Process [1]

2.8 The Function of the Setup Time and Post Weld Holding Time

2.8.1 Set-Up Time:

- Compressing the work piece.
- Buildup of electrode force to present value.
- Setting up of reproducible resistance before welding.
- Electrode resetting after bounce.
- Preventing resetting of electrode on work piece under electrical voltage.

2.8.2 Post Welds Holding Time:

- Holding time of work piece during cooling of molten metal.
- Prevention of pore formation in the welding nugget.
- Prevention of lifting the electrode under voltage [4].

2.9 Selection of Spot Welding Electrodes

In production, the shape and size of the electrodes have an effect on the weld outcome. The geometry of a different electrode geometries is shown in Figure (2.10).

The most important parameter in the electrode geometry is the contact area between the electrode and the metal sheet. The contact will affect both the contact pressure and the current density of the weld. In optimization of weld parameters, it may be ideal to use different electrodes on each side of the stack-up.

The tip curvature of the electrode is a measure against the degradation of the electrode tip. As the electrode degrades the initial curvature will deform into a flat surface. An initially flat surface would cause a concave tip after continuous welding [5].

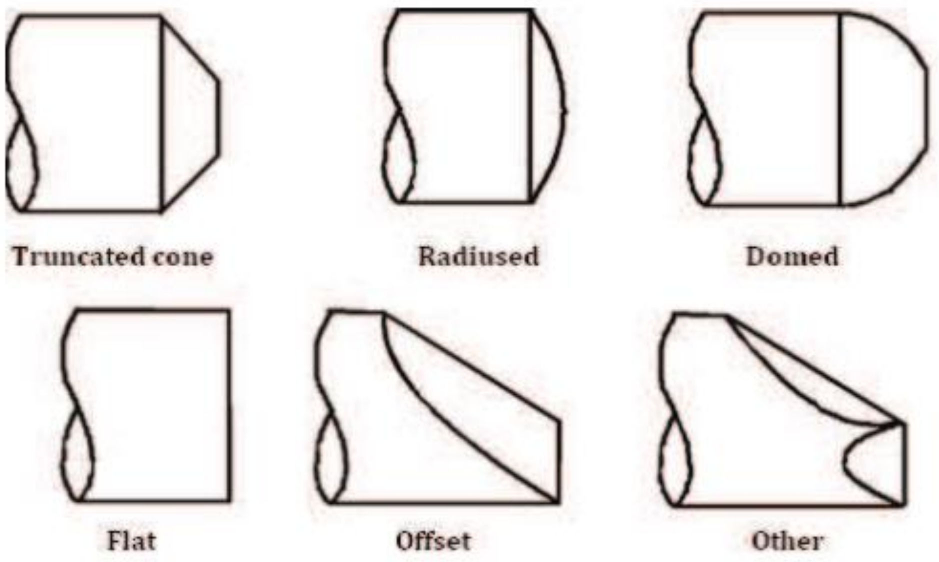

Figure 2.10: Electrode Geometry Types [5]

2.10 Electrode material

The most important functions of the electrodes are to conduct electric current and to squeeze the sheets together. Therefore, electric conductivity, compressive strength and hardness are important factors in finding an appropriate electrode material.

The most common electrode material is a cupper-chromium-zirconium alloy, while higher resistance alloys of nickel, beryllium and/or cobalt may be used for higher strength steels and stainless steels [5].

2.11 Spot Welding Machine

Resistance welding is used commonly for mass-production industries, where production run and consistent conditions are maintained. The resistance welding machine works automatically and less skill workers are needed. Resistance welding has the advantage of producing a high volume of work at a high speed, the product can be produced at high quality. Resistance spot welding also has been used in the repair industry, for example in Europe and Japan the resistance spot welding has been used in unibody collision repair industry for more than 25 years. This method is acceptable because resistance spot welding is ideal for welding many parts of unibody's thin-gauge area that need good strength and no distortion. Figure (2.11) (a) shown the person conduct the manual portable spot welding gun and Figure (2.11) (b) is Portable spot welding gun on robot (automatic) [1].

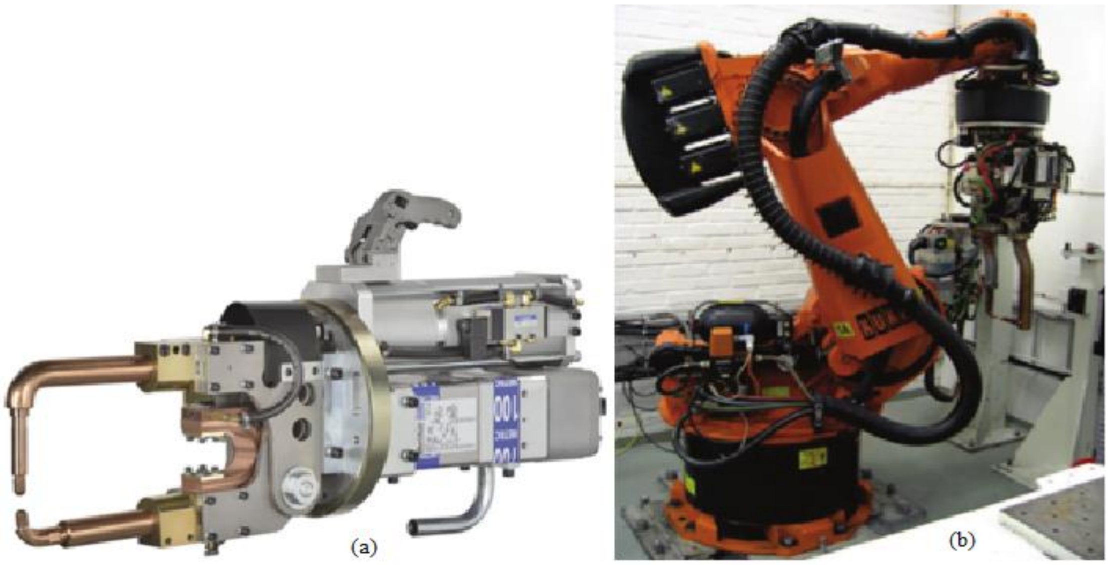

Figure 2.11: (a)Manual portable spot welding gun (b) Portable spot welding gun on robot (automatic) [1].

2.11.1 The Main Components of Resistance Spot Welding Machine

A controlled variable may be, for instance the electrode path, the resistance progress, the welding current or the welding voltage. Figure (2.12) shows the main components of resistance spot welding machine [6].

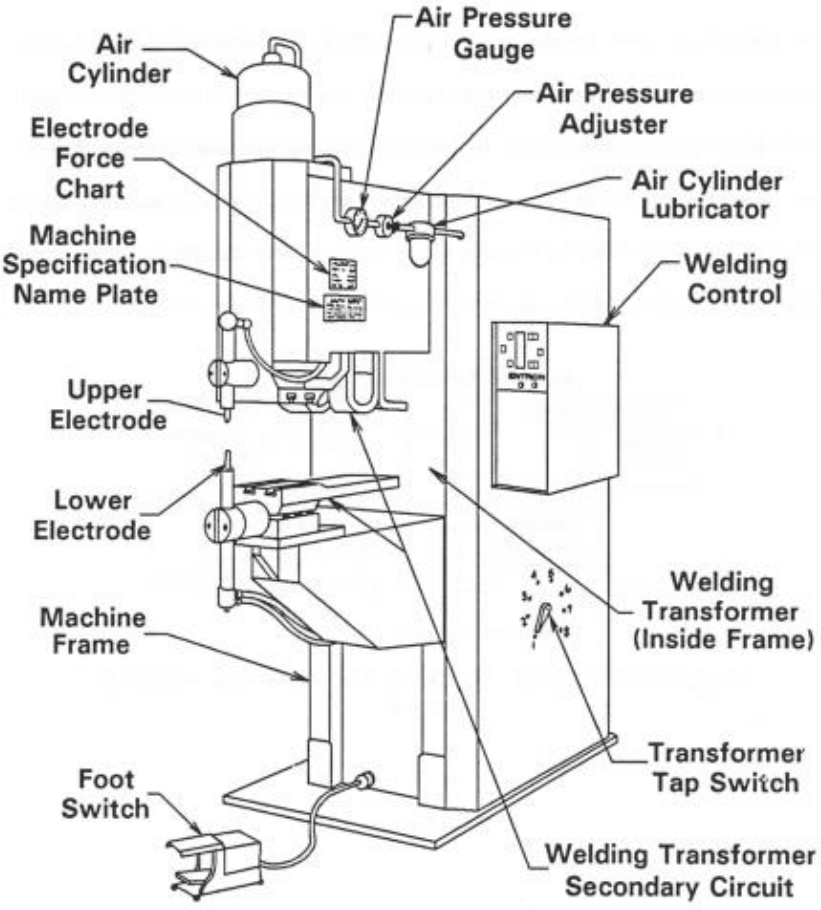

Figure 2.12: The Main Components of Resistance Spot Welding Machine [6]

2.11.2 Power sources

The structural design of a DC supply unit is, however, more complicated and, therefore, more expensive than an AC supply unit. As conventional welding machines operate with a 50HZ primary current supply, the welding current can be controlled only in ms units (1 cycle). When the inverter –direct current technique or, respectively, the medium–frequency technique is used a finer setting of the current on period and a more precise control of the welding current is possible.

In order to realize higher currents and shorter welding times, the impulse capacitor resistance welding technique is applied. The rectified primary current is stored in capacitors and, through a high-voltage transformer, converted to high welding currents. The advantages of this technique are low heat input and high reproducibility. Because of the high-energy density, materials with good conductivity can be welded and also multiple projection welds can be carried out. A disadvantage of this method is apart from the high equipment costs, the difficult regulation of the welding current is shown in Figure (2.13) [4].

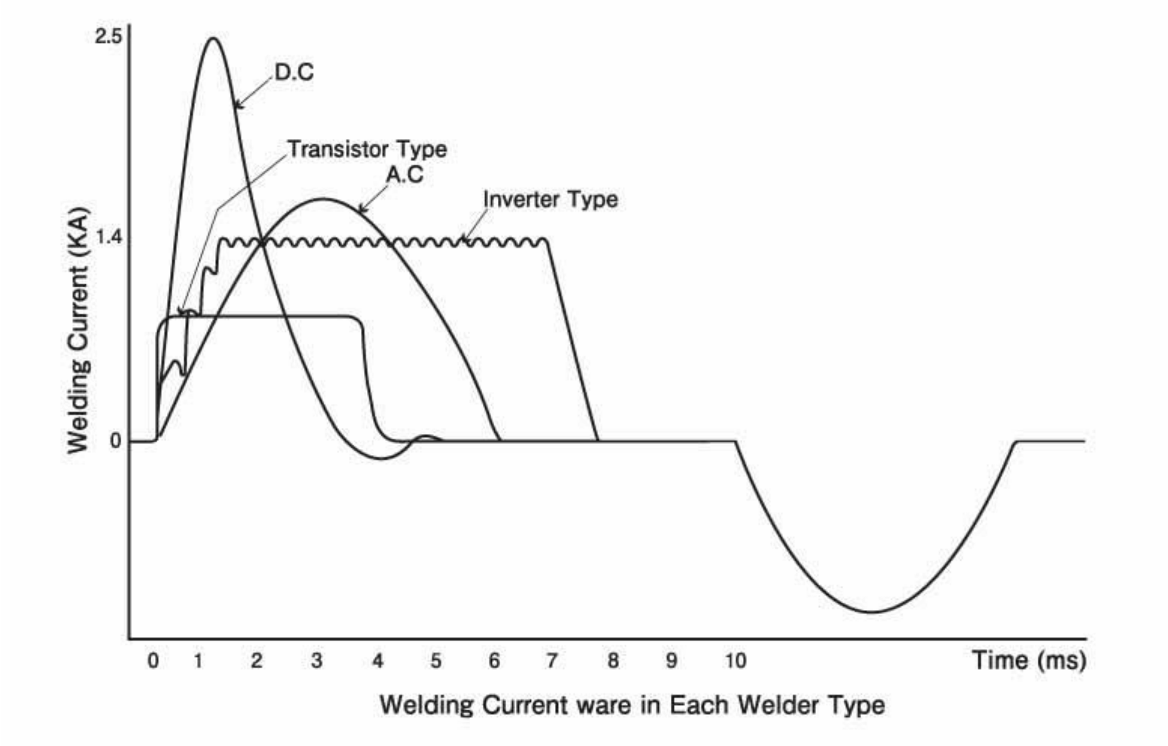

Figure 2.13: Types of Current [4]

2.12 Materials

Material is the back bone for any industry. The first and foremost reason for the relaxation in the quality of the material lies in the selection of a particular material for the production.

Selection of material for the manufacturing should have some basic criteria’s like their case of handling, cost, applications etc. after taking up many projects the research should be carried on the selection of material for the product. That much importance is selection of material

Materials for engineering applications are further classified into:

- Non-ferrous (Al, Cu, etc.….)
- Ferrous (with iron content)

Non-ferrous materials are those which are those which don’t have carbon content in it. Because of the absence of carbon, it lacks in its own strength. That’s why non- ferrous materials couldn’t be used for much engineering applications. But it can be treated specially by precipitation hardening (Duralumin (Al,Cu)) used for aerospace application[4].

Ferrous materials are those with the presence of iron and carbon. Even though there is a chance of corrosion in this material it has its own importance in all the industries because of its:

- High strength
- Availability
- High ductility

2.12.1 Iron-Carbon Phase Diagram

Iron-carbon phase diagram describes the iron-carbon system of alloys containing up to 6.67% of carbon, discloses the phase’s composition and their transformation occurring with the alloys during their cooling or heating.

Carbon content 6.67% corresponds to the composition of the iron carbide fe3c.The diagram is presented in the figure (2.14).

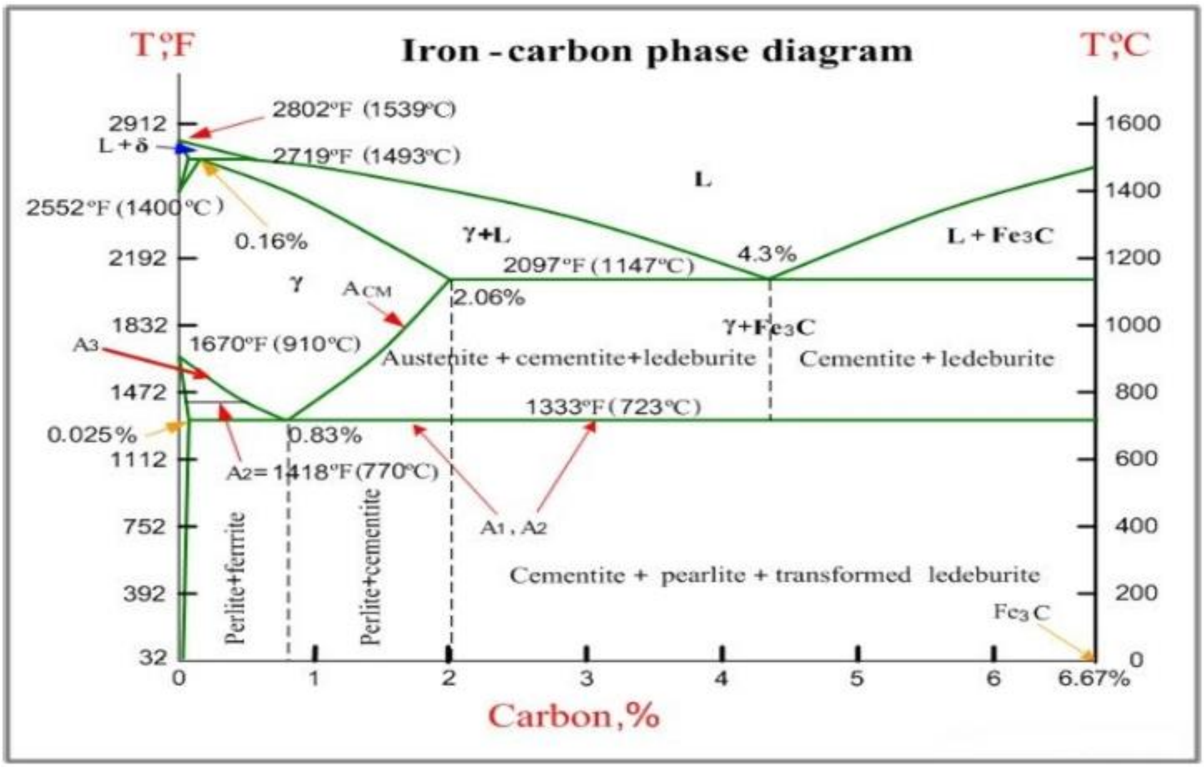

Figure 2.14: Iron-Carbon Phase Diagram [4]

The following phases are involved in the transformation, occurring with iron-carbon alloys:

- L-liquid solution of carbon in iron.
- δ-ferrite- solid solution of carbon in iron.

Maximum concentration of carbon in δ-ferrite is 0.09% at 2719°F (1493°C) temperature of the paratactic transformation. Austenite does not exit below 1333°F (723°C) and maximum carbon concentration at this temperature is 0.83% [4].

2.12.2 Critical Temperature:

- Upper critical temperature (point) A_3 is the temperature, below ferrite starts to form as a result of ejection from austenite in the hypereutectoid alloy.

- Upper critical temperature (point) A_{cm} is the temperature, below which cementite starts to form as a result of ejection in the hypereutectoid alloys.
- Lower critical temperature (point) A_1 is the temperature of the austenite-to-partite eutectoid transformation. Below this temperature austenite does not exist.
- Magnetic transformation temperature A_2 is the temperature below which α-ferrite is ferromagnetic [4].

2.12.3 Continuous Cooling of Plain Carbon Steels Diagrams

Because most industrial heat treatment processes use controlled cooling rather than isothermal transformation, continuous-cooling transformation (CCT) diagrams are more representative of actual transformations than TTT diagrams. Cooling of a weldment of RSW is also far from isothermal; therefore, CCT diagrams are more applicable to understanding the microstructures of a weldment. CCT diagrams are similar to TTT diagrams except that in CCT diagrams transformations occur over a range of temperatures. Bainite rarely forms, or only a small amount of it forms, upon continuous cooling, as a cooling path rarely goes through the austenite→bainite transformation region without touching austenite→ferrite or austenite→pearlite regions first. A typical CCT diagram of a mild steel is shown in Figure (2.15). A continuous cooling with a slow cooling rate results in a mixture of ferrite and pearlite; an intermediate cooling tends to produce a mixture of ferrite, bainite, and martensite, and a rapid cooling (above the critical cooling rate) creates a structure of all martensite.

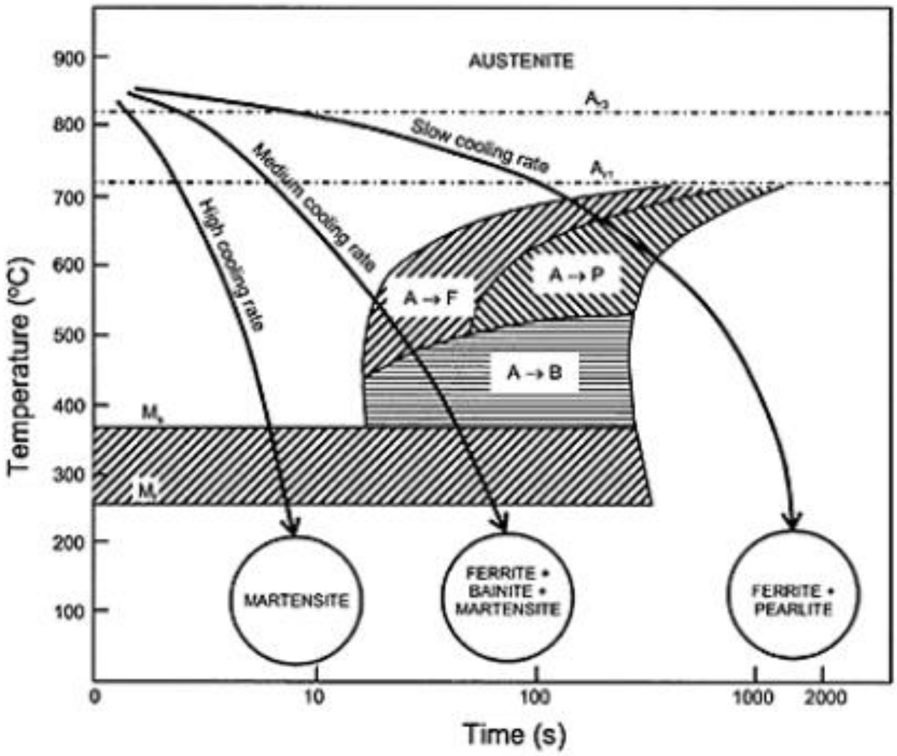

Figure 2.15: A Typical CCT Diagram of a Mild steel: A, Austenite; F, Ferrite; P, Pearlite; B, Bainite; M, Martensite [4]

Elements such as titanium, molybdenum, and tungsten lower the eutectoid carbon content and raise the transformation temperature, and therefore, they are called ferrite stabilizers. In TTT and CCT diagrams the existence of such elements raises the pearlite nose and moves it to the right side. Other elements such as nickel and manganese lower the eutectoid carbon content and lower the transformation temperature, so they are austenite stabilizers. Their effect is demonstrated on the TTT and CCT diagrams by lowering the pearlite nose and moving it to the right side. In fact, all metals except cobalt increase the hardenability of steels. That is, they move the nose of the pearlite curve to the right, allowing martensite to form with less rapid quenching. Hardenability is a measure of how rapid a quench is necessary to form martensite, not a measure of the hardness of martensite [1].

2.13 Carbon steel

Carbon steel, or plain-carbon steel, is a metal alloy. It is a combination of two elements, iron and carbon. Other elements are present in quantities too small to affect its properties. The only other elements allowed in plain carbon steel are manganese (1.65% max), silicon (0.60% max) and copper (0.60% max).Steel with a low carbon content has the same properties as iron, soft but easily formed. As carbon content rises the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers steel's melting point and its temperature resistance in general.

2.13.1 Classification of Carbon Steel

Typical compositions of carbon are:

- **Mild (low Carbon) Steel:**

Approximately 0.14% to 0.20% carbon content with up to 0.4% manganese content (e.g. AISI 1018 steel). Less strong but cheap and easy to shape; surface hardness can be increased through carburizing.

- **Medium Carbon Steel:**

Approximately 0.29% to 0.54% carbon content with 0.60 to 1.65% manganese content (e.g. AISI 1040 steel). Balances ductility and strength and has good wear resistance; used for large parts, forging and car parts.[3]

- **High Carbon Steel:**

Approximately 0.55% to 0.95% carbon content with 0.30 to 0.90% manganese content. Very strong, used for springs and high-strength wires.

- **Very High Carbon Steel:**

Approximately 0.96% to 2.1% carbon content, specially processed to produce specific atomic and molecular microstructures.

Steel can be heat-treated which allows parts to be fabricated in an easily formable soft state. If enough carbon is present, the alloy can be hardened to increase strength, wear, and impact resistance. Steels are often wrought by cold-working methods, which is the shaping of metal through deformation at a low equilibrium or metastable temperature [7].

2.13.2 Mild/Low Carbon Steel

Mild/low carbon steel has excellent weldability and produces a uniform and harder case and it is considered as the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength and ductility. Provided with higher mechanical properties, AISI 1018 hot rolled steel also includes improved machining characteristics and Brinell hardness.

Specific manufacturing controls are used for surface preparation, chemical composition, rolling and heating processes. All these processes develop a supreme quality product that are suited to fabrication processes such as welding, forging, drilling, machining, cold drawing and heat treating.

2.13.2.1 Applications of Low Carbon Steel

- It is used in bending, crimping and swaging processes.
- Carburized parts that include worms, gears, pins, dowels, non-critical components of tool and die sets, tool holders, pinions, machine parts, ratchets, dowels and chain pins use mild/low carbon steel.

- It is widely used for fixtures, mounting plates and spacers.
- It is suitably used in applications that do not need high strength of alloy steels and high carbon.
- It provides high surface hardness and a soft core to parts that include worms, dogs, pins, liners, machinery parts, special bolts, ratchets, chain pins, oil tool slips, tie rods, anchor pins, studs etc.
- It is used to improve drilling, machining, threading and punching processes.
- It is used to prevent cracking in severe bends [8].

2.13.2.2 Physical and Mechanical Properties of Low Carbon Steel

Table 2.1: Physical and Mechanical Properties of Low Carbon Steel

Property	Metric	Imperial
Hardness, Brinell	126	126
Hardness, Knoop	145	145
Hardness, Rockwell	71	71
Hardness, Vickers	131	131
Density	7.87 g/cm^3	0.284 lb/in^3
Tensile Strength, Ultimate	440 Mpa	63800 psi
Tensile Strength, Yield	370 Mpa	53700 psi
Elongation at Break	15.0 %	15.0 %
Reduction of Area	40.0 %	40.0 %
Modulus of Elasticity	205 GPa	29700 ksi
Bulk Modulus	140 GPa	20300 ksi
Poisson Ratio	0.290	0.290
Machinability	70 %	70 %
Shear Modulus	80.0 GPa	11600 ksi

2.13.2.3 Chemical Composition of Low Carbon Steel

Table 2.2: Chemical composition of Low Carbon Steel

Element	Wt. % age
C	0.14 - 0.20
Fe	98.81 - 99.41
Mn	0.10 - 0.80
P	$\leq$ 0.040
S	$\leq$ 0.050

2.14 Weldability of Materials

Low carbon steel is one of the most readily spot welded materials, as well as being the most commonly used material for stampings and fabrication. It can be spot welded to many ferrous and non-ferrous alloys with varying success, depending on the combination of metals joined.

Higher carbon and low- alloy steels can also be spot welded, although with reservations, because of a tendency to from harder welds, which may degrade weld performance. As carbon content increases, so does brittleness, with an associated propensity for cracking and weld separation.

In addition, higher strength steels may require special techniques or treatments like tempering after welding. Spot weldability of HSLA (high-strength low-alloy) steels is directly related to composition and type of micro alloying element. It is advisable to check with the supplier before specifying spot welding here.

Stainless steels are spot weldable, some grades more readily than other. Austenitic grades of the 300 series are the most commonly welded types, followed by ferrite, martensitic stainless are the least common because welded joints are always much more brittle. All stainless steels require careful adjustment of welding parameters and or special method to obtain optimum quality welds [4].

2.15 Welding Procedure Specification

A Welding Procedure Specifications (WPS) is a formal written document describing welding procedure which provides direction to the welder or welding operators for making sound and quality production welds as per the code requirements, the purpose of the document is to guide welders to the accepted procedures so that repeatable and trusted welding techniques are used. A WPS is developed for each material alloy and for each welding type used. Specific codes and/or engineering societies are often the driving force behind the development of company's WPS. A WPS is supported by a Procedure Qualification Record (PQR or WPQR). A PQR is a record of a test weld performed and tested (more rigorously) to ensure that the procedure will produce a good weld. Individual welders certified with a qualification test documented in a Welder Qualification Test Record (WPQR) that shows they have the understanding demonstrated ability to work within the specified WPS.

According to the American Welding Society (AWS), a WPS provides in detail the required welding variables for specific application to assure repeatability by properly trained welders. The AWS defines welding PQR as a record of welding variables used to produce an acceptable test weldment and the results of test conducted on the weldment to qualify a Welding Procedure Specification.

The American Society of Mechanical Engineers (ASME) similarly defines a WPS as a written document that provides direction to the welder or welding operator for making production welds in accordance with Code requirements. ASME also defines welding PQR as a result of the tested [10].

2.16 Tensile Shear Test

This method is suitable and sample to test the strength and toughness of the welding joint of sheet metal in terms of the tensile strength of joint is fail or tear apart. tensile shear test is using to determine strain energy at rupture that can be achieve after the overlapping sheet metal joining together using resistance spot welding.

Toughness is the ability of a material to absorb energy and plastically deform without fracturing, or material's resistance to fracture when stressed. Also, can be defined to respect to regions of stress-strain diagram. toughness is related to the area under the stress-strain curve Figure (2.16) in order to be tough a material must be both strong and elongation. For example, brittle materials (like ceramics) that are strong but with limited ductility are not tough; conversely, very ductile materials with low strengths are also not tough. To be tough a material should withstand both high stresses and high strains [9].

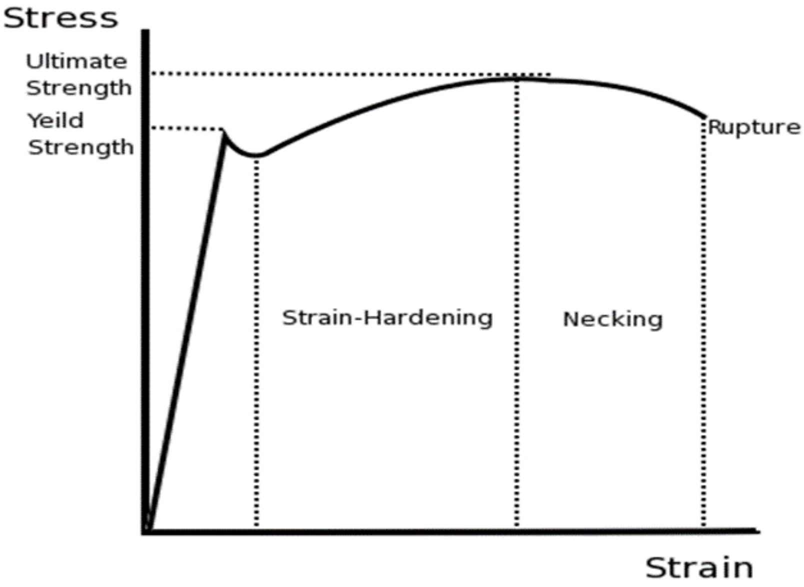

Figure 2.16: Stress-Strain Diagram [9]

Tensile toughness (T) is measured in units of joule per cubic meter ($J \cdot m^{-3}$) in the SI system and inch-pound-force per cubic inch ($in \cdot lbf \cdot in^{-3}$) in US customary units.

2.17 Quality Control of Resistance Spot Welds (RSW)

There are generally three indexes for the quality control of resistance spot welds (RSW):

1.Fusion zone (FZ) size

FZ size, which is defined as the width of the weld nugget at the sheet/sheet interface in the longitudinal direction, is the most important factor in determining the quality of the spot welds.

2.Weld Mechanical Performance

Spot weld mechanical performance is generally considered under static/quasi-static and fatigue loading conditions; spot welds in real service condition experience complex loading conditions, including shear, tear, tensile, compression, bending and torsion stresses.

3.Failure Mode

This is the manner in which the spot weld fails. Failure mode and failure mechanism largely depend on the complex interplay between the weld geometry and the material properties of the FZ/heat affected zone (HAZ)/base metal (BM) as well as the test geometry and the stress state in each weld. Therefore, the prediction of the failure mode and failure location is a challenging issue. Generally, the RSW failure occurs in two modes:

1.Interfacial failure (IF)

2.Pullout failure (PF)

Figure (2.17) shows typical fracture paths during the mechanical testing of a spot weld. In the interfacial mode, failure occurs via crack propagation (path A), while in the pullout mode, failure occurs via nugget withdrawal from one sheet. In this mode, fracture may initiate in BM (path B), HAZ (path C) or HAZ/FZ (path D), depending on the BM and the loading conditions.

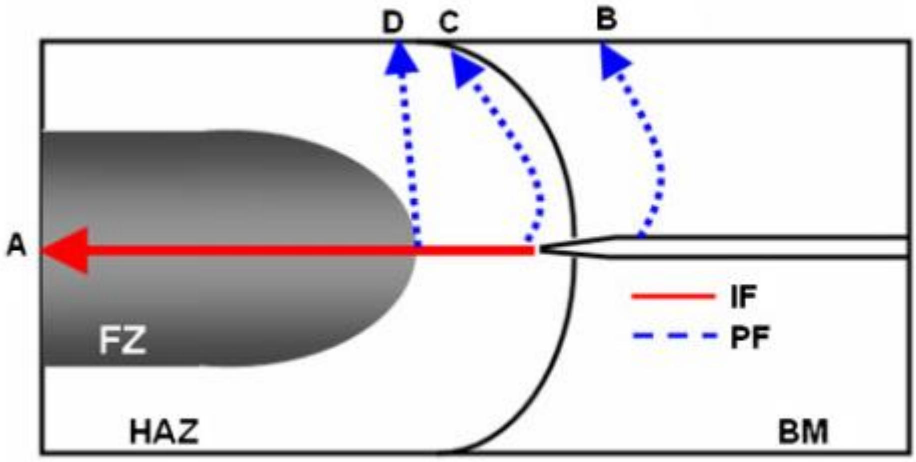

Figure 2.17: General Fracture Paths During Mechanical Testing of RSW: IF, Path A; PF, Paths B, C and D

Spot weld failure mode is a qualitative measure of the weld quality. Failure mode can significantly affect the load bearing capacity and the energy absorption capability of RSW. Generally, the pullout mode is the preferred failure mode due to its higher associated plastic deformation and energy absorption. Thus, vehicle crashworthiness, as the main concern in automotive design, can dramatically reduce if the spot welds fail via interfacial mode. The PF mode during quality control indeed indicates that the welds have been able to transmit a high level of force, thus causing severe plastic deformation in its adjacent components and increased strain energy dissipation in crash conditions. Therefore, it is needed to adjust the welding parameters so that the PF mode is guaranteed. [4]

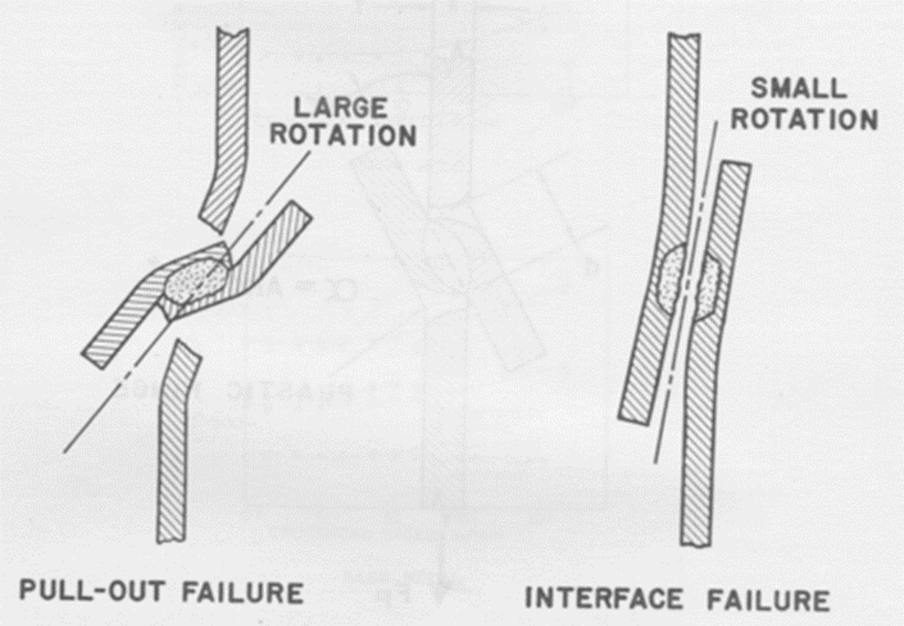

Figure 2.18: Failure Type in Tensile Shear Test [4]

2.18 Stress Analysis and Failure Mode Prediction

Interfacial failure of RSW is crack propagation of the weld nugget and the driving force is shear stress. The load to cause interfacial failure can be expressed by following equation:

$$P_{IF} = A_{IF} * t_w = \pi \frac{d^2}{4} t_w \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2\text{-}2)$$

Where:

P_{IF} = Failure load for interfacial fracture (KN)

A_{IF} = The weld interface area (mm^2)

d = The weld nugget diameter (mm)

t_w=The shear strength of the material at the weld interface (MPa)

In this solution, the shear stress distribution on the weld interface was assumed to be uniform.

For the pullout failure, the failure is predominantly caused by uniaxial tensile load and the weld nugget is assumed to be circular column. The tensile stress distribution in longitudinal direction is shown in Figure (2.19) (a). Only one half of the circumference of weld nugget was subjected to tensile stress. A harmonic tensile stress distribution around the weld nugget is assumed, as shown in Figure (2.19) (b). σ_{max} is the maximum tensile stress occurring at the loading line.

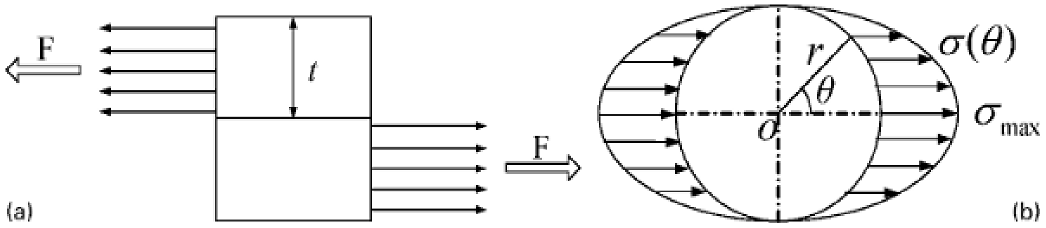

Figure 2.19: Assumed Stress Distribution Around Weld Nugget [4]

The distribution of the stress can be written as:

$\sigma(\theta)\ \sigma_{\max}\cos(\theta)$………………………….……………..……… (2-3)

Using the assumed stress distribution, the applied tensile load is related to the local stresses as follows:

$P_{PF} = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sigma(\theta) r2t\cos(\theta)\, d(\theta) = \frac{\pi}{4}\ d2t\sigma_{\max}$……………..……. (2-4)

Where:

P_{PF} = The applied load (KN)

r = The weld nugget radius (mm)

t = The sheet thickness (mm)

i= Number of Welds

At the initiation of fracture, equation (2-4) becomes:

$P = i\frac{\pi}{4}\, de\sigma_{haz}$ ………………..…………..……………. (2-5)

Where:

P = Shear Force (KN)

σ_{haz} = The fracture tensile stress of the material (MPa)

e = Combine Sheet Thickness (mm) = 2t

Equations (2-2) and (2-5) are plotted graphically in Figure 3.6. According to the analysis, the lower of the two predicted failure loads will determine the mode of failure that occurs. Thus, the point where the two curves intersect indicates where the failure mode changes. [4]

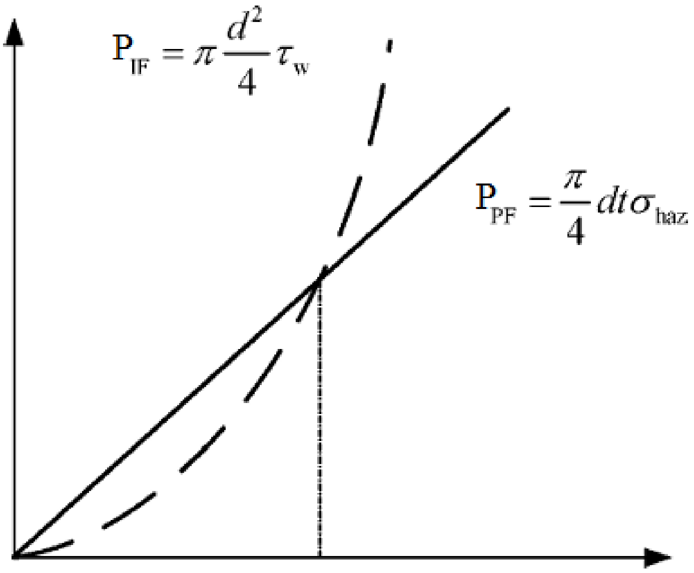

Figure 2.20: Predicted Failure load of lap Shear Specimen as Function of Weld Diameter [10]

Suppose strain (ε) in strain energy expression is replaced by strain at rupture (ε_R) Figure (2-16) above, the resulting strain energy density. The explicit mathematical description for modulus of toughness (U_T) is:

$$U_T = \int_0^{\varepsilon_R} \sigma \, d\varepsilon = \frac{\sigma_Y + \sigma_U}{2} * \varepsilon_R$$ ……....……………………

(2.6)

Where:

σ = Shear Stress in the cylindrical area of the weld (Mpa)

σ_Y= Yield Strength (Mpa)

σ_U= Tensile Strength (Mpa)

$\sigma = \frac{\mathrm{P}}{A_C}$ ……………………………….……..…………… (2-7)

Where:

P= Shear Force (KN)

A_C= Cylindrical Area of the Weld (mm^2)

$A_C = i\pi de$ …………….……………………………...………. (2-8)

Where:

i= Number of Welds

d= Spot Weld Diameter (mm)

e = Combine Sheet Thickness (mm)

Toughness of the joining parts:

$\mathrm{T} = \int_0^{\Delta \mathrm{L_R}} \mathrm{P}\, \mathrm{d}\sigma = \frac{\mathrm{P_Y}+\mathrm{P_U}}{2} \Delta \mathrm{L_F}$ ……………..……………. (2-9)

or

T = U_TV ………………………………………….……...…… (2-10)

Where:

P_Y= Yield Shear Force (KN)

P_U= Ultimate Shear Force (KN)

V= Volume of the Weld (mm^3)

Strain in the material (▯)

▯ = $\frac{\Delta L}{L}$ ……………………….………….....……………..…… (2-11)

Where:

ΔL = Change in Length (mm)

L = Original Length (mm) = 2a

Elongation (%) = $\frac{\Delta L}{L}$ % ……………………………..……….. (2-12)

The specimens underwent the tensile shear test to obtain the load before break due to shear force applied to weld area [10].

CHAPTER THREE

METHDOLOGY

Methodology

Evaluation of spot weld quality is a vital issue for the reliability of the fabricating sheet metal assemblies and for improving the economics of industrial productions.

The method adopted in this research comprises an experimental study of the distribution of spot welding for samples of the metal sheet (low carbon steel), the samples were subjected to tensile loading in universal testing machine to determined strength and toughness of joint weld. The chart shown in Figure (3.1) explain steps carrier out in the experimental work.

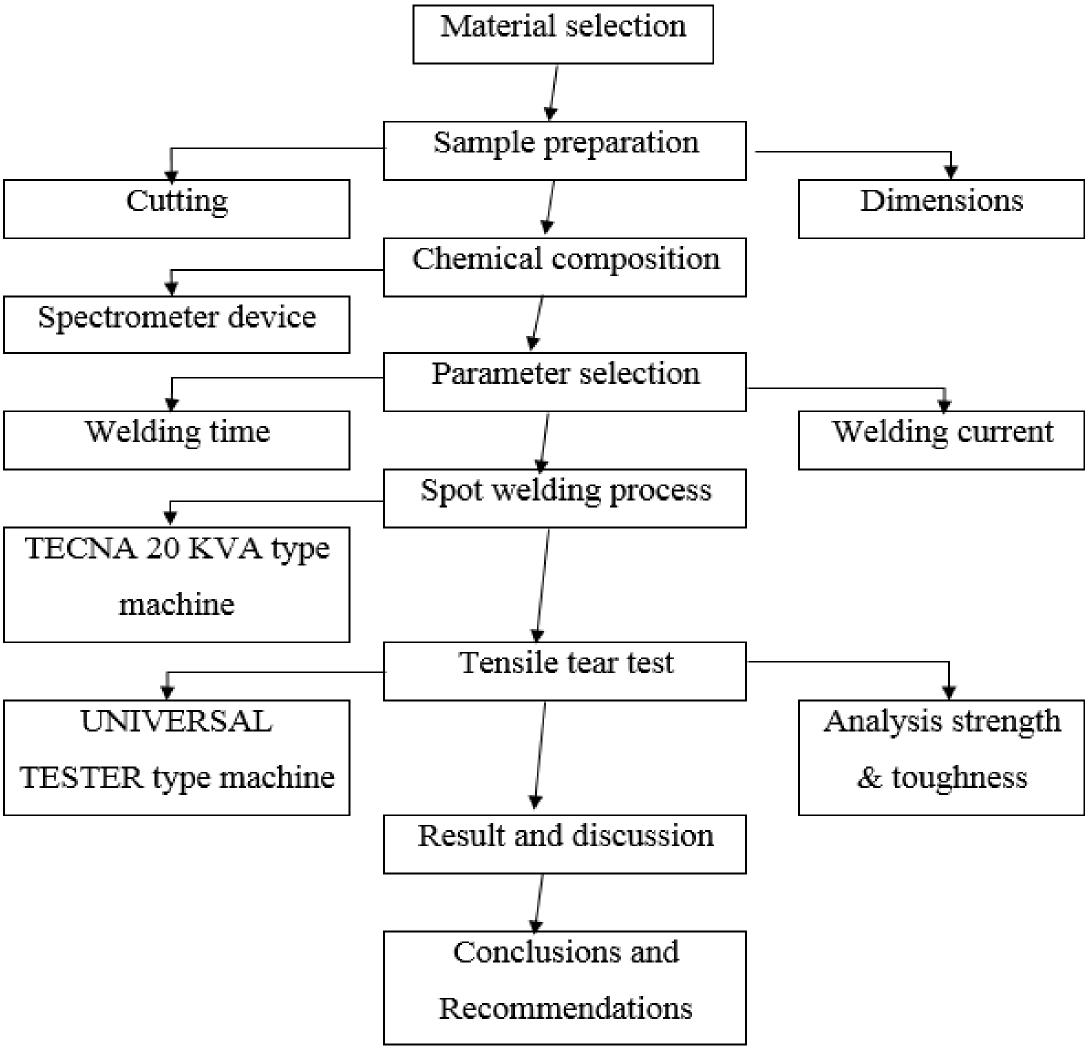

Figure 3.1: Steps Carrier out in the Experimental Work

The steps depicted the above in Figure (3.1) may be explained of follows:

a. Material Selection

Determine The material used in the present work for this experimental study, and determine the chemical composition and type of sheet steel.

b. Sample Preparation

The sample fabricate into lap joint each sheet is labeled according to Figure (3.2). since the plate assembly consists of two sheets for each specimen.

The material was cut according to drawing dimension. for all models, the sample length (L) and width (b) were held constant for all plates had the same dimensions. Also, the thickness (t) of each plate had the same dimensions for the lowest thickness and the highest thickness.

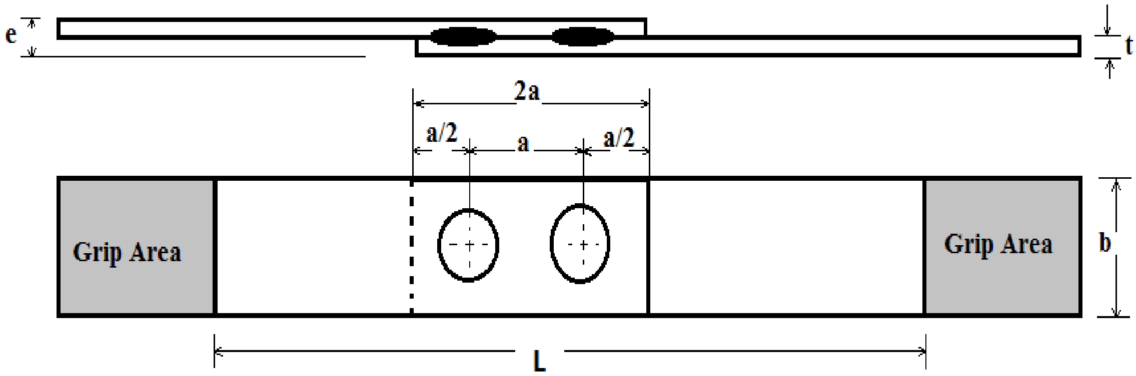

Figure 3.2: Welding Sample with Label

The size of the spot in the weld depends on the size of the tip. Size of electrode diameter has been kept as per AWS recommendation [4].

c. Welding Process

The resistance spot welding technique is ready to run after the sample preparation of sheet metal completed. in this project the specimens are the combination of same thickness of sheet metal, the current and time that applied for the welding is different. the parameters of spot weld machine are kept constant for all specimens.

CHAPTER FOUR

EXPERIMENTAL TEST OF MILD STEEL RSW PROCESS

Experimental Test of Mild Steel RSW Process

This chapter focuses on the mild steel spot welding process and the different variables that affect weld quality. The first stage of the chapter concentrates in determining the optimum welding schedule for the selected material and stack up combination.

Chemical Composition, spot welding process and tensile shear testing were performed in the Mechanical Engineering Department, Faculty of Engineering, University of Khartoum. Excel program was used in the extraction process explains plotted.

4.1 Sample Preparation

The specimens were cut from a sheet of 1m x 2m. The specimens were cut parallel to the rolling direction of the sheets. The dimensions are 270 mm length and 30 mm width, the grip area for each plate 50 mm, the overlap value was changed for each specimen shown in Figure (4.1). This overlap was chosen as per AWS recommendation [4].

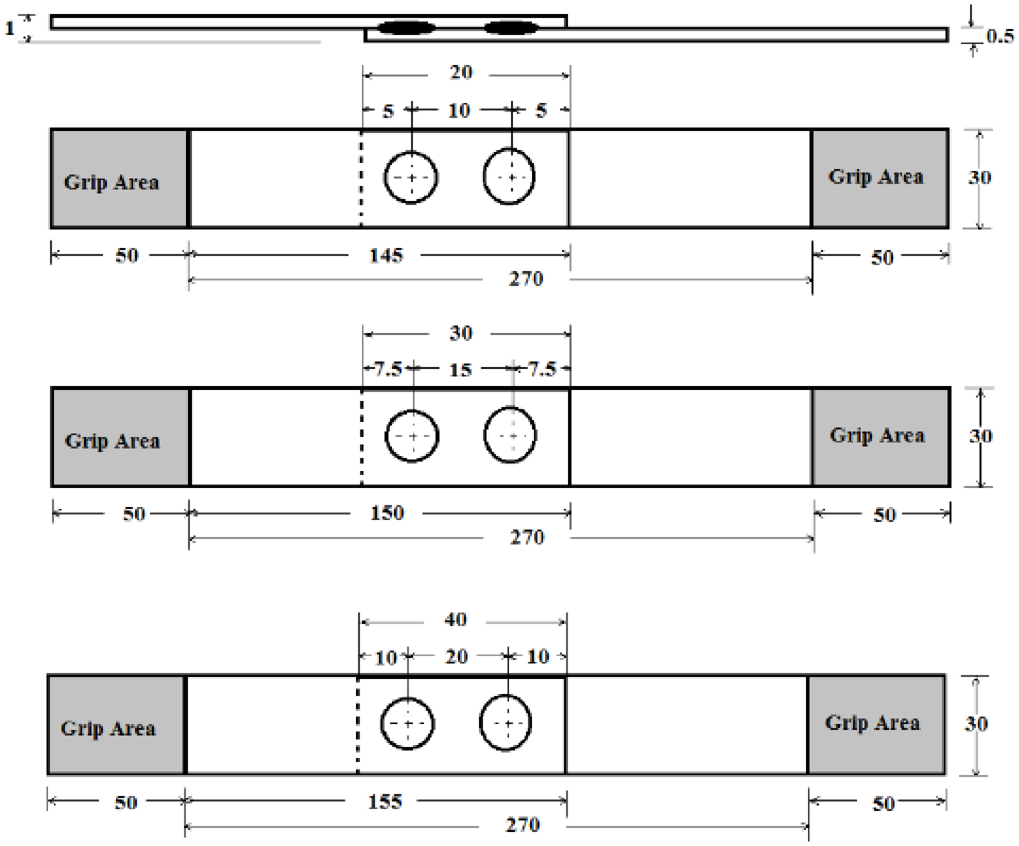

Figure 4.1: Configuration and Dimensions of Specimen (all Dimensions in mm)

4.1.1 Material

The material used in the present work is Mild steel (Grade 1.8969 S600MC) hot rolling sheets of 0.5 mm thickness, to determine the chemical composition and type of sheet steel was used spectrometer device Figure (4.2). The nominal chemical composition for each element of the above material is listed in table 4.1.

Figure 4.2: Spectrometer Device

Table 4.1: Chemical Composition Mild steel (Grade 1.8969 S600MC)

Designation	Average percentage of alloying elements							
	Fe	C	Si	Mn	P	S	Cr	Ni
1.8969 S600MC	99.3	0.105	0.0349	0.213	0.0242	0.0092	0.0702	0.0020

4.1.2 Experimentation

The three process parameters viz. Current, Electrode Force and Weld Time were selected as given in table 4.2. The parameters which were kept constant are also listed in this Table. Experiments were conducted according to the test conditions specified by the table 4.2. Each experiment was repeated two times in each of the trial conditions. Thus, six work-pieces were selected of thickness 0.5mm. Size of electrode diameter tip 5 mm has been selected from AWS recommendation [4]. The machine test used in this experimental are TECNA 20 KVA type.

Table 4.2: Selected Process Parameters and Their Range

Sr. No.	Process Parameters	Range	Unit
1	Current	6 – 8	KA
2	Electrode Force	1400	N
3	Weld Time Cycles	8 – 10	50 c/s
4	Thickness of 1.8969 S600MC sheet	0.5	mm
5	Electrode Type	Straight	Nil
6	Electrode Tip Diameter	5	mm
7	Shape of Electrode Tip	Circular	Nil
8	Type of Current Used	AC	KA
9	Gap in the Electrodes	22	mm

Parameters and their Values at different levels given in Table 4.3 for six specimens. This specimen can be shown in Figure (4.3) below.

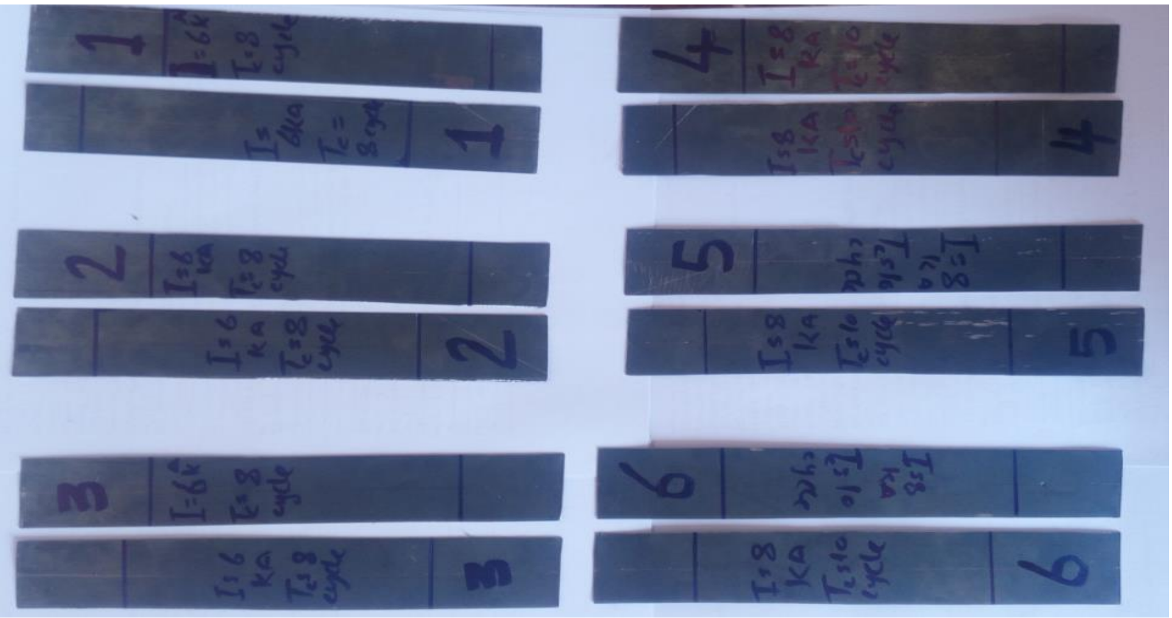

Figure 4.3: Sample Preparation

Table 4.3: Process Parameters and their Values at Different levels

Sr. No	Sample	weld pitch (mm)	Process Parameters			Weld Dia. (mm)
			Electrode Force (KN)	Weld Current (KA)	Weld Time (Cycles)	
1	A	10	1.4	6	8	5
2	B	15	1.4	6	8	5
3	C	20	1.4	6	8	5
4	D	10	1.4	8	10	5
5	E	15	1.4	8	10	5
6	F	20	1.4	8	10	5

After spot welding process, the Prepared samples in Figure (4.4) are ready to execution tensile shear test.

Figure 4.4: Prepared Samples

4.2 Tensile Shear Test

The test samples were subjected to tensile loading in universal testing machine and its corresponding load values are noted as shown in the Figure (4.5). The machine test used in this experimental are MICROPROCESOR-CONTROLLED ELECTRO HYDRAULIC SERVO UNIVERSAL TESTER type.

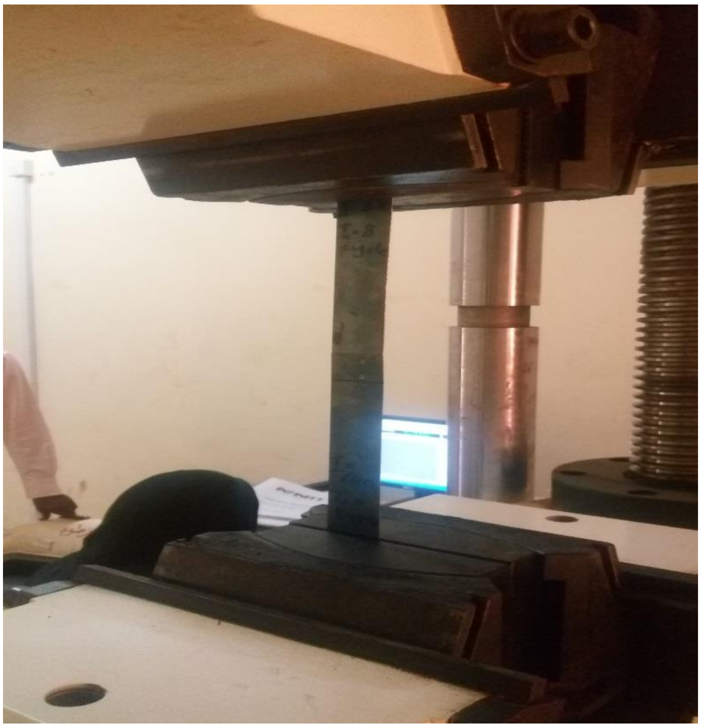

Figure 4.5: Tensile Shear Test

Joint mechanical properties were evaluated by measuring the peak load to failure during overlap tensile shear testing, show result in table 4.4a and table 4.4b.

Table 4.4a: Tensile Shear Test Results for Samples (A, B and C)

Sr. No.	**Sample (A)**		**Sample (B)**		**Sample (C)**	
	Load(KN)	**Displacement (mm)**	**load (KN)**	**Displacement (mm)**	**load (KN)**	**Displacement (mm)**
1	0	0	0	0	0	0
2	0.30	0.15	0.36	0.11	0.39	0.18
3	0.61	0.25	0.71	0.21	0.76	0.23
4	0.83	0.31	0.85	0.31	0.89	0.35
5	0.98	0.36	0.89	0.35	0.9	0.4
6	1.45	0.42	0.93	0.46	1.2	0.56
7	1.78	0.52	0.97	0.48	1.67	0.68
8	2.12	0.65	1.10	0.60	1.98	0.79
9	2.11	0.71	1.80	1.10	1.96	0.92
10	2.40	0.87	2.15	2.80	2.21	2.22

11	2.46	1.40	2.1	3.91	2.30	3.17
12	2.50	2.70	1.80	5.42	2.14	5.16
13	2.65	3.80	1.67	6.30	2.00	6.23
14	2.72	4.10	1.50	7.10	1.89	7.8
15	2.68	5.80				
16	2.61	6.10				

Table 4.4b: Tensile Shear Test Results for Samples (D, E and F)

Sr. No.	**Sample (D)**		**Sample (E)**		**Sample (F)**	
	Load(KN)	**Displacement (mm)**	**load (KN)**	**Displacement (mm)**	**load (KN)**	**Displacement (mm)**
1	0	0	0	0	0	0
2	0.31	0.15	0.35	0.13	0.39	0.11
3	0.60	0.21	0.65	0.21	0.66	0.18
4	0.92	0.26	0.94	0.25	0.7	0.2
5	1.20	0.35	0.99	0.30	0.9	0.23
6	1.51	0.44	1.60	0.36	1.4	0.29
7	1.80	0.51	1.90	0.40	2.13	0.38
8	2.08	0.62	2.51	0.46	2.6	0.41
9	2.10	0.65	2.62	0.60	2.83	0.55
10	2.21	0.72	2.71	0.66	2.85	0.61
11	2.32	0.85	2.84	0.81	2.94	0.72
12	2.48	1.22	2.98	1.10	3.36	3.11
13	2.60	2.00	3.11	1.61	3.40	6.09
14	2.90	3.7	3.32	4.2	3.43	7.99
15	2.95	4.81	3.35	6.56	3.45	9.11
16	2.35	5.63	2.62	8.11	3.13	10.21

4.3 Calculations

Load and displacement data results after tensile shear test in table 4.3, can be calculation the strength and toughness for samples from equations in chapter 2.

From equation (2-7), tensile strength for sample (A) can be found:

$$\sigma_U = \frac{P_U}{A_U} = \frac{P_U}{i\pi de} = \frac{2{\cdot}72 * 10^3}{2 * \pi * 5 * 1} = 86{\cdot}60 \text{ Mpa}$$

Also From equation (2-7), yield strength for sample (A) can be found:

$$\sigma_Y = \frac{P_Y}{A_Y} = \frac{P_Y}{i\pi de} = \frac{2\cdot11 * 10^3}{2 * \pi * 5 * 1} = 67\cdot16 \text{ Mpa}$$

From equation (2-11), Strain for sample (A) can be found:

$$\varepsilon = \frac{\Delta L}{L} = \frac{26\cdot1-20}{20} = 0\cdot305$$

From equation (2-6), modulus of toughness for sample (A) can be found:

$$U_T = \frac{\sigma_Y + \sigma_U}{2} * \varepsilon_R = \frac{67\cdot16 + 86\cdot60}{2} * 0\cdot305 = 23\cdot45 \text{ J/m}^3$$

From equation (2-10), tensile toughness of the joint for sample (A) can be found:

$$T = U_T V = U_T i\pi dsL$$

$$T = 23\cdot45 * 10^6 * 2 * \pi * 5 * 10^{-3} * 1 * 10^{-3} * 20 * 10^{-3} = 14\cdot733 \text{ J}$$

From equation (2-12), elongation for sample (A) can be found:

$$\text{Elongation } (\%) = \frac{\Delta L}{L}\ \% = \frac{26.1-20}{20} = 30\cdot5\%$$

4.4 Results

According to tensile shear calculations table, the peak load, ultimate strength, yield Strength, toughness, elongation and location of failure, for each specimen tested during schedule optimization are shown in table 4.5.

During tensile testing, Location of failure for samples A, D, E and F produce welding while the C and D show top button pull-out shown in Figure (4.6).

(a) (b)

Figure 4.6: Location of failure mode, (a) welding, (b) Top Button pull-out

Table 4.5: Results of Tensile Test of lap Shear Specimens

Sample	**Peak load (KN)**	**Yield Strength (Mpa)**	**Ultimate Strength (Mpa)**	**Toughness (J)**	**Elongation (%)**	**Location of failure**
A	2.72	67.16	86.60	14.733	30.50	Weld
B	2.15	35.00	68.44	11.55	23.70	Top Button pull-out
C	2.30	62.38	73.22	16.61	19.5	Top Button pull-out
D	2.95	73.85	93.90	14.86	28.2	Weld
E	3.35	83.40	106.63	24.17	27.03	Weld
F	3.45	90.71	109.85	32.17	25.53	Weld

Acceptance criteria According to the American Welding Society (AWS) standard, the minimum values of tensile shear load shall be not less than the values given in AWS.

All Samples have strength value larger than AWS standard.

Figure (4.7) explains plotted based on the values of the stress and strain for samples A, B and C results.

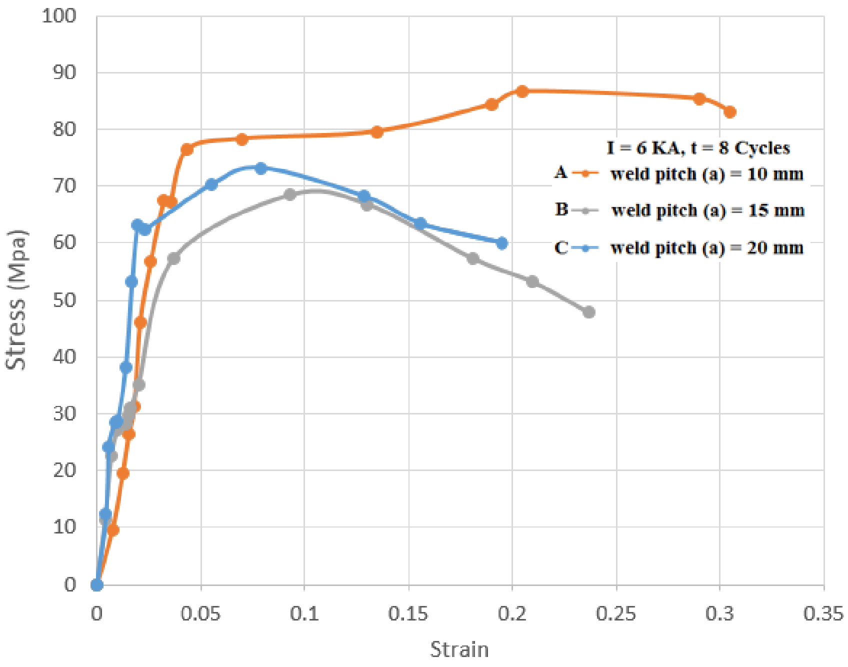

Figure 4.7: Stress-Strain Curve for Samples A, B and C

Figure (4.8) explains plotted based on the values of the stress and strain for samples D, E and F results.

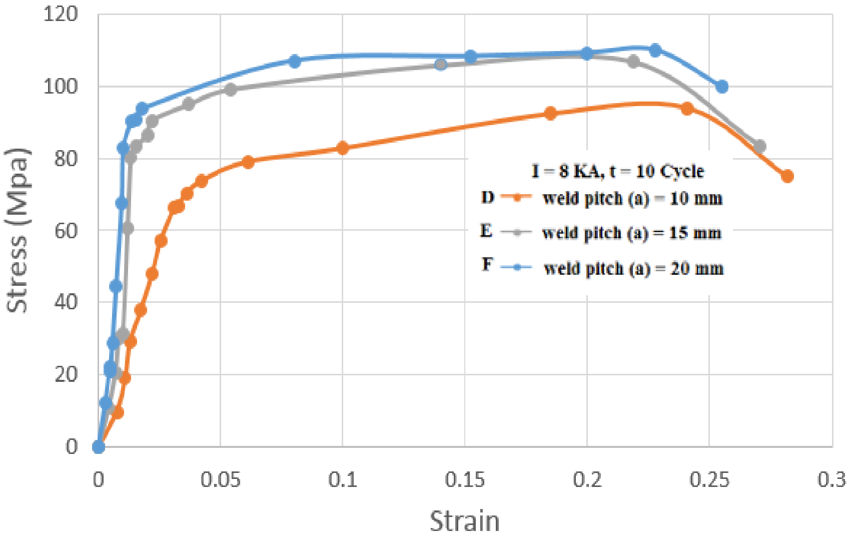

Figure 4.8: Stress-Strain Curve for Samples D, E and F

Figure (4.9) explains plotted based on the values of the toughness of the joint and strength results.

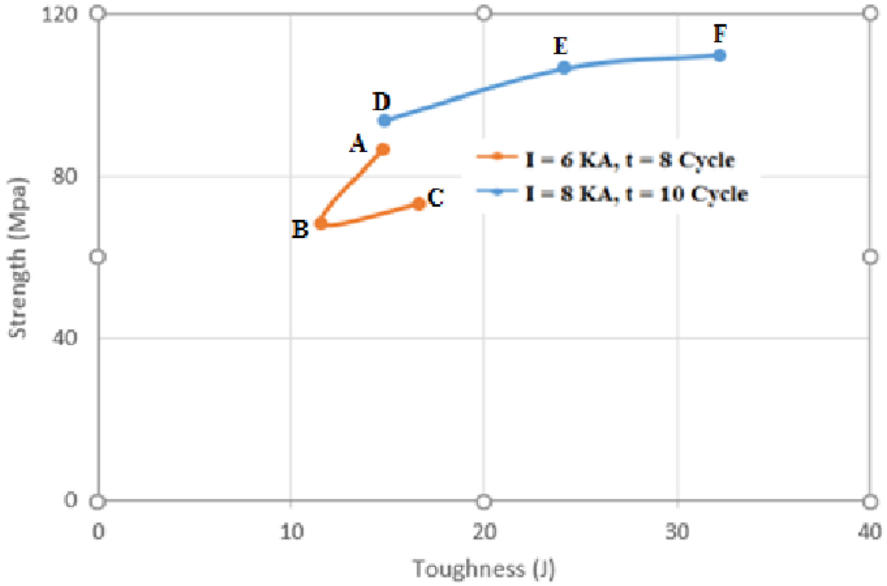

Figure 4.9: Toughness vs Strength Curve

Figure (4.10) explains plotted based on the values of the toughness of the joint and elongation results.

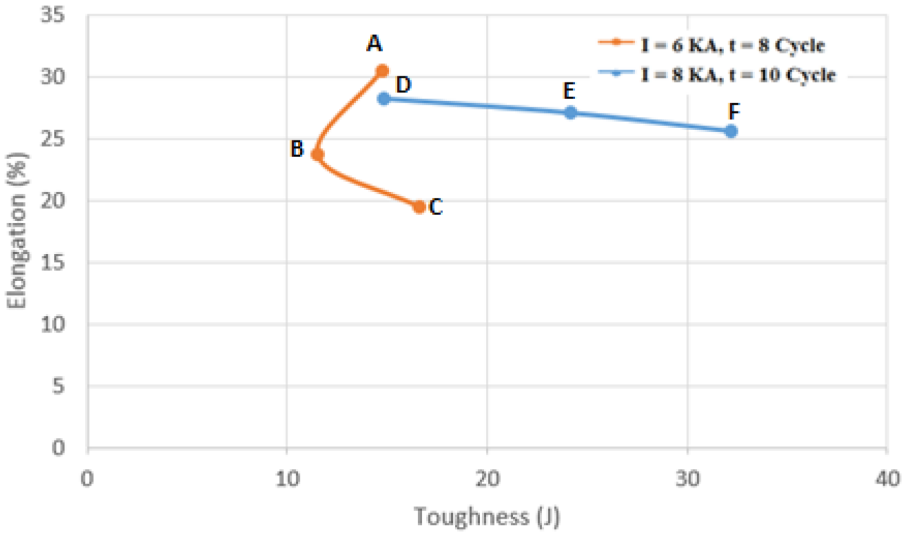

Figure 4.10: Toughness vs Elongation Curve

Figure (4.11) explains plotted based on the values of the strength of the joint and welding pitch results.

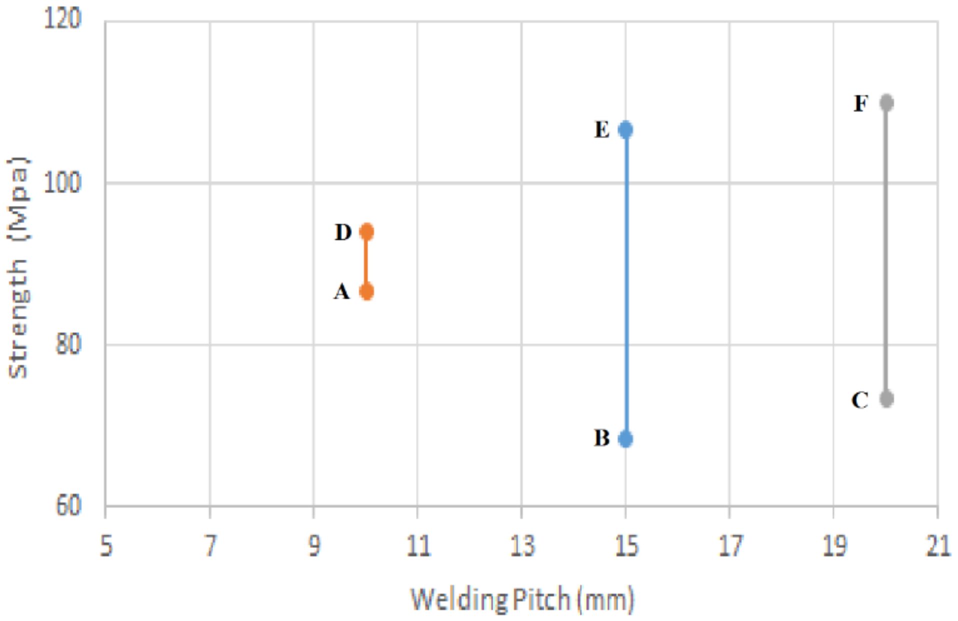

Figure 4.11: Strength vs Welding Pitch

Figure (4.12) explains plotted based on the values of the strength of the joint and welding current results.

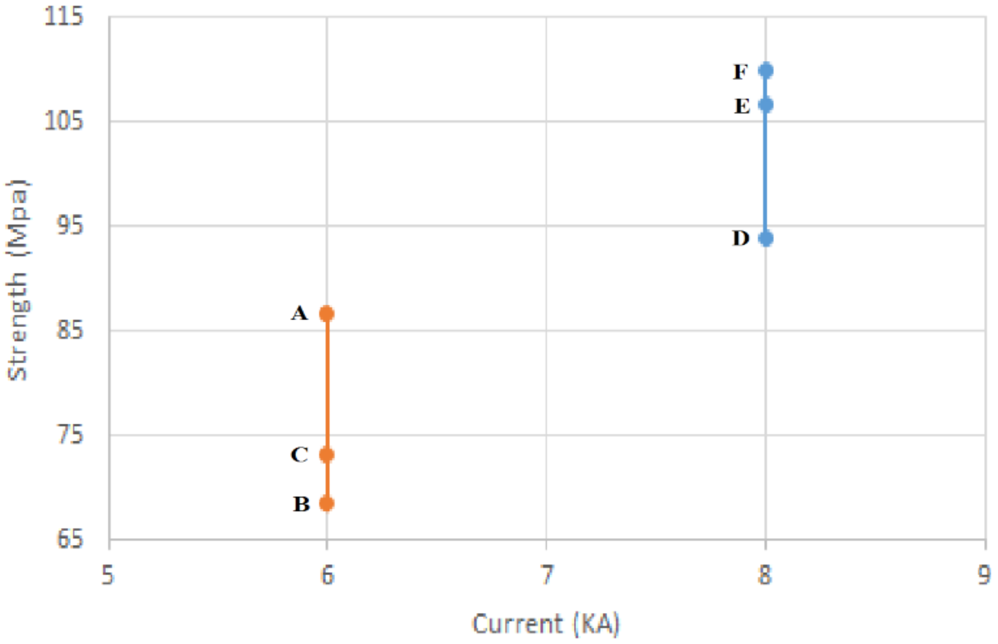

Figure 4.12: Strength vs Welding Current

4.5 Discussions

The resulting of the welding of low carbon steel Grade (1.8969 S600MC) hot rolling above given chemical composition and welding conditions can be discuss the results according to welding current and welding time cycle for joining of weld which are following:

- From Figure (4.7) maximum tensile strength 86.60 Mpa has sample (A) at weld current = 6 KA, weld time = 8 Cycle and weld pitch = 10 mm.
- From Figure (4.8) maximum tensile strength 109.85 Mpa has sample (F) at weld current = 8 KA, weld time = 10 Cycle and weld pitch = 20 mm.
- From Figure (4.9) and figure 4.10 maximum tensile toughness 32.17 J has sample (F) at weld current = 8 KA, weld time = 10 Cycle, weld pitch = 20 mm, strength 109.85 Mpa and elongation 25.53% best than the maximum tensile toughness 16.61 J has sample (C) at weld current = 6 KA, weld time = 8 Cycle, weld pitch = 20 mm, strength 73.32 Mpa and elongation 19.50 %.
- From Figure (4.10) maximum elongation = 30.50% have sample (A) but not have maximum tensile toughness.
- Location of failure for sample (A) was weld result because the pitch between spot weld was smaller.
- Quality joint for samples D, E and F was best than samples A, B and C.
- For sample B and C top pullout Location of failure mode, maximum tensile strength and toughness was 73.22 Mpa 16.61J respectively at sample C.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and Recommendations

5.1 Conclusions

At the end of this study the following can be concluded:

- With an increase in welding current and welding time, the joint strength of welding increase. It is favorable to select relatively welding current and welding time to obtain pullout failure mode.
- With an increase in welding current and welding time, the joint toughness of welding increase.
- With a decrease in welding pitch, the joint of weld became strong against to pullout failure mode.
- Optimum elongation, toughness and strength at sample F according to weld failure mode. and sample C according to pullout failure mode.

5.2 Recommendations

It is recommended to:

- Design of experiments can be used to characterize the new spot welding.
- Finite element analysis of spot welding process can be done to optimize the weld strength and toughness of joint.
- Using new experiments to determine toughness and strength as tensile peel strength.
- Using new methods as impact load to following new characterizes.
- Using computer programs analyses and comparing results.
- Using another materials steel, object different mechanical and chemical properties.

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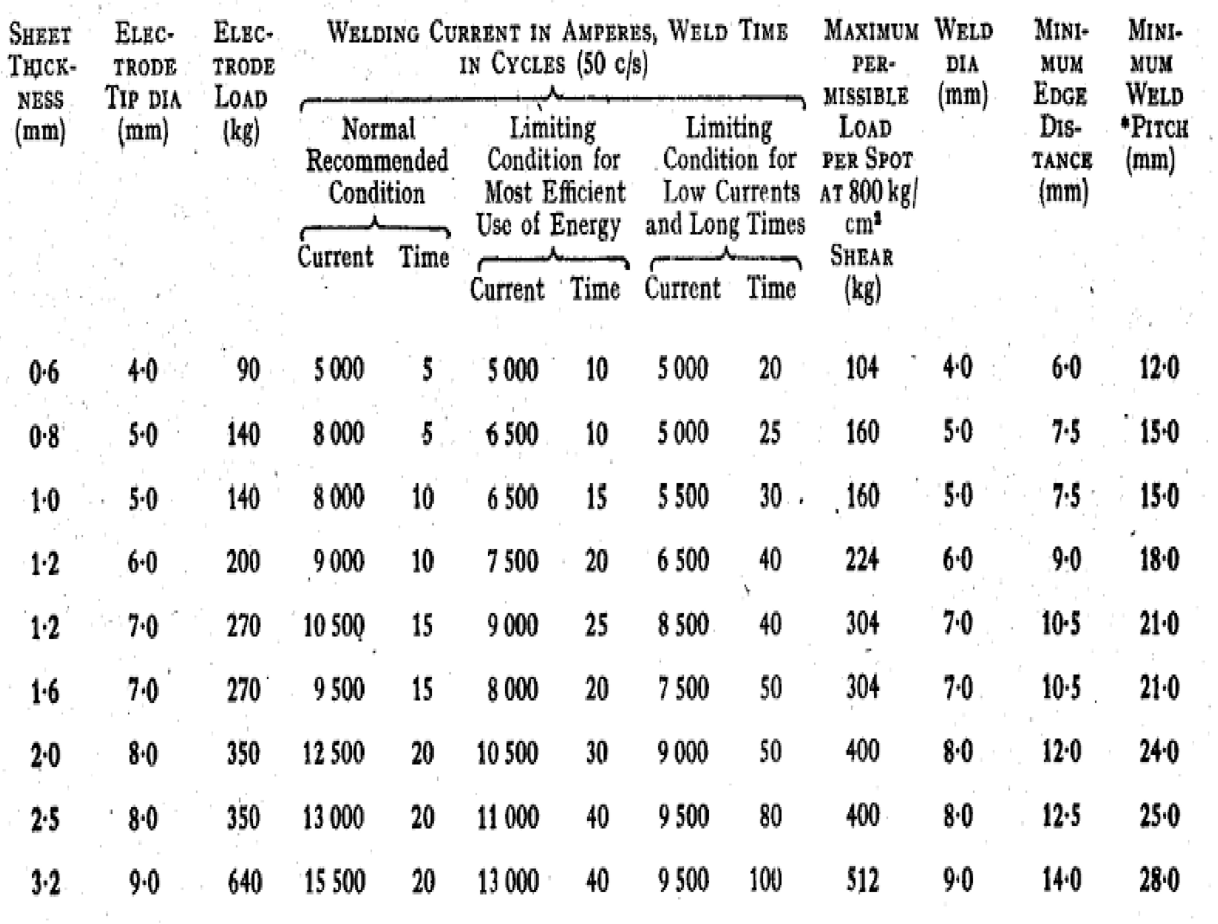
APPENDIX

(A)

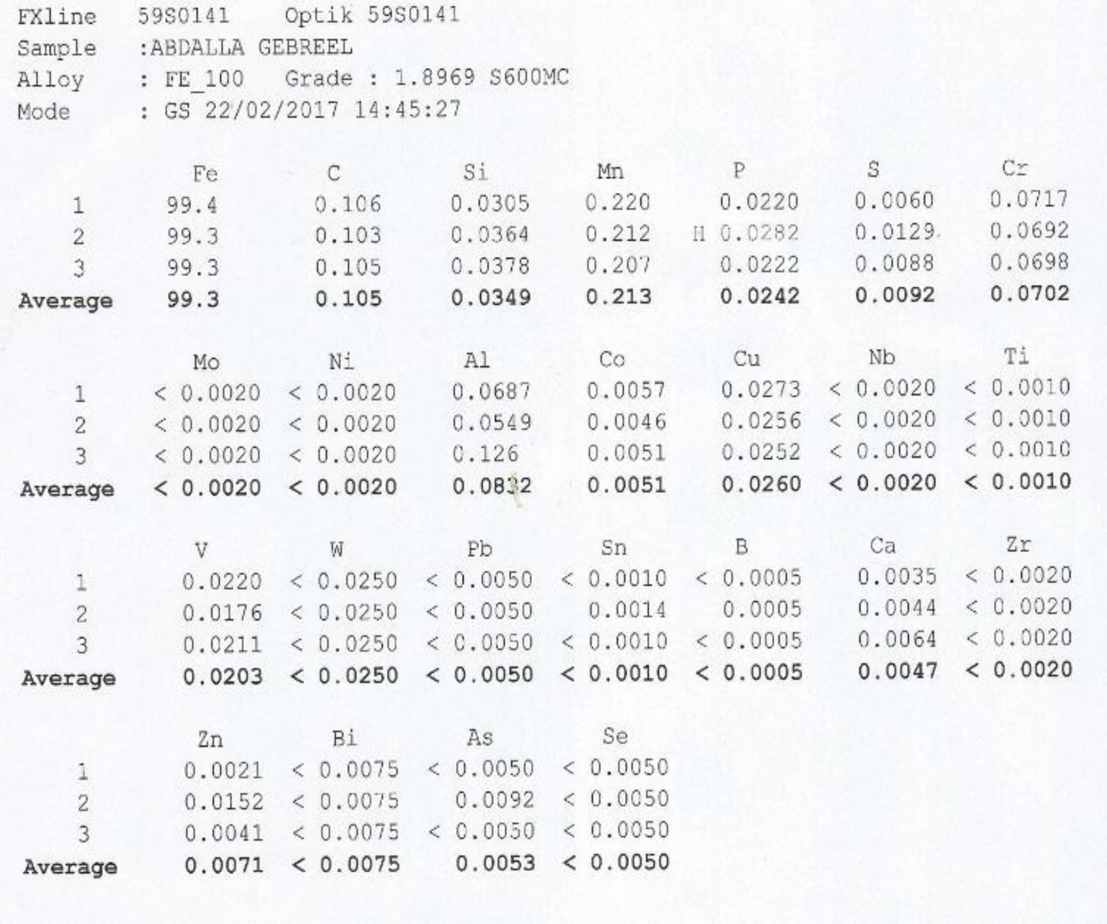
Design data for spot welding tow equal thickness of low carbon mild steel sheets (in metric units), According to the American Welding Society (AWS).



SHEET THICKNESS (mm)	ELECTRODE TIP DIA (mm)	ELECTRODE LOAD (kg)	WELDING CURRENT IN AMPERES, WELD TIME IN CYCLES (50 c/s)						MAXIMUM PERMISSIBLE LOAD PER SPOT AT 800 kg/cm^2 SHEAR (kg)	WELD DIA (mm)	MINIMUM EDGE DISTANCE (mm)	MINIMUM WELD *PITCH (mm)
			Normal Recommended Condition		Limiting Condition for Most Efficient Use of Energy		Limiting Condition for Low Currents and Long Times					
			Current	Time	Current	Time	Current	Time				
0·6	4·0	90	5 000	5	5 000	10	5 000	20	104	4·0	6·0	12·0
0·8	5·0	140	8 000	5	6 500	10	5 000	25	160	5·0	7·5	15·0
1·0	5·0	140	8 000	10	6 500	15	5 500	30	160	5·0	7·5	15·0
1·2	6·0	200	9 000	10	7 500	20	6 500	40	224	6·0	9·0	18·0
1·2	7·0	270	10 500	15	9 000	25	8 500	40	304	7·0	10·5	21·0
1·6	7·0	270	9 500	15	8 000	20	7 500	50	304	7·0	10·5	21·0
2·0	8·0	350	12 500	20	10 500	30	9 000	50	400	8·0	12·0	24·0
2·5	8·0	350	13 000	20	11 000	40	9 500	80	400	8·0	12·5	25·0
3·2	9·0	640	15 500	20	13 000	40	9 500	100	512	9·0	14·0	28·0

(B)

Chemical composition and type of sheet steel was used in this study by using spectrometer device.



```
FXline    59S0141     Optik 59S0141
Sample    :ABDALLA GEBREEL
Alloy     : FE_100    Grade : 1.8969 S600MC
Mode      : GS 22/02/2017 14:45:27

              Fe          C           Si          Mn          P           S           Cr
      1      99.4        0.106       0.0305      0.220       0.0220      0.0060      0.0717
      2      99.3        0.103       0.0364      0.212     H 0.0282      0.0129      0.0692
      3      99.3        0.105       0.0378      0.207       0.0222      0.0088      0.0698
Average      99.3        0.105       0.0349      0.213       0.0242      0.0092      0.0702

              Mo          Ni          Al          Co          Cu          Nb          Ti
      1    < 0.0020    < 0.0020      0.0687      0.0057      0.0273    < 0.0020    < 0.0010
      2    < 0.0020    < 0.0020      0.0549      0.0046      0.0256    < 0.0020    < 0.0010
      3    < 0.0020    < 0.0020      0.126       0.0051      0.0252    < 0.0020    < 0.0010
Average    < 0.0020    < 0.0020      0.0832      0.0051      0.0260    < 0.0020    < 0.0010

              V           W           Pb          Sn          B           Ca          Zr
      1      0.0220    < 0.0250    < 0.0050    < 0.0010    < 0.0005      0.0035    < 0.0020
      2      0.0176    < 0.0250    < 0.0050      0.0014      0.0005      0.0044    < 0.0020
      3      0.0211    < 0.0250    < 0.0050    < 0.0010    < 0.0005      0.0064    < 0.0020
Average      0.0203    < 0.0250    < 0.0050    < 0.0010    < 0.0005      0.0047    < 0.0020

              Zn          Bi          As          Se
      1      0.0021    < 0.0075    < 0.0050    < 0.0050
      2      0.0152    < 0.0075      0.0092    < 0.0050
      3      0.0041    < 0.0075    < 0.0050    < 0.0050
Average      0.0071    < 0.0075      0.0053    < 0.0050
```

(C)

Type of machine test used in this experimental to resistance spot welding Process are TECNA 20 KVA type.

(D)

Type of machine test used in this experimental to Tensile Shear the samples operation are MICROPROCESOR-CONTROLLED ELECTRO HYDRAULIC SERVO UNIVERSAL TESTER type.