OPTIMIZATION OF PROCESS PARAMETER FOR RESISTANCE SPOT WELDING USING TAGAUCHI METHOD

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CHAPTER-1

INTRODUCTION

Resistance spot welding, RSW in short, is one of the oldest techniques widely being used for joining metals in various industries because of its simplicity, easy for automation and reliability for mass production. RSW is an autogenous welding process, meaning that unlike other methods, it does not require filler metals. RSW harnesses the metal's natural electrical resistance to generate heating. The procedure begins with electrodes which clamp two metal sheets. The current flows through the sheets from one electrode to the other, and resistance to this flowing current generates heat. A temperature is reached where the metal sheets fuse at the faying surfaces and a molten region is generated in between two sheets. As the current shuts off, the melt rapidly solidifies due to cooling water, forming a solid nugget.

Ever since the original invention by Professor Elihu Thomson in 1877, the process has been applied actively for the assembly of metal sheets in the automobile and aircraft industries **[33].**

The level importance of the resistance spot welding can be seen through spot welding in cars as there are more than 3000-6000 spot welds. It has excellent techno economic benefits such as low cost, high production rate and adaptability for automation which make it an attractive choice for auto-body assemblies, truck cabins, rail vehicles and home appliances.

Furthermore, other metal-to-metal connections, such as wire-to-wire joints in the electronics industry, are accomplished by resistance spot welding. Application to specific measures, such as the diameter of the welding spot, determines the quality of the joint.

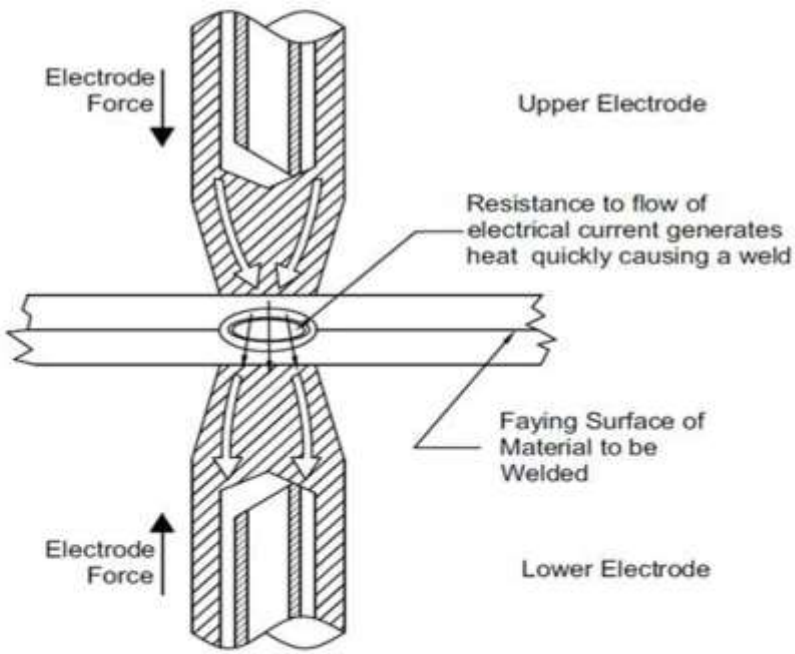

FIGURE 1.1 Working of RSW

The process is used in preference to mechanical fasteners, such as screws, rivets, when disassembly for maintenance is not required. RSW is extensively used in joining low carbon steel components, High strength low alloy steel, stainless steel, aluminum, nickel, titanium and copper alloys commercially.

With automatic control of the current settings, timing and electrode force, sound spot welds can be produced at high production rate. This is particularly true for thin sheets or steel strips, whether coated or uncoated.

1.1PRINCIPLE OF RESISTANCE SPOT WELDING

Resistance spot welding process uses heavy current which is passed for short period of time through the area of interface of metals and applying pressure on the metals to be joined. In resistance spot welding process there is no flux used, and the use of filler metal is very rare. Resistance welding operations are normally automatic and, therefore, all process parameters are pre-set and maintained constant. Heat generated in a localized area is enough to heat the metal to a sufficient temperature, so that the parts can be joined with the application of pressure.

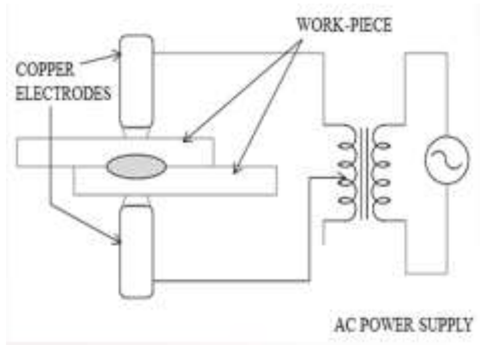

FIGURE 1.2 Principal of RSW

Spot welding operation is based on four factors that are:

1. Amount of current that passes through the work piece.
2. Pressure that the electrodes applied on the work piece.
3. The time the current flow through the work piece.
4. The area of the electrode tip contact with the work piece.

1.2 HEAT GENERATION

Heat generation in resistance spot welding is based on the Ohm's law. The amount of heat generated in an electrical conductive work piece depends on mainly three parameters welding current, resistance of work piece and time of current flow.

The heat generated by resistance is expressed as below:

$$H = I^2RT \qquad \text{(Eq-1.1)}$$

Where,

H=Heat Generated

I=Current

R=Resistance

T=Time

Thus, optimization of such welding parameters for each material is the key for controlling weld quality.

1.3APPLICATION

Spot welding is typically used when welding particular types of sheet metal, welded wire mesh or wire mesh.

Aluminium alloys can be spot welded, but their much higher thermal conductivity and electrical conductivity requires higher welding currents. This requires larger, more powerful, and more expensive welding transformers.

Perhaps the most common application of spot welding is in the automobile manufacturing industry, where it is used almost universally to weld the sheet metal to form a car. Spot welders can also be completely automated, and many of the industrial robots found on assembly lines are spot welders.

Spot welding is also used in the orthodontist's clinic, where small-scale spot welding equipment is used when resizing metal "molar bands" used in orthodontics Another application is spot welding straps to nickel–cadmium or nickel–metal hydride cells to make batteries. The cells are joined by spot welding thin nickel straps to the battery terminals. Spot welding can keep the battery from getting too hot, as might happen if conventional soldering were done.

CHAPTER-2

2.1 LITERATURE REVIEW

Various authors show the light on spot weld parameter optimization by using different techniques and their influence on different materials.

The principle of resistance welding was first used by English physicist James Joule, in 1856.In his experiments he buried a bundle of wire in charcoal and welded the wires by heating them with an electric current. This is believed to be the first application of heating by internal resistance for welding metals. It remained for Elihu Thompson to perfect the process for practical applications. In 1877 Thompson invented a small low pressure resistance welding machine but in the early 1880s it was used as a commercial welding technique by Ford Motors.

As the name implies, it means that due to internal resistance of the material to be welded to current flow that causes a localized heating at the point **[33].**

RSW is a thermo-electric process in which heat is generated at the interface of the parts to be joined by passing an electric current through the parts for a precisely controlled time and under a controlled pressure (also called force).

Working of modern resistance welding is still done by using heat and pressure and electric current creates the heat that is required to make the welds. Secondary voltage and current are controlled with tap switches mounted remotely or on the transformer. The welding current is controlled by turning a solid-state switch (siliconcontrolled rectifier or SCR) on and off. The current is passed through copper secondary conductors, welding arms, and the welding electrodes. In the past, ignitron tubes were used before the invention of SCRs. Today's modern mid frequency DC welding machines use diode packs built into the transformers and insulated gate bipolar transistors in the controls to control the current and convert it into direct current.

2.2WELDING PARAMETERS

During welding, molten zone at the faying sheet surface becomes the weld nugget, so if more heat can be generated, a larger volume of metal can be melted, resulting in a bigger nugget. Larger weld nuggets are generally good for weld performance **[34,53].** The weld nugget size should be large enough for better impact property as well as preferable weld failure mode **[34, 53]**.

There are mainly four welding parameters which control the quality of RSW. They are given below:

- Current
- Weld time
- Pressure

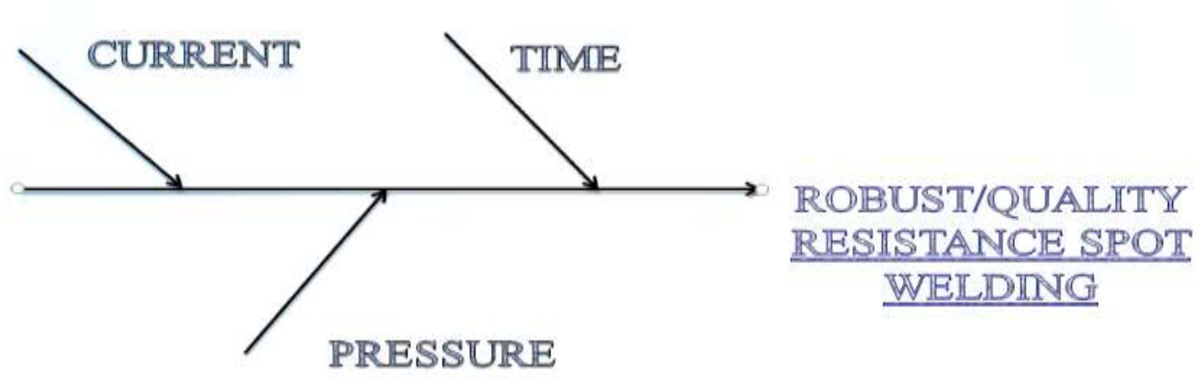

Figure.2.1 Cause and effect diagram of main welding parameters

2.2.1 EFFECT OF WELDING CURRENT

In RSW, the generated heat is proportional directly to the weld current. Two types of current wave forms are available for conventional RSW processes; they are AC (alternating current) and DC (direct current) wave forms. In the automotive industry, the spot welding process with single-phase AC has been predominant **[6].** DC systems can be used by rectification of single-phase or multi-phase AC into DC. Inverter equipped spot welders can provide very high frequency (2000 Hz) DC, which is effective in terms of energy use **[6].** Also, DC system-based spot welding usually requires more equipment, thus bringing reliability problems, and is more costly **[51],** but it minimizes the heat loss and provides uniform heat flow. Fig. 2.2 compares each current wave form, and in a single-phase AC there is an inevitable energy loss because of a series of current zero points, while DC systems provide reliable uniform heat flow. Many investigations on the differences that may come from different power systems, AC or DC, have been conducted by many authors **[47,24].**

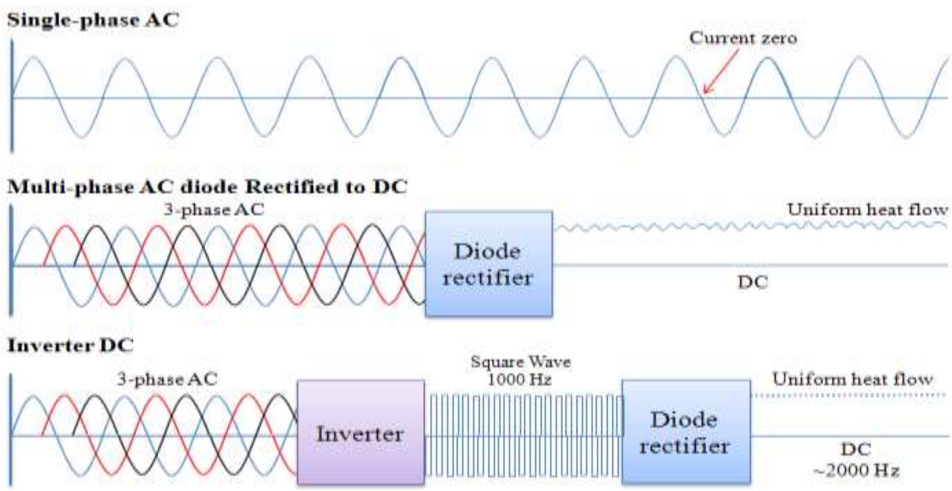

Figure.2.2 comparisons of different welding current wave forms

In the formula, Q = *12Rt*, current has a greater effect on the generation of heat than either resistance or time. Therefore, it is an important variable to be controlled. Two factors that cause variation in welding current arc fluctuations in power line voltage and variations in the impedance of the secondary circuit with AC machines, Impedance variations are caused by changes in circuit geometry or by the introduction of varying masses of magnetic metals into the secondary loop of the machine. Direct current machines are not significantly affected by magnetic metals in the secondary loop and are little affected by circuit geometry. In addition to variations in welding current magnitude, current density may vary at the weld interface. This can result from shunting of current through preceding welds and contact points other than those at the weld. An increase in electrode face area, or projection size in the case of projection welding, will decrease current density and welding heat. This may cause a significant decrease in weld strength.

A minimum current density for a finite time is required to produce fusion at the interface. Sufficient heat must be generated to overcome the losses to the adjacent base metal and the electrodes. Weld nugget size and strength increase rapidly with increasing current density. Excessive current density will cause molten metal expulsion (resulting in internal voids), weld cracking, and lower mechanical strength properties. Typical variations in shear strength of spot welds as a function of current magnitude are shown in Figure 2.3. In the case of spot welding excessive current will overheat the base metal and result in deep indentations in the parts and, it will cause overheating and rapid deterioration of the electrodes.

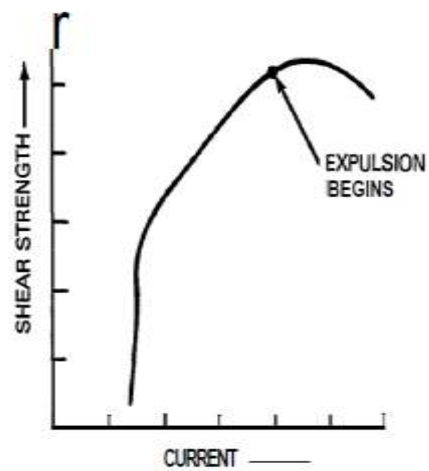

Figure 2.3 Effect of welding current on spot weld shear strength

2.2.2 EFFECT OF WELD TIME

Spot welding process generally consists of 4 steps, which are squeezing, welding, holding and final releasing **[19].** In AC systems, the weld time is expressed in cycles (one cycle is 1/50 of a second in a 50 Hz power system), while millisecond is used for DC systems. During squeeze time, metal sheets are placed in position and clamped by electrodes. When the electrode force has reached the desired level, welding proceeds by the application of current. During this time, melting and joining occurs. Weld time should be determined according to material type, weld quality as well as productivity. The current is shut off during the hold time, so the nugget is allowed to cool. Finally the metal is released, and the next welding sequence begins. The time for each step should be set according to the material, thickness and the coating conditions **[32].**

The rate of heat generation must be such that welds with adequate strength will be produced without excessive electrode heating and rapid deterioration. The total heat developed is proportional to weld time. Essentially, heat is lost by conduction into the surrounding base metal and the electrodes; a very small amount is lost by radiation. These losses increase with increases in weld time and in metal temperature, but they are essentially uncontrollable. During a spot welding operation, some minimum time is required to reach melting temperature at some suitable current density. Excessively long weld time will have the same effect as excessive amperage on the base metal and electrodes. Furthermore, the weld heat-affected zone will extend farther into the base metal.

In most cases, the heat losses at some point during an extended welding interval will equal the heat input; temperatures will stabilize.

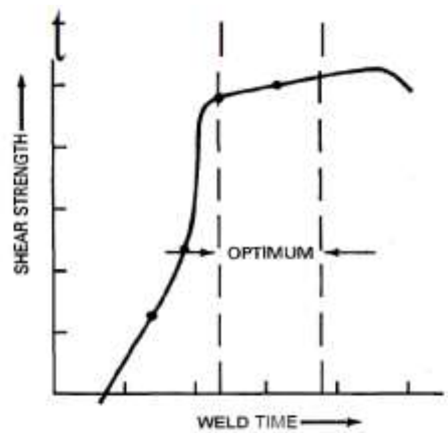

Figure.2.4 Tensile-shear strength as a function of weld time

An example of the relationship between weld time and spot weld shear strength is shown in Figure 2.4 assuming all other conditions remain constant. To a certain extent, weld time and amperage may be complementary. The total heat may be changed by adjusting either the amperage or the weld time. Heat transfer is a function of time and the development of the proper nugget size requires a minimum length of time, regardless of amperage. When spot welding heavy plates, welding current is commonly applied in several relatively short impulses without removal of electrode force. The purpose of pulsing the current is to gradually build up the heat at the interface between the work pieces. The amperage needed to accomplish welding can rapidly melt the metal if the heat pulse time is too long, resulting in expulsion.

2.2.3 EFFECT OF WELDING PRESSURE

Electrode force is applied on electrodes to press and secure metal sheets in position. Electrode force *P* is expressed as below, where *t* is the metal thickness in mm, *TS* tensile strength of the steel sheets in MPa **[20].**

$$P = 2.5.t.\left(\frac{TS}{300}\right)\hat{}(0.5) \quad \text{(Eq-2.1)}$$

According to the above equation, stronger steels will require greater electrode force. If the force is insufficient to push the two metal sheets tight, a small contact diameter results, which alters the amount of heat that is generated, according to equation above.

The resistance R in the heat formula is influenced by welding pressure through its effect on contact resistance at the interface between the work pieces. Welding pressure is produced by the force exerted on the joint by the electrodes. Electrode force is considered to be the net dynamic force of the electrodes upon the work, and it is the resultant pressure produced by this force that affects the contact resistance. Pieces to be spot welded must be clamped tightly together at the weld location to enable the passage of the current. Everything else being equal, as the electrode force or welding pressure is increased, the amperage will also increase up to some limiting value. The effect on the total heat generated, however, may be the reverse. As the pressure is increased, the contact resistance and the heat generated at the interface will decrease. To increase the heat to the previous level, amperage or weld time must be increased to compensate for the reduced resistance. The surfaces of metal components, on a microscopic scale, are a series of peaks and valleys. When they are subjected to light pressure, the actual metal to- metal contact will be only at the contacting peaks, a small percentage of the area. Contact resistance will be high. As the pressure is increased, the high spots are depressed and the actual metal-to-metal contact area is increased, thus decreasing the contact resistance. In most applications, the electrode material is softer than the work pieces; consequently, the application of a suitable electrode force will produce better contact at the electrode to work interfaces than at the interface between the work pieces **[6].**

2.3TAGUCHI METHOD

- GENICH TAGUCHI

Genichi Taguchi (January 1, 1924 – June 2, 2012) was an engineer and statistician. From the 1950s onwards, Taguchi developed a methodology for applying statistics to improve the quality of manufactured goods. Taguchi methods have been controversial among some conventional Western statisticians. But others have accepted many of the concepts introduced by him as valid extensions to the body of knowledge.

After the war, in 1948 he joined the Ministry of Public Health and Welfare, where he came under the influence of eminent statistician Matosaburo Masuyama, who kindled his interest in the design of experiments. He also worked at the Institute of Statistical Mathematics during this time, and supported experimental work on the production of penicillin at Morinaga Pharmaceuticals, a Morinaga Seika company.

Since 1982, Genichi Taguchi has been an advisor to the Japanese Standards Institute and executive director of the American Supplier Institute, an international consulting organization. His concepts pertaining to experimental design, the loss function, robust design, and the reduction of variation have influenced fields beyond product design and manufacturing, such as sales process engineering.

2.3.1INTRODUCTION

It is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost **[49].** Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained 11 wide popularity in the engineering and scientific community **[10,39].** The desired welding parameters are determined based on experience & books.

Steps of Taguchi method are as follows:

(1) Identification of main function, side effects and failure mode.

(2) Identification of noise factor, testing condition and quality characteristics.

(3) Identification of the main function to be optimized.

(4) Identification the control factor and their levels.

(5) Selection of orthogonal array and matrix experiment.

(6) Conducting the matrix experiment.

(7) Analyzing the data, prediction of the optimum level and performance.

(8) Performing the verification experiment and planning the future action. **[37]**

This study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage **[15].** Although similar to design of experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design.

By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore reducing costs and increasing profit. Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach: system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design. The objective of the parameter design **[44]** is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values.

The parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum condition; and conducting Confirmation runs with the optimal levels of all the parameters. The main effects indicate the general trend of influence of each parameter. Knowledge of the contribution of individual parameters is the key to deciding the nature of the control to be established on a production process.

Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence **[55].** Taguchi suggests **[23]** two different routes for carrying out the complete analysis. In the standard approach the results of a single run or the average of repetitive runs are processed through the main effect and ANOVA (raw data analysis). The second approach, which Taguchi strongly recommends for multiple runs, is to use the signal-to-noise (S/N) ratio for the same steps in the analysis. In the present investigation, only the raw data analysis was performed. The effects of the selected FSW parameters on the selected performance characteristics were investigated through the plots of the main effects based on raw data. The optimum condition for each of the performance characteristics was established through the raw data analysis. An algebraic model for predicting the best mechanical performance was developed. The optimal FSW parameters were verified using a confirmation experiment.

2.4 FAILURE MECHANISM AND ULTIMATE STRENGTH OF RSW

A spot-welded joint can be considered to consist of three zones the fusion zone (FZ), the heat affected zone (HAZ), and the approaching base metal zone (BM). Besides the welding metallurgy effect on the strength of spot-welded joint, the strength of spot-weld joint is also influenced by weld size, sheet thickness, edge distance, and spacing between the spot welds . Due to the spot welding processing, the HAZ near FZ has the highest hardness, which means the area has the higher yielding and ultimate strength. According to spot welding failure location, there are interfacial nugget failure and pullout nugget failure. Pull-out nugget failure is dominant for big weld size, which appears in HAZ and nugget remains intact. For tensile-shear load, the nugget rotation is the main cause of the pull-out failure for spot-welded joint, the rotation of nugget makes high stress around nugget in load direction.

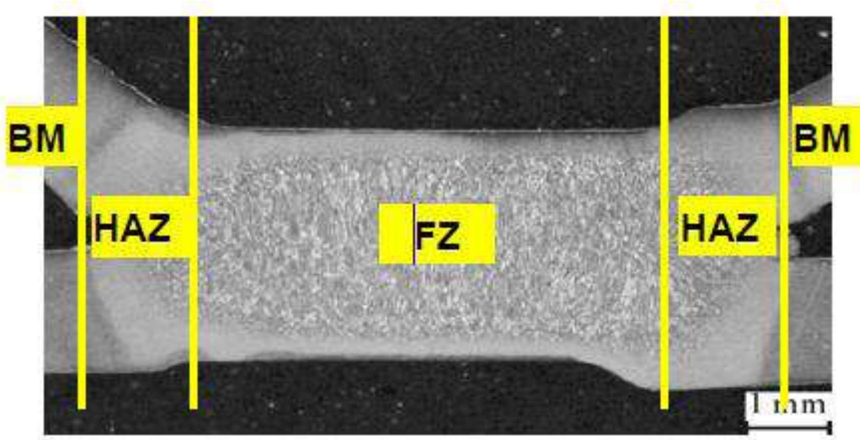

Figure.2.5 Different zones of HAZ of spot weld.

Although the spot weld has been used extensively, a simple failure criterion that is able to predict the failure strength of a spot weld subjected to various loading conditions does not exist. Conventional practice in industry is to perform extensive tests to obtain sufficient data sets for design purpose **[13, 46]**

The drawback of this approach is that there are simply too many variables to consider, e.g., welding parameters, sheet thickness, weld nugget size for a given material. Consequently, it is costly to develop a meaningful and useful database.

A verified, mechanics based failure theory would be very useful to the designers and significantly reduce the number of test required and thus the cost involved. Due to its complex geometry, analytical solution for stresses in a spot weld is difficult to obtain. Radaj **[39]** Radaj and Zhang **[40]** and Zhang **[57-58]** have adopted a fracture mechanics approach and provided very detailed stress distribution around a weld nugget. The derived linear elastic stress intensity factor solutions are mathematical in nature and its practical application to the failure of spot weld under monotonic loading has not been fully realized. Wung **[50]** and Wung et al. **[52]** have recently reported the failure strength of spot weld under in-plane torsion and advocated the force based failure criterion which is used in commercial finite element code such as LS-DYNA3D.

Zuniga and Sheppard **[59]** performed failure test of spot weld on high strength steel and studied detailed failure mechanisms of lap-shear and coach peel samples. One of the main findings from their work is that the failure mechanism for lap-shear sample is localized necking ~shear localization! in the base metal and near the boundary between HAZ and base metal. Because of this finding they then attempted using the plastic strain in the thickness direction near the weld nugget as the failure criterion to interpret the strength of spot weld.

Barkey et al. **[5]** and Lee et al. **[28]** designed a test sample and a fixture such that a spot weld test sample can be loaded under pure shear, mixed shear/normal, or pure normal load by changing the loading position of the fixture. Ultimate strength data of spot welds using the fixture were reported and curve fitted to a force based failure criterion for design consideration. Similarly, Lin et al. [29] reported another mixed mode test fixture and some test results.

2.5 QUALITY OF SPOT WELDED JOINTS

The quality of a weld is usually expressed by its measurable features, such as the physical attributes and the various strengths, when inspected in either a destructive or nondestructive manner. A weld's quality can be described in three ways: by its physical or geometric features, its strength or performance, or the process characteristics during welding.

The geometric features are either directly visible after a weldment is made or revealed through destructive tests, such as peeling or cross-sectioning or seeing the microstructures, or nondestructive tests using, for example, ultrasonic or x-ray devices.

The commonly used weld attributes are:

- Nugget/button size
- Penetration
- Indentation
- Cracks (surface and internal)
- Porosity/voids
- Sheet separation
- Surface appearance

Among these weld attributes, weld size, in terms of nugget width or weld button diameter, is the most frequently measured and most meaningful in determining a weld's strength. When two sheets are joined by a weld at the nugget, its size determines the area of fusion and its load-bearing capability. However, the nugget/weld size alone is often insufficient in describing a weld's quality, as it does not necessarily imply the structural integrity of the weld. Other features of a weld, such as penetration, may complement the nugget size and provide useful information on the degree of adhesion. Weld and nugget are considered interchangeability by many, especially in oral presentations. Although closely related, however, they are not the same by definition or measurement. In fact, a weld is meant to contain all parts of a weldment, such as the heat-affected zone (HAZ), in addition to the nugget. Confusion is also in the use of button diameter or nugget diameter. As a nugget and its size are usually revealed by cross sectioning for metal graphic examination, a nugget is exposed for measuring its width, not diameter, It also shows other features that can be revealed by cross-sectioning a weldment.

2.6 ELECTRODE LIFE

The metallurgical interaction between electrodes and sheets is possible because of joule heating during welding. Therefore, the electrical and thermal processes determine the electrode wear and, ultimately, electrode life. In this section, the effects of electrical, thermal, and metallurgical processes and their interactions on the electrode life are discussed. Contact resistance depends on the surface condition, and it determines the heat generation and metallurgical reactions at the electrode-sheet interface. When welding galvanized steel sheets, the low contact resistance due to the high conductivity of zinc warrants a significantly higher welding current than welding bare steel. A more profound influence of free zinc at the electrode-sheet interface is on electrode wear. The alloying of copper with zinc to form brass increases the resistivity at the electrode face. This in turn raises the electrode temperature during welding. The face of an electrode is deformed through repeated heating and mechanical impacting at the interface, and the brass formed on the electrode face is often picked up by the sheets, leaving a golden colored ring of the indentation mark on the sheets. Therefore, the zinc coating promotes electrode wear. Figure shows a pair of electrodes after a large number of welds on zinc coated steel sheets. The electrode surfaces have a clear sign of oxidation and brass formation. Both the domed and flat electrode surfaces are damaged, with significantly enlarged contact areas. Welding using a current value as originally designated when the electrodes were new will result in substandard welds due to insufficient current density.

The electrode life obtained may be lower than that derived using optimized welding conditions. For example, the electrode life obtained can depend greatly on the type of welding gun used or the angle of approach of the electrode. For multiple spot welders, it is essential that all welding stations are balanced electrically and that the same air pressure is supplied to each station. Electrode shape and configuration, water cooling arrangements, and electrode dressing schedules need to be optimized. The last item is most important because satisfactory weld quality can only be provided when the necessary electrode condition and shape are maintained over a production run.

2.7 MONITORING AND CONTROLLING

Unlike other welding processes, resistance spot welding (RSW) is difficult to directly monitor on the weld nugget development, since melting and solidification processes primarily happen between the work pieces. A common practice is to control the input, such as welding parameters, and monitor the output, such as the attributes of a weld and process signals. However, little is known about the nugget formation process from the input and output. Complexity rises due to the interacting electrical, mechanical, thermal, and metallurgical processes.

Gedeon et al.**[15]** presented a work on monitoring these parameters and showed that displacement curves and dynamic resistance provided significant information for evaluating weld quality. However, difficulties are encountered in obtaining these signals due to strong magnetic interference of the process, especially when alternating current is used in welding.

The ultimate goal of monitoring and control is to develop a robust on-line monitoring and diagnosis system for weld quality assurance so as to improve the manufacturer’s confidence level and help to reduce the cost of welded structures. A general purpose RSW monitoring and control system consists of three parts:

- Welding system
- Monitoring unit
- Control unit

The system begins with an input to the welder, usually in the form of a welding schedule specifying welding current (or voltage or heat, depending on the weld controller), time, and electrode force. The output of the welder is then fed into the monitoring unit, which comprises data acquisition and signal processing. The processed information is then passed on to the control unit. If an action is warranted, the automatic control unit will modify the input and alter the schedules for subsequent welding processes. The results of the monitoring system can also be used for the purposes of statistical process control of weld quality and process maintenance scheduling.

The objective of monitoring and controlling can be summarized as:

- Weld size estimation.
- Expulsion detection and its severity evaluation.
- Process fault diagnosis.
- Process control.

2.8 PROCESS PARAMETERS

Monitoring a welding process provides useful information on the physical processes involved in welding, and it is a necessary step toward successful control of the process. A direct measurement of weld quality, such as weld size or weld strength, can sometimes be used as a means of monitoring welding process. However, such monitoring ignores the details in welding; it considers only the end results of welding instead, and its usefulness is very limited. A process monitoring of real meaning contains detailed observation of the process through the use of various sensors, and it is correlated with weld quality.

2.8.1 ELECTRIC RESISTANCE

Although practically uncontrollable, it is important to understand the effect of resistance on weld ability in RSW. Fig. 2.11 illustrates regions where electrical resistivity exists in RSW, and it can be observed that there are two major types, bulk and contact resistance. The total is then the sum of all the resistance values which are in series. Bulk resistance largely is the characteristic of the sheet material that is spot welded. For most metals, it increases with temperature, and a stiff peak is obtained for alluminium at 925k, the melting point of the metal (Fig.2.6)

Contact resistance is significantly affected by pressure and surface condition. Brown measured resistance change during spot welding (Fig. 2.7).In the case of AC welding, resistance drops rapidly at the initial stage because of the decreased contact resistance from the high current peak that is absent in DC. Highly concentrated current generates great heat and brakes down the contact surface, destroying possible oxide phases on surface that can act as insulators **[6].** As a result, heating efficiency in spot weld process can be compromised for AC welding. Later, because of the fact that bulk resistance increase in proportion to temperature, the overall resistance of AC eventually approaches to that of DC. Fig. 2.7 is the comparison of contact resistance profiles of AC and DC welding suggested by Li et al., and it shows a rapid drop of contact resistance in the case of AC welding **[51].**

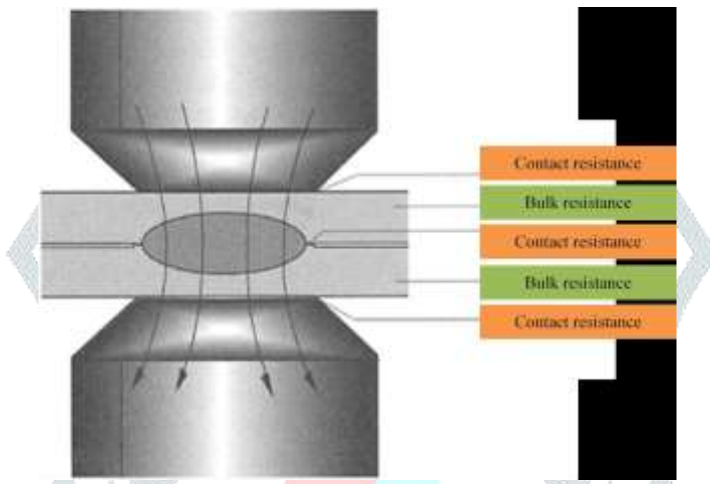

Figure 2.6 Resistance in general spot welding process **[44]**

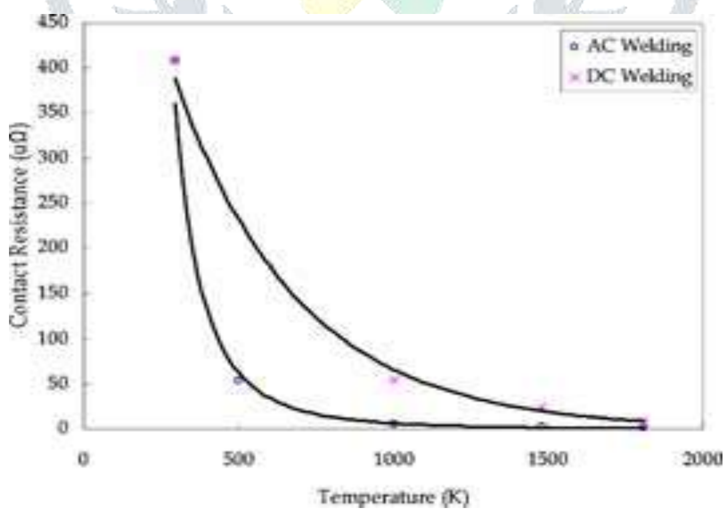

Figure 2.7 Contact resistance comparisons of AC and DC welding **[42]**

Resistance of a resistor is usually calculated from the ratio of voltage to current. However, the voltage measured during a resistance welding contains two parts: contributions from resistance and inductance, as depicted in equation:

$$V=(di/dt)A\cos\theta \qquad \text{(Eq-2.2)}$$

In the equation, *Lm* is the inductance, a (unknown) function of the loop, and it varies with many factors, such as the size and material properties of the work pieces. It can be clearly seen that the ratio *V/I*2 produces the resistance value *R* only when *dI*2*/dt* is zero. *dI*2*/dt* equals zero when the current reaches its peak points. Therefore, the number of points of a dynamic resistance measurement that can be calculated for an alternating current (AC) welder is twice the number of cycles. Attempts have been made to obtain a continuous dynamic resistance curve by first removing the induced voltage noise, and then taking direct division of the voltage by current. Considering that there are periodic zero values on welding current signals, dynamic resistance is not attainable in those areas. Close to those areas, the magnitude of the current is small, and thus the signal-to noise ratio is very low, compared to the points close to the peaks. Therefore, dynamic resistance can only be reliably calculated at the points around the current peaks. Without losing much information, the dynamic resistance curve can be obtained with piece wise polynomial curve fitting through the points obtained at the current peaks.

2.8.2 ELECTRIC CURRENT

The electric current signal is more difficult to deal with than voltage, as the current value is very high in a secondary loop and the measurement is done indirectly. It is usually measured using either a sensor based on the Hall Effect or a toroid sensor. Toroid sensors are fairly popular for electric current measurement. As they are based on the induced voltage by a welding current, it is difficult to separate the measurement from the process noise, which is also the result of induction. A high alternating welding current induces a strong time-varying magnetic field. Any wire loops in the field will pick up induced voltage, whose magnitude is given by Faraday's law:

$$V=(di/dt)A\cos\theta \qquad \text{(Eq-2.3)}$$

Where, *V* is induced voltage, *i* is induced current, *di/dt* is the time change rate of the current, *A* is the area of the loop, and θ is the angle of the loop to the magnetic field. Faraday's law is the basis for current measurement using a toroid sensor. It is obvious that variations in position or orientation of the toroid can cause variations in the effective area, and hence in the current measurement. However, the error is usually under 5% of the reading when simply hanging the toroid on the arm of a welding machine. The error can be further reduced by properly fixing the position of the toroid in the magnetic field.

There are two other methods to measure a current using either a Hall Effect sensor or a resistive shunt. Hall Effect sensors measure the voltage across a semiconductor due to the surrounding magnetic fields. They are small, and thus are more sensitive to temperature change. They are also sensitive to variations in orientation and position. The resistive shunt method directly measures the voltage across a known resistor in the current path. It is a standard means of measuring low amperage or DC currents. However, for RSW applications, electrodes have to be modified to use resistive shunt for measuring electric current.

2.8.3 ELECTRIC VOLTAGE

The tip voltage can be measured with two wire leads attached to the electrode tips. As the voltage is kept at a fairly low level at the electrode tips, its value can be directly measured using standard equipment. However, the voltage signal may be corrupted by the noise induced by an alternating current. Induced voltage becomes a strong noise on electrode tip voltage signals because its measurement has a (unavoidable) wire loop in the magnetic field. It is well known that to minimize the inductive noise, one can use twist pairs to reduce the area of the wire loop. However, the wire loop can never be fully eliminated. For production applications, the two wire leads have to follow the arms and encompass the entire throat of a welding machine. To suppress the induced noise on the tip voltage measurement, a compensating loop can be added. However, adjusting the compensating coefficient is machine dependent and can be time consuming.

2.9 WELDING ELECTRODE

Materials for RSW electrodes should have sufficiently high thermal and electrical conductivities and sufficiently low contact resistance to prevent burning of the work piece surface or alloying at the electrode face. In addition, the electrode should have adequate strength to resist deformation at operating pressures and temperatures. Because the part of the electrode that contacts the work piece becomes heated to high temperatures during welding, hardness and annealing temperatures must also be considered. Electrode materials for RSW have been classified by RWMA and in International Standards Organization (ISO) standard ISO 5182

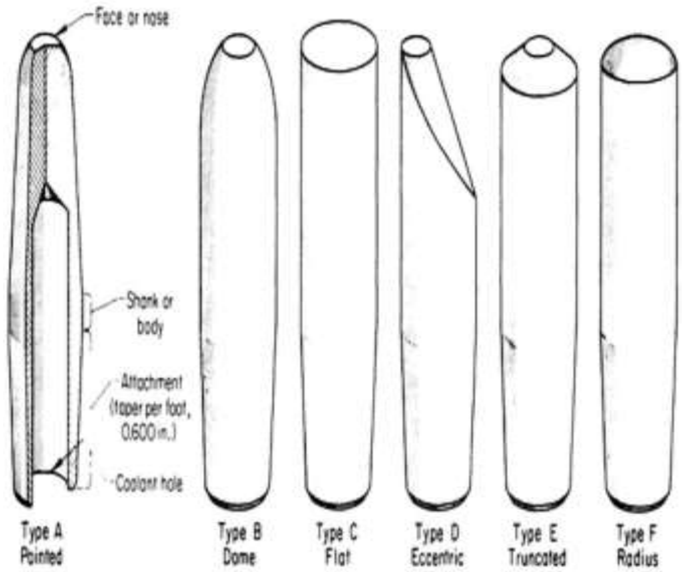

Figure.2.8 standard welding electrodes

2.10 TEMPERATURE DISTRIBUTION

There are, in effect, 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 in figure 2.9: (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 on the surface condition of the base metal and the electrode, the size and contour of the electrode face, and the electrode force. (Resistance is roughly inversely proportional to the contacting 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.

(3) 3 and 5, the total resistance of the base metal itself, which is directly proportional to its resistivity and thickness, and inversely proportional to the cross-sectional area of the current path.

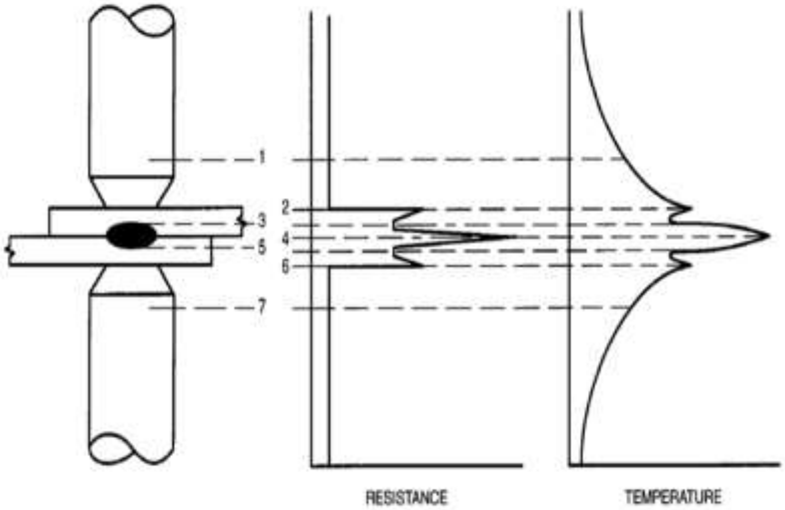

Figure.2.9 Temperature & Resistance distribution

(4) 4, the base metal interface resistance 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. This illustration was taken about 4/60th (1/15th) of a second after the welding current starts.

Heat dissipation does not start after the electric current is shut off—at any instant, the heat generated in the system is conducted through either the sheets or the electrodes. Maintaining a low temperature in the electrodes is vital to weld quality and electrode life.

2.11 WELD LOBE CURVE

In general type of weld-lobe curve diagram it simply shows the window of operation within which weld quality can be guaranteed. Although many variations of the lobe diagram can exist, the electrode force is customarily set constant, and the diagram is drawn on the basis of current versus time.

The lower boundary in the graph is determined at the condition in which the weld current is not high enough, so weld nugget size would not grow as big as minimum weld nugget size, which is 4*t*0.5 (*t*=metal sheet thickness). Criteria for the minimum nugget size may vary depending on the standards and applications for example 5*t*0.5 for more severe condition. Sun explained that the conventionally suggested minimum weld nugget size 4*t*0.5 is insufficient to guarantee spot weld ability for 800 grade high steels **[53].** Marya came up with a new and stricter criterion for determining minimum weld size, and it is expressed as **[34],**

$$\Phi \text{ (mm)} \geq 2.7d \text{ (mm)} + 1.6 \qquad (2.4)$$

where φ is a weld nugget diameter, and d is the sheet thickness.

The upper boundary is drawn from the points over which expulsion occurs. Expulsion is one kind of a weld defect and leads to the loss of metal, so it is detrimental to weld quality **[18].** Different materials have different weld conditions, so different lobe curves. For weld quality, welding should be done within the range of two boundaries.

2.12 WELD DEFECTS

Spot welds are not free from defects, which can be largely categorized into two groups; external and internal discontinuities **[18].**

- External discontinuities

Defects that appear on the weld surface fall into this category. They usually can be observed by bare eyes or with the aid of low magnifying microscope. The prevention of external defects in most cases comes from the adjustment of welding parameters **[18].**

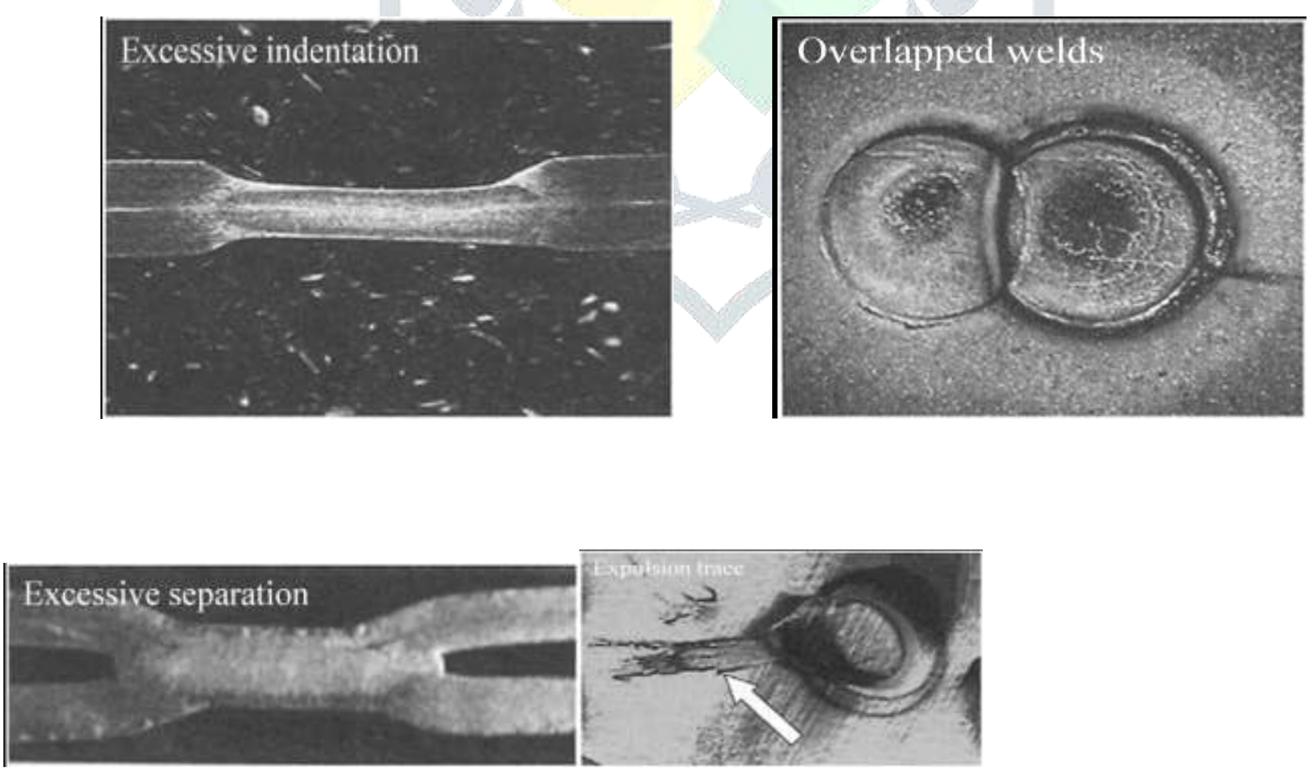

Fig 2.10 Several examples of external discontinuities in RSW **[44]**

- Internal discontinuities

Internal discontinuities are found inside of the welds and revealed only by means of metallographic examination of weld cross sections or non-destructive tests. Gaseous bubbles from the fusion stage, as the nugget solidifies, leads to porosity due to solidification shrinkage. This does not however pose a threat as long as such voids confined in the center of the nugget because it is at the heat affected zone where the most strain is concentrated **[18, 22].**

Weld cracks can also be found in spot welded materials. Various remedies for weld crack in aluminium alloy have been tested by Hongyan et al. **[18].** Mechanical means to suppress weld crack are experimented; for example, flat electrode types are better than domed ones in suppression of weld crack **[18].**

2.13 TEST METHODS FOR EVALUATION

Mechanical testing is an important aspect of weld ability study. Such testing is either for revealing important weld characteristics, such as weld button size, or for obtaining quantitative measures of a weld's strength. As a weld's strength generally refers to its capability of standing both static and dynamic loads, mechanical testing of a weld ment can be static or dynamic, and it can be either instrumented or not instrumented. Although the dynamic strength of spot welds is recognized as an important quality index because of its implication on the performance of welded structures, static tests have been almost exclusively conducted for weld ability. This is mainly because of the complexity, relatively low reliability and repeatability, and high cost associated with dynamic testing.

2.13.1 CHISEL TEST

It is used to measure the ductility of spot welds on welded structures. The objective is to detect brittle (cold) welds, including no-weld. Weld button size is occasionally estimated after the joint is opened up. As the chisel wedge is hammered in between welds, an operator can feel and hear whether a weld is brittle. Because the testing and result interpretation depend heavily on experience/skill, a dedicated person is usually needed to conduct such tests. Repeatability in chisel testing is relatively low. An automated chisel test is used when testing heavy-gauge sheet welding.

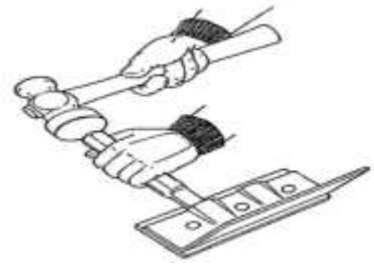

Figure.2.11 Diagram of chisel test

2.13.2 PEEL (ROLLER) TEST

The peel test is a simple shop test that can be made with a hand tool, as shown in figure. It is applicable to sheets of a large range of gauges. In the test, the sheets are first separated on one end of a lap joint, and one sheet is rolled up by the roller while the other is gripped (usually by a vice). As the roller rolls over the weld, one work piece is torn off at the weld and a weld button is left if the weld is ductile, or the sheets can be separated without much effort if the weld is brittle. In the case of multiple-welded specimens, as in the study of weld spacing or shunting, a specimen can be cut into pieces with single welds and then tested, although the welds may be peeled in sequence using customized devices. Caution should be taken when measuring weld buttons of irregular shape, and especially when tails of base metal are left on the button.

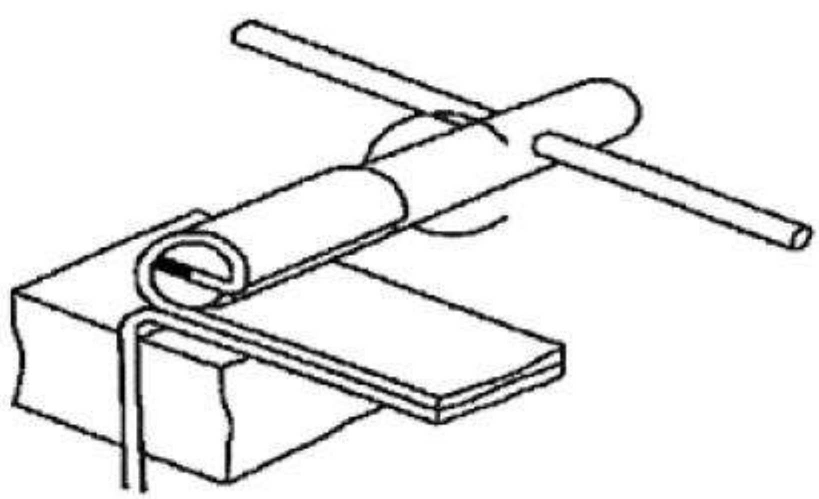

Figure.2.12 Diagram of peel (roller) test

2.13.3 BEND TEST

A bend test is a relatively simple shop floor test to obtain a quick check of spot weld soundness in production, particularly the existence of cracks.9 Un notched transverse weld guided bend tests are frequently used to estimate the ductility of weldments and to qualify welders and welding operators and producers. Bend tests are aimed at detecting weld flaws oriented in the way that can be revealed by the longitudinal sectioning. To obtain a complete picture of the welds, transverse sectioning and loading may also be needed. In general, a bend test is intended as an aid to process control rather than a requirement. It can be performed with equipment readily available in most shops and requires only visual examination

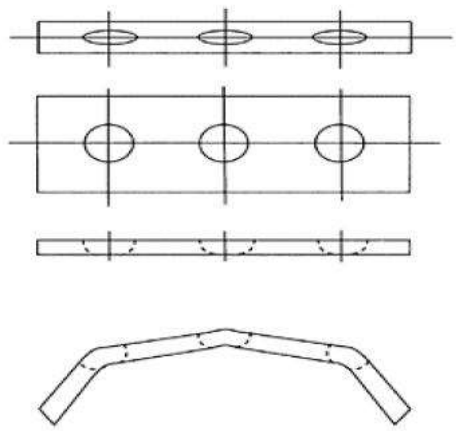

Figure 2.13 Diagram of bend test

2.13.4 IMPACT TESTING

- In this a heavy pendulum is used to apply the force required to shear or fracture a test sample taken from welds HAZ.
- It is further classified as Izod or Charpy method which is used to measure the welds ability to withstand an impact force.
- In this method low charpy test readings indicate brittle weld metal whereas higher readings the toughness of weld samples.

2.13.5 HARDNESS TESTING

Hardness is defined as the property of material which defines the resistance to permanent indentation.
To test the hardness of material, there are four common methods such as:

- Rockwell test
- Scleroscope test
- Brinell test
- Microhardness test

2.14 NON DESTRUCTIVE TESTING

Traditionally, weld quality is monitored through destructive testing. Final assurance of weld quality requires that a percentage of the assembled parts be destroyed to verify the welding process. The disadvantages of such a procedure are obvious. It takes time, during which corrections to the weld controls and process are not possible. Remedial measures can be taken only after a number of welds are made using the set welding schedules. Substandard welds may be produced before necessary adjustment of welding schedules is made, and detecting and repair of the welds are generally costly. Many efforts to non-destructively evaluate welds have been made to save the cost of scrap parts that result as a percentage of the assembled parts destroyed in the verification process. Non-destructive evaluation of resistance welds can be made in a number of ways. Acoustic emission, eddy current, and x-ray are some of the techniques that have been attempted for resistance spot weld quality inspection. Many of them have limitations in demonstrating effective solutions in the manufacturing workplace.

2.15 CLASSIFICATION OF SPOT WELDING TECHNIQUE

Spot welding is classified as follows:

- Direct single spot welding
- Direct multi spot welding
- Series multi spot welding
- Push pull welding

2.15.1 DIRECT SINGLE SPOT WELDING

Single-spot welds are usually made by direct welding. Figure 2.14 shows schematically three arrangements used for making this type of weld; these arrangements may be modified to meet special requirements. In all of the arrangements shown, one transformer secondary circuit makes one spot weld.

The simplest and most common arrangement in which two work pieces are sandwiched between opposing upper and lower electrodes, is shown in Fig.2.14 (a). In Fig. 2.14(b), a conductive plate or mandrel having a large contacting surface is used as the lower electrode; this reduces marking on the lower work piece and conducts heat away from the weld more rapidly and may be necessary because of the shape of the work piece. In the arrangement in Fig 2.14(c), a conductive plate or mandrel beneath the lower work piece is used for the same purposes but in conjunction with a second upper electrode.

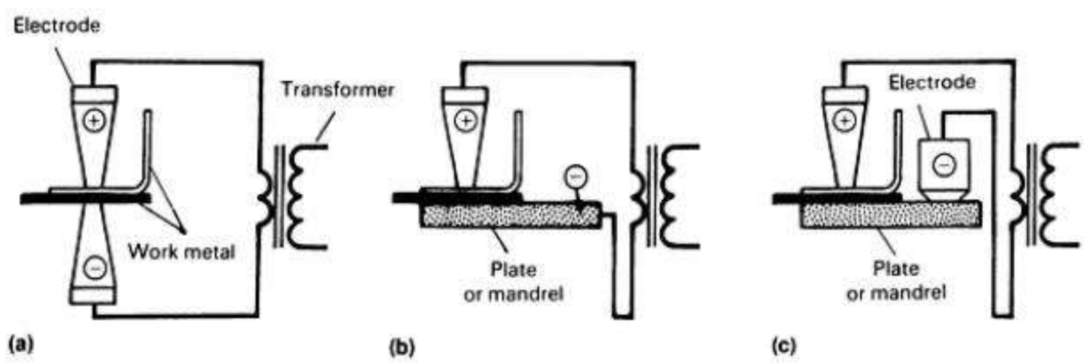

Figure 2.14 Diagram of single-spot welding

2.15.2 DIRECT MULTIPLE-SPOT WELDING

In direct multiple-spot welding (as well as in series multiple-spot welding, described below), tip contour and surface condition must be the same for each electrode. Also, the force exerted by all the electrodes on the work pieces must be equal, regardless of inequalities in work metal thickness. The force can be equalized by using a spring-loaded electrode holder or a hydraulic equalizing system. The use of a conductive plate or mandrel minimizes weld marks on the lower work piece.

2.15.3 SERIES MULTIPLE-SPOT WELDING

Three arrangements for making a number of spot welds simultaneously is done by series Welding. In this each of the two transformer secondary circuits makes two spot welds. A portion of the current bypasses the weld nuggets through the upper work piece.

2.15.4 PUSH-PULL WELDING

The advantage to this process is that the secondary loop area is quite small. This is common for components such as floor pans where a normal welding unit would have a throat several feet deep.

2.16 HOW TO CREATE A SATISFACTORY RSW

Most basic controls set the time and welding amps and the air pressure is set with the remote regulator on the welding machine. An option for most modern weld controls is a built-in force monitor, and with the addition of a programmable regulator, the weld force can be set apart of the weld schedule. Controls can be set to fire based on time, or for fast production times and with the force option, they can be programmed to fire when the weld force is reached. The four elements required to make a satisfactory weld are heat (H) in the work piece, electrical current (I) in the work piece, resistance (R) of the metal being welded, and time (T). The common formula for weld development is $H = I^2RT$. You can vary the heat by changing any of the elements in the formula.

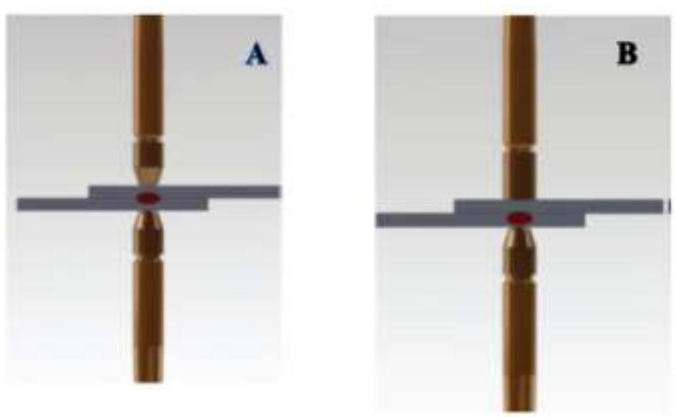

Figure 2.15 Diagram of A C Satisfactory RSW

Direct welding, where the current passes from the transformer to a top electrode directly through the material into a bottom electrode and back to the transformer, is the most commonly used process Fig.2.15. When we are unable to back up the work piece or the size or shape of the work piece dictates using a flat backup shunt bar, it is suggested the series welding process be used Fig.2.16 . In this case, the two electrodes are connected to the opposite poles of the transformer, and the current passes through the transformer, the one electrode through the work piece into a copper backup shunt bar, then back out to the second electrode and back to the transformer. Series welding is recommended for joining only 18-gauge and thinner materials**.[11]**

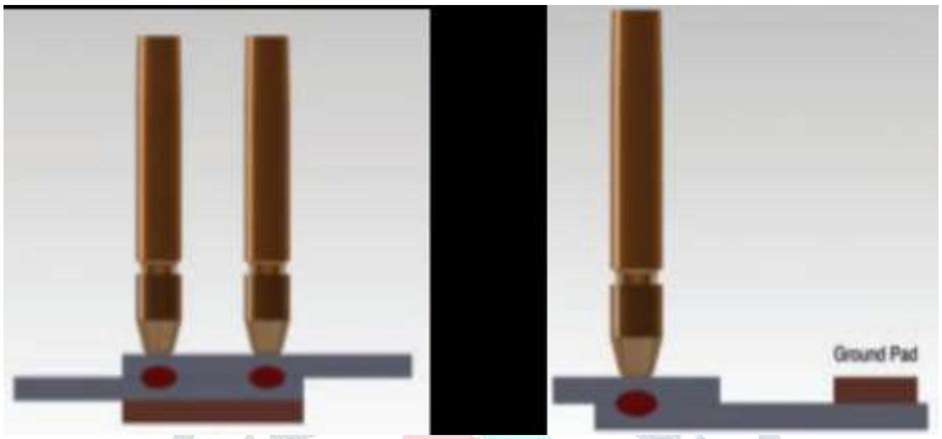

Figure 2.16 satisfactory weld for dc current

2.17 PROCESS TO SELECT THE MATERIAL

The Selection of materials for welded construction applications involves a number of considerations, including design codes and specifications where they exist. Mobile structures, such as automobiles and aerospace vehicles, have quite different materials requirements for weight, durability, and safety than stationary structures, such as buildings and bridges, which are built to last for many years. In every design situation, economics--choosing the correct material for the life cycle of the part and its cost of fabrication--are of great importance. The properties of the various metallurgical structures associated with the thermal cycles encountered in the welding operation must also be included in the design process. The various subsections in this article offer guidance for material selection applications involving bridges and buildings, pressure vessels and piping, shipbuilding and offshore structures, aerospace systems, machinery and equipment, automobiles, Rail road systems, and sheet metal.

2.17.1 PILLARS OF MATERIAL SELECTION

- STRUCTURAL INTEGRITY

It is one of the essential principles of material selection as it deals with the study of structure's capability to withstand the desired load and to prevent the breaking or tearing of design. It has to pass several test to ensure the properties of material such as weld soundness, ductility, toughness, strength etc..

- SERVICE LENGTH

The material choosen should meet the conditions initially and should response to the fluctuation of the working condition of the structure. The length of service is often dictated by obsolescence. Military hardware fabricated during wartime is an example of structures with relatively high obsolescence and short service life. Rocket cases for the propulsion of space vehicles need to last one launching. At the other end of the spectrum, hydroelectric projects have expected lifetimes of a century or longer.

- JOINING PROCESS

Weld ability is the property of a material that dictates its ease of joining. This property often determines whether preheat is needed for successful welding and whether some type of post weld heat treatment is required to restore properties degraded by the welding operation. Although weld ability usually relates to the joining of relatively thick plates, the choice of materials for sheet metal applications must also take the welding process into account.

- DESIGN CODES

Material selection is often dictated by the codes by which the design is governed, but there is still frequently a choice of materials. For example, pressure vessel codes offer a choice of steels, depending on the service temperature. Structural codes for buildings and bridges allow the use of both plain carbon and low-alloy steels. However, the codes tend to narrow the choice of materials.

- ECONOMICS

It's one of the most important principles that should be studied well before choosing the material as it broadly determines the price of material. More costly steel that does not require painting or other protection from atmospheric corrosion may be a more economical choice, if not for initial construction, then for the life of the structure.

- AMBIENT TEMPERATURE AND PRESSURES

Most welded structures are designed to work in normal atmospheric conditions. The properties of common materials are well known for such conditions, and ample data are available to assist the designer in material selection.

Table 2.1 Principal attributes of a material

Physical Properties	**Mechanical Properties**	**Corrosion Properties**
Density	Tensile Strength	General Corrosion
Melting Point	Impact Strength	Pitting Attack
Thermal Expansion	Fatigue Strength	Stress Corrosion
Electrical Conductivity	Creep Strength	Erosion
Ferromagnetism	Ductility	Cavitation
	Hardness	
	Fracture Toughness	

2.17.2 WELDABILITY RATINGS

Material Selection Practically all combinations of ductile metals and alloys can be spot welded (Table 2.1). Some, like copper to aluminium, and aluminium to magnesium, form alloys having little strength. Others, such as zinc and some of the high-chromium alloys, experience grain growth even during a very short welding period. Although welding times are relatively short, the material is adversely affected by the heat conducted through the sheet to the point that the physical properties such as the strength and corrosion resistance of the material surface are typically reduced in value. The short welding period is also necessary in stainless steel to prevent carbide precipitation when the carbon content is high enough to permit it. High-carbon steels weld readily, but the weld will be in the full-hardened state and will require subsequent heat treatment. This can be accomplished automatically by a control that applies preheating, post heating, or both as part of the welding cycle. To ensure that the control can apply the compensating quench or temper cycle, the electrodes must open immediately after the cycle is complete. Excessive hold time will quench the joint, negating the benefits associated with this control function **[56].**

Zinc-alloy die castings can be welded with little loss of strength, but the ductility is reduced. Free-turning Bessemer screw-machine steel frequently refuses to weld, or results in brittle welds, and hence its use for welded parts should be avoided. Usually, however, when clean, properly prepared metal parts are spot welded, the strength of the welds is perfectly satisfactory. Table 2.2 lists combinations that have been successfully welded. Many other combinations may also be satisfactorily welded. Copper and silver are difficult to weld, but they may be welded by the use of low conductivity electrodes (for example, refractory alloys such as Elkonite and Trodaloy). Copper alloys are more commonly resistance brazed. In many applications, the weld ability of copper is increased if it has a tinned surface **[7].**

Table 2.2 Weld ability ratings

A, excellent; B, good; C, fair; D, poor; E, very poor; F, impractical

METALS	ALUMINUM	STAINLESS STEEL	BRASS	COPPER	GALVANIZED IRON	STEEL	LEAD	MONEL	NICKEL	NICHROME	TINPLATE	ZINC	PHOSPHOR BRONZE	NICKEL SILVER	TERNEPLATE
ALUMINUM	B	E	D	E	C	D	E	D	D	D	C	C	C	F	C
STAINLESS STEEL	F	A	E	E	B	A	F	C	C	C	B	F	D	D	B
BRASS	D	E	C	D	D	D	F	C	C	C	D	E	C	C	D
COPPER	E	E	D	F	E	E	E	D	D	D	E	E	C	C	E
GALVANIZED IRON	C	B	D	E	B	B	D	C	C	C	B	C	D	E	B
STEEL	D	A	D	E	B	A	E	C	C	C	B	F	C	D	A
LEAD	E	F	F	E	D	E	C	E	E	E	...	C	E	E	D
MONEL	D	C	C	D	C	C	E	A	B	B	C	F	C	B	C
NICKEL	D	C	C	D	C	C	E	B	A	B	C	F	C	B	C
NICHROME	D	C	C	D	C	C	E	B	B	A	C	F	D	B	C
TINPLATE	C	B	D	E	B	B	...	C	C	C	C	C	D	D	C
ZINC	C	E	E	E	C	F	C	F	F	F	C	C	D	F	C
PHOSPHOR BRONZE	C	D	C	C	D	C	E	C	C	D	D	D	B	B	D
NICKEL SILVER	F	D	C	C	E	D	E	B	B	B	D	F	B	A	D
TERNEPLATE	C	B	D	E	B	A	D	C	C	C	C	C	D	D	B

2.18 OPTIMIZATION TECHNIQUES

Optimization techniques which are used are OA and ANOVA. The techniques are defined below-

2.18.1 ORTHOGONAL ARRAY TECHNIQUE

OA provides representative (uniformly distributed) coverage of all variable pair combinations. This technique is particularly useful for integration testing as well as testing of different combinations of configurable options.

- INTRODUCTION

Orthogonal arrays were originally discovered as a numerical curiosity by monks **[8].** The arrays went largely unnoticed, lying dormant in the aging notes of these monks, until the 1950s. It was then that these "numerical curiosities" were picked up by the statistics community and put to use in statistical test design. Dr. Genichi Taguchi was one of the first proponents of orthogonal arrays in test design. His techniques, known as Taguchi Methods, have been a mainstay in experimental design in manufacturing fields for decades.

Orthogonal arrays are two dimensional arrays of numbers which possess the interesting quality that by choosing any two columns in the array you receive an even distribution of all the pair-wise combinations of values in the array.

Table 2.3 OA levels

Number of Levels	Number of Parameters (P) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

Number of Levels	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

In robust engineering, the main role of OAs is to permit engineers to evaluate a product design with respect to robustness against noise and cost involved. The OA is an inspection device to prevent a "poor design" from going "downstream." Arrays can have factors with many levels, although two- and three-level factors are most commonly encountered.

Table 2.4 OA table

	Factors			
Runs	0	0	0	0
	0	1	1	2
	0	2	2	1
	1	0	1	1
	1	1	2	0
	1	2	0	2
	2	0	2	2
	2	1	0	1
	2	2	1	0

2.19 ANALYSIS OF VARIANCE

This method is used for data analysis for treatment comparison to find out that treatment for comparison generates the same outcomes or not. An ANOVA is an analysis of the variation present in an experiment. It is a test of the hypothesis that the variation in an experiment is no greater than that due to normal variation of individuals' characteristics and error in their measurement. The concept behind experimental design and the formulation of an ANOVA model is to identify the sources of variation and construct the proper tests to compare them. Statisticians love to tests hypothesis. The basis for every statistical test is to phrase the question in terms of a null hypothesis, essentially that everything is equal, and then to test whether that can be accepted within a certain probability. If the null hypothesis is rejected that allows the researcher to say that "significant differences were found in ... with a probability <0.05."The tests in an ANOVA are based on the F-ratio: the variation due to an experimental treatment or effect divided by the variation due to experimental error. The null hypothesis is this ratio equals 1.0, or the treatment effect is the same as the experimental error. This hypothesis is rejected if the F-ratio is significantly large enough that the possibility of it equaling 1.0 is smaller than some pre-assigned criteria such as 0.05 (one in twenty) **[52].** One-way analysis of variance (ANOVA) tests allow you to determine if one given factor, such as drug treatment, has a significant effect on gene expression behavior across any of the groups under study.

A significant p-value resulting from a 1-way ANOVA test would indicate that a gene is differentially expressed in at least one of the groups analyzed. If there are more than two groups being analyzed, however, the 1-way ANOVA does not specifically indicate which pair of groups exhibits statistical differences. Post Hoc tests can be applied in this specific situation to determine which specific pair/pairs are differentially expressed.

CHAPTER-3

OBJECT AND SCOPE OF THE PRESENT INVESTIGATION

The survey of available literature and work indicates that much work has been done on strength and nugget properties of steel sheets joined together.

The present work is to find out the influence of the various process parameters such as welding current, electrode pressure, and weld time on the tensile shear strength of the resistance spot welded joints for ASS 304 stainless steel sheets.

The experiments have been planned to be performed on the equipment and facilities available in the workshop and laboratories of Mechanical Engineering Department.

The objectives of the experiments include the following:

1. To deposit spot welds using the variables and setting the welding conditions according to the variables and setting the welding conditions according to the statistical planning.

2. To measure the tensile shear strength for different designed parameters conditions as planned.

3. To analyze the results using ANOVA technique.

CHAPTER-4

EXPERIMENTAL PROCEDURE

The three main parameters in spot welding are current, contact resistance and weld time. In order to produce good quality weld the above parameters must be controlled properly. The amount of heat generated in this process is governed by the formula,

$$Q = I^2 R T \qquad \text{(Eq-4.1)}$$

Where,

Q = heat generated, Joules
I = current, Amperes
R = resistance of the work piece, Ohms
T = time of current flow, second

4.1 SELECTION OF MATERIAL & EQUIPMENT

The material is selected according to the weld ability which must rely on basic properties of the material, such as strength, corrosion or erosion resistance, ductility, and toughness.

- **MATERIAL USED:**

Material used is ASS 304 austenitic stainless steel sheets of thickness 1.2 mm and 1.5 mm.

- **EQUIPMENT USED:**

  - Resistance spot welding machine (5 KVA, PHASE 2, DUTY CYCLE 50%)
  - Universal Testing Machine (Measuring range 0-400 KN)

4.2 SELECTION OF ORTHOGONAL ARRAY

Depending upon number of levels in a factor, a 2 or a 3 level OA can be selected. If some factors are two-level and some three-level, then whichever is predominant should indicate which kind of OA is selected. Once the decision is made about the right OA, then the number of trials for that array must provide an adequate total dof, When required dof fall between the two dof provided by two OAs, the next larger OA must be chosen.

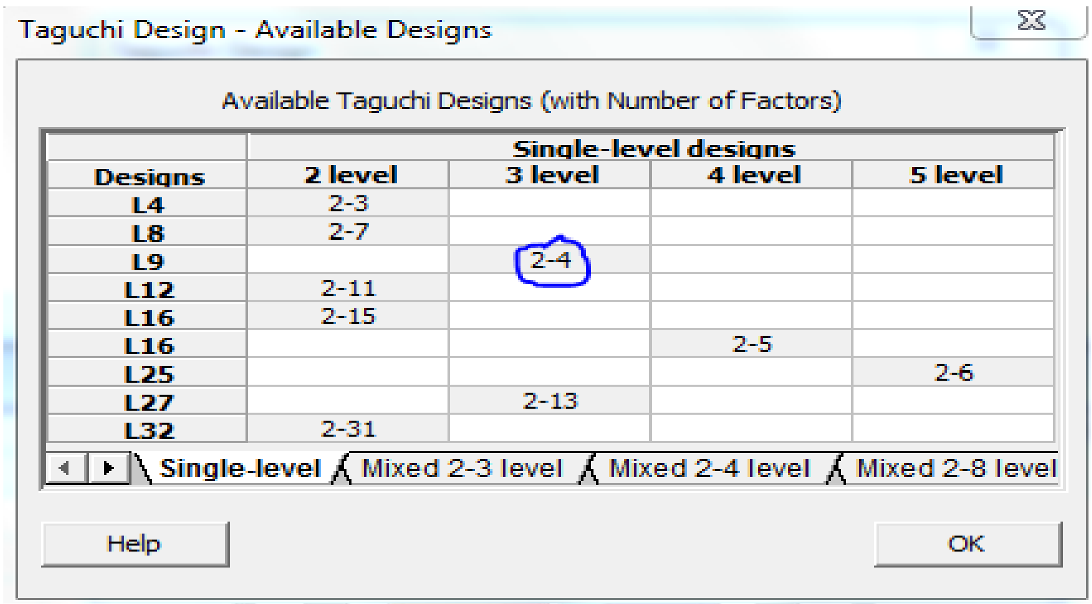

Figure.4.1 Figure of orthogonal array selection

Table 4.1 OA L9 Table

A	B	C
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

4.3 FIRST EXPERIMENT (TENSILE STRENGTH)

The results have been recorded and analysis of the tensile strength of the welded specimen was done. The results are shown in tables below. The following figures show the method for achieving tensile strength.

Figure 4.2 Picture of spot welding machine used for experiment

Figure 4.3 Picture of tensile strength evaluation by UMT machine

Analysis of variance: (ANOVA)

Taguchi recommends analyzing data using the S/N ratio that will offer two advantages; it provides guidance for selection the optimum level based on least variation around on the average value, which closest to target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target. The experimental results are analyzed to investigate the main effects.

According to Taguchi method, S/N ratio is the ratio of "Signal" representing desirable value, i.e. mean of output characteristics and the "noise" representing the undesirable value i.e., squared deviation of the output characteristics. It is denoted by η and the unit is dB. The S/N ratio is used to measure quality characteristic and it is also used to measure significant welding parameters.

According to quality engineering the characteristics are classified as Higher the best (HB) and lower the best (LB). HB includes T-S strength and Nugget diameter which desires higher values. Similarly LB includes Heat Affected Zone (HAZ) for which lower value is preferred.

The Taguchi method also provides a better feel for the relative effect of the different parameters/factors that can be analyzed by the analysis of the variance (ANOVA). It is a statistical method to estimate quantitatively the relative significance factors on quality characteristics **[7][8].** If the p-value is less than the significance level, the factor is then regarded to be statistically significant. The relative significance of factors is often represented in terms of F-ratio or in percentage contribution. Greater the F-ratio indicates that the variation of the process parameter makes a big change on the performance. ANOVA for S/N ratio parametric optimization in spot welding at 95% confidence level is given below:

TABLE 4.2 PROCESS PARAMETERS WITH THERE VALUES AT THREE LEVEL

For 1.2 mm thickness

LEVELS	CURRENT(KA)	ELECTRODE FORCE(KN)	TIME(sec)
1	5.5	0.54	3
2	6.9	0.75	4
3	8.4	0.86	6

TABLE 4.3 Experimental data for tensile shear (T-S) strength

CURRENT	ELECTRODE FORCE	TIME	T-S	S/N
1	1	1	3.10	2.51297
1	2	2	3.54	1.80135
1	3	3	3.94	0.90802
2	1	2	4.23	1.53354
2	2	3	4.33	0.38163
2	3	1	4.01	1.35496
3	1	3	3.55	2.75600
3	2	1	2.82	1.17621
3	3	2	3.76	1.722

For 1.5 mm thickness

LEVELS	CURRENT	ELECTRODE FORCE	TIME
1	8.4	0.75	3
2	10.3	0.86	4
3	11.8	0.96	6

TABLE 4.4 Experimental data for tensile shear (T-S) strength

CURRENT	ELECTRODE FORCE	TIME	T-S	S/N
1	1	1	4.20	2.09631
1	2	2	4.06	2.95537
1	3	3	3.86	3.62966
2	1	2	3.93	1.48015
2	2	3	3.7	2.36422
2	3	1	4.1	1.14565
3	1	3	4.46	1.95231
3	2	1	4.21	0.39774
3	3	2	4.30	1.15297

TABLE 4.5 Response Table for S/N Ratio (1.2 mm)

LEVEL	CURRENT	ELECTRODE FORCE	TIME
1	0.67	0.75	0.40
2	1.92	0.68	0.86
3	0.58	0.88	0.90
DELTA	1.34	0.20	0.50
RANK	**1**	**3**	**2**

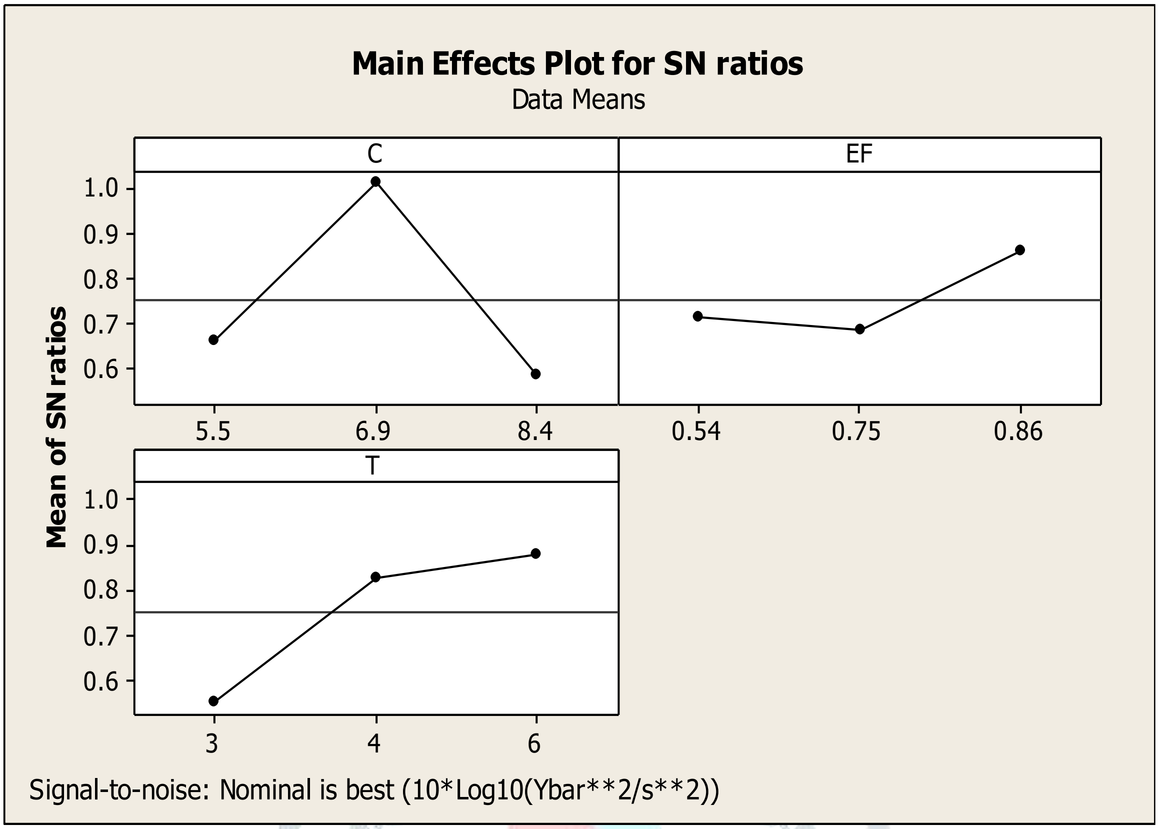

Figure 4.4 Main effect plot for signal to noise ratio for T-S (1.2 mm)

TABLE 4.6 ANOVA for S/N ratios (1.2 mm)

CF	DOF	SS	MS	F-RATIO	P	RANK
CURRENT	2	1.124	0.562	3.77	0.087	1
ELECTRODE FORCE	2	0.196	0.098	0.32	0.736	3
TIME	2	0.691	0.345	1.56	0.284	2
ERROR	2	0.89				
TOTAL	8	2.901				

R-Sq=93.8%; R-Sq= 84.2%; significant factor 95%

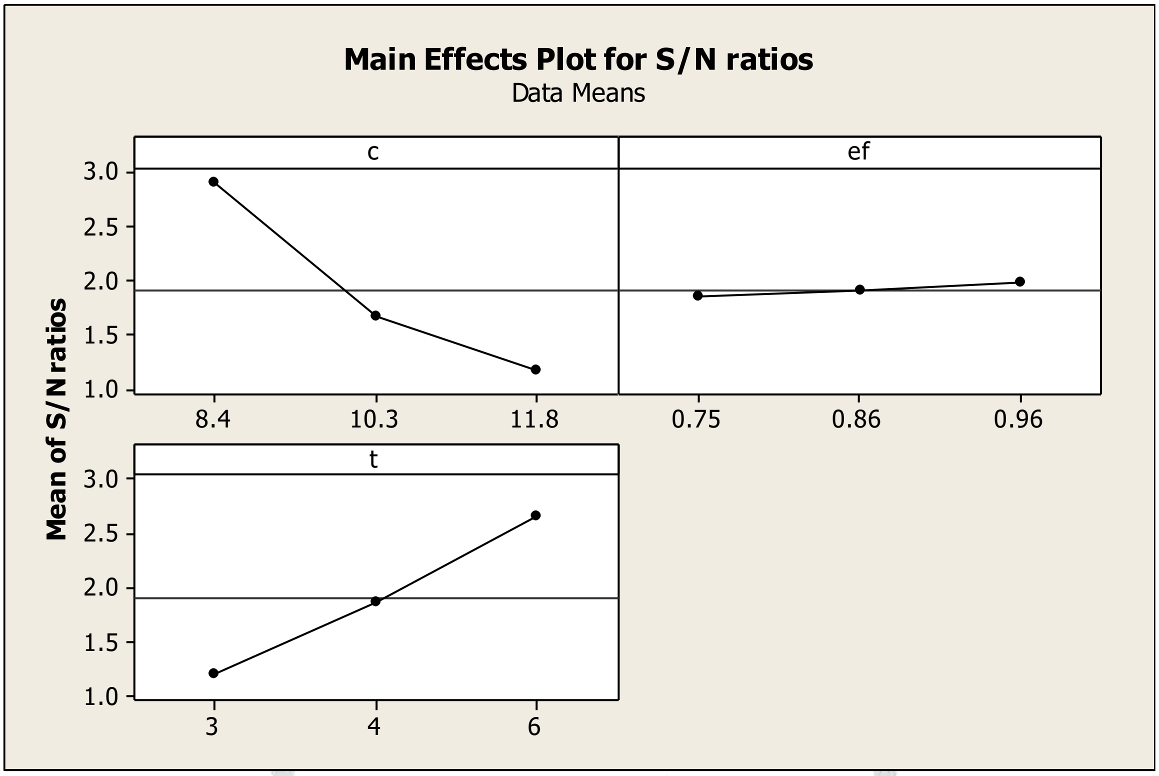

Figure 4.5 Main effect plot for S/N ratio for T-S(1.5 mm)

TABLE 4.7 Response table for S/N ratios (1.5mm)

LEVEL	**CURRENT**	**ELECTRODE FORCE**	**TIME**
1	2.85	1.7	1.2
2	1.6	1.8	1.8
3	1.20	2.0	2.7
DELTA	1.65	0.3	1.5
RANK	1	3	2

TABLE 4.8 ANOVA for S/N ratio (1.5 mm)

CF	**DOF**	**SS**	**MS**	**F-RATIO**	**P**	**RANK**
CURRENT	2	4.7391	2.3695	4.70	0.012	1
ELECTRODE FORCE	2	0.026	0.0133	0.51	0.677	3
TIME	2	3.055	1.5501	0.30	0.018	2
ERROR	2	0.055	0.0279			
TOTAL	8	7.9218				

R-Sq=90.3%; R-Sq=85%; significant factor 95%.

CHAPTER-5

RESULT AND DISCUSSIONS

- From the result it is found that, only current is most significant parameter for the best tensile strength and desired size of spot weld, which is responsible to increase heat and finally to change microstructure of metal.

- The parameter i.e. total cycle time is less significant as compared to current and electrode force is not more significant.

- Results drawn from the experiment using Taguchi method shows that the most optimal values at which we can get the best welding results are: For 1.2mm- medium current (6.9kA), high electrode force (0.86kA), and high holding time(6 sec) ,and for 1.5mm- low current (8.4 kA), high electrode force (0.96kN), and high holding time(6 sec).

- The response of S/N ratio with respect to T-S strength also indicates that current is the most significant parameter to control the tensile shear strength whereas time and electrode force are less significant in this regard for both the thicknesses.

- In this way various parameter has different values of probability of significance for optimization of spot weld at 95% confidence level.

- The highly effective parameter for the development weld strength is the welding Current.

CHAPTER- 6

LIMITATIONS & SCOPE FOR FUTURE WORK

The following limitations and problems have been experienced during the course of the Present investigation:

1. There is high variation in current in the welding duration hence it‘s very difficult to measure current.

2. Steel sheet are very thin (1.2 mm & 1.5 mm) hence while measuring the tensile strength holding grip problem occurs in UTM machine.

3. Due to the air cold electrodes. Duty cycle of the welding machine is high which consume large amount of time.

4. The above study is applicable only for that particular material (ASS 304 stainless steel sheets) there will be significant variation in parameters for other materials

5. Both the experiments have been analyzed by ANOVA with 95 % level of confidence, and an error of ±5% .