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# THE THREE STAGE PROCESS OF SPOT WELDING: A REVIEW

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## INTRODUCTION

Spot welding is a process in which contacting metal surface are joined by the heat obtained from resistance to electric current flow. Work-pieces are held together under pressure exerted by electrode. Typically the sheets are in the 0.5 to 3 mm thickness range. The process uses two shapes copper alloy electrodes to concentrate welding current into a small spot and to simultaneously clamp the sheet together. Forcing a large current through the spot will melt the metal and form the weld.

The amount of energy is chosen to match the sheets material properties, it thickness, and type of electrode. Applying too little energy won't melt the metal or will make a poor weld. Applying too much energy will melt too much metal and make a hole rather than a weld [1].

Spot welding involves three stages; the first stage which involves the electrodes being brought to the surface of the metal and applying a slight amount of pressure. The current from the electrodes is then applied briefly. After the current is removed, the electrodes remain in place in order for the material to cool. Weld times range from 0.01 sec to 0.63 sec depending on the thickness of the metal, the electrode force and the diameter of the electrodes. The equipment used in the spot welding process consists of tool holders and electrodes. The tool holders function as a mechanism to hold the electrodes firmly in place and also support optional water hoses which cool the electrodes during welding. The electrodes generally are made of a low resistance alloy, usually copper, and are designed in many different shapes and sizes depending on the application needed.

Design of experiments (DOE) is a techniques that enable a designers to determine simultaneously a interactive effects of a factors that effected the result in any design. Design of experiments (DOE) helps to pinpoint the sensitive partss and sensitive areas in a designs. The designer are then able to fix these problems and get the optimum parameter of design.

Response surface methodology (RSM) explores the relationship between explanatory variables and response variable in statistic. Response surface methodology (RSM) is a sequence of design of experiments (DOE) to obtain an optimal response. It is sufficient to determine which explanatory variables have an impact on the interest of response variables.

## PROBLEM STATEMENT

Resistance spot welding (RSW) is the most effective process for joinning both similar and dissimilar metals. Resistance spot welding is commonly used in the automotive industries for body assembly production lines. The major advantages of spot welding is efficient energy used, and high production rates. To improve the strength and good quality of welding the welding parameter is to be investigated. A small change of the parameter will effect all the other parameters. The main parameter for spot welding is welding current, welding time, force, and hold time.

Nowadays, the world faces of energy crisis and environmetal problems, energy saving and safety have become the most important issuses for auto making industry. To achieve these goals, weight reduction is the most effective to leads to the fast development and application of advanced high strength steels. In this research, DP600 is an Advanced High Strength Steel (AHSS) have been chosen to find the optimum parameters for the spot welding to determining the quality of a weld nugget development because the characteria of the material such as light weight, low ratio of yield strength to tensile strength, high work hardening capacity and good energy absorption. The good formability of DP600 allows the users to increase the strength of the components. Therefore, the products can be made stronger and safer under load.

Resistance spot welding is a key technology in automotive assembly industries that the process is fast and easily weld many different material combination that are difficult to join by other welding process. The weldability of different materials such as advanced high strength steel DP600 and low carbon steel is to investigated quality of a nugget development due to the formation of hardness, tensile strength. This research is to study the influence of resistance spot welding (RSW) parameters such as welding current, welding time, pressure and speed on the development of nugget formation, focused on weld nugget and Heat Affected Zone (HAZ).

## OBJECTIVE OF STUDY

The main purpose of this study

- To find the optimum parameter to optimize the size of weld nugget and Heat Affected Zone (HAZ) in order to obtain a good quality of Resistance Spot Welding using Factorial Design and Response Surface Methodology (RSM).
- To developed a mathematical model to predict the size of weld nugget and Heat Affected Zone (HAZ) using Response Surface Methodology (RSM).

Significance of the Project

The development mathematical models can be effectively used to predict the size of weld zone which can improve the welding quality and performance in Response Surface Methodology (RSM).

## SCOPE OF STUDY

The scope of study is to investigate on the resistance spot welding process using Factorial Design and Response Surface Methodology (RSM) to find the optimum parameters to optimize the size of weld nugget and Heat Affected Zone. The material used is DP600 advanced high strength steel 0.8mm thickness combined with low carbon steel 1.0mm thickness. The machine used is OBARA guns type diameter 6mm. The electrode copper alloys detail as below:

Alloy RWMA Class Hard Elec. Cond & Desc Use To Weld

CMW 3 2 83B 85% CU + CHROMIUM CRS & GENERAL WELDING

The microscope used is the compound light microscope. It commonly binocular (two eyepieces). The compound light microscope combines the power of lenses and light to enlarge the subject being viewed. The eyepiece allows for 10x or 15x magnification and when combined with three or four objective lenses which can be rotated into the field of view and produce higher magnification to a maximum of around 1000x generally. In the lab of material, microscope is used to watch and catch the picture of size weld nugget and Heat Affected Zone (HAZ).

## LITERATURE REVIEW

### Introduction of Resistance Spot Welding (RSW)

Resistance Spot welding is a process in which metal surface are joined widely used in the automotive structural application for many years for the fabrication of sheet metal assemblies. The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the work piece. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal. The resistance spot welding has the advantage which is high speed and suitability for automation.

Figure 1: Resistance Spot Welding Machine with Work [3]

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

In Resistance Spot Welding (RSW), methodology is development to determine the optimum welding conditions that maximize the strength of joints. Response Surface Methodology (RSM) utilized to develop an effective model to predict weld strength by incorporating parameters such as pressure, weld time and the others [7]. In this case study from journal that conducted as per central composite face centered design for spot welding of 0.2 and 0.3mm thick copper and brass speciments. Response surface model interfaced with the Genetic Algorithm to

optimize the welding conditions for desired weld strength. The welding process of copper and brass produced large heat affected zone (HAZ) and fusion zone (FZ).

Figure 2: Schematic represent [7]

Table 1: Variables for joining of Cu- brass specimens [7]

In response surface method the important is design of experiments. Identified the factors which have a significant influence on weld strength. It is weld pressure, weld time, and amplitude of vibration of horn. For 0.2 and 0.3 mm thick copper-brass speciments to determine maximum and minimum value of welding parameters large numbers of trial runs. From the trial runs the most suitable parameters were identified in table 1 above.

Response surface model for weld strength is a collecting of mathematical and statistical techniques useful for the modeling and analysis of problems in response of interest is influenced by variables and the objective is to optimize thsi response [7]. Then developed mathematical models to predict the weld strength. For the experiments the equation is

Where yi is the the response of weld strength, xi is pressure, weld time and amplitude, ¿½0, ¿½j, ¿½jj and ¿½ij represent the constant, linear, quadratic and interaction terms. For the spot welding equations like below :

After 20 experiments are conducted at different levels of parameters the value of weld strength obtained from experiments and those predicted from response surface model along the design matrix.

Table 2: Weld strength and RSM [7]

Figure 3: Effect of amplitude and weld time on weld strength [7]

Figure 4: Effect of pressure and weld time of weld strength [7]

Figure 5: Effect of amplitude and pressure on weld strength [7]

And for another experiments that used Response Surface methodology (RSM) by spot welding that used aluminum as a specimen [8]. They investigated effect between aluminum foam and the metal spot-welded colum. Based on their experiment. Numerical simulation and analytical models was developed to partition the energy absorption quantitatively into the foam filter component and the hat section component and the relative contribution of each component to the interactive effect.

Figure 6: schematic drawing of the spot welding-welded used in the experiment [8]

Response Surface Methodology (RSM) is a method to understanding the correlation between multiple input variables and output variable.

Figure 7: Comparison of the experiment and numerical result [8]

Figure 8: Response surface of sea for the foam filled spot welded column [8]

Figure 9: Response surface of peak force for the foam filled spot welded column [8]

Table 3: Optimum foam filled square column [8]

From the Response Face methodology (RSM) they get the optimum value of the t = thickness, a = thickness, density, pressure and SEA.

## ELECTROTHERMAL PROCESS OF WELDING

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

Q= I Rt (modification of the Ohms Law) [3]

where Q is heat (Joule), I is current (Ampere) , R is electrical resistance of the circuit (ohm,O) and t is time (second) which is allowed to flow in the circuit. For resistance welding, the heat generation at all location in a weldment is more relevant than, rather than the total heat generated, as heating is not and should not be uniform in the weldment. That means, consideration should more on the heat rate than the total heat, as it will determines the temperature history, and, in turn, the microstructure [3]. For example, considering an aluminum welding, melting may not be happen if the welding current applied is low, due to the low electrical resistivity of aluminum. In general, the electric and thermal process should be considered together in welding.

## SPOT WELDS PARAMETER

The parameter
1. Electrode Force

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

2. Squeeze Time

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

3. Weld or Heat Time

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

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

4. Hold Time

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

5. Weld Current

The weld current is used during welding is being made. The amount of weld current is controlled by two things; first, the setting of the transformer tap switch determines the maximum amount of weld current available; second the percentage of current control determines the percentage of the available current to be used for making the weld. Low percentage of current settings is not normally recommended because it might affect the quality of the weld. Proper welding current can be obtained with the percentage current set between seventy and ninety percent by adjust the tap switch. The weld current should be kept as low as possible. When determining the current to be used, the current is gradually increased until weld spatter occurs between the metal sheets. This indicates that the correct weld current has been reached. Weld current also influences the value of nugget diameter. Different value of current, it will produce different dimension of the nugget diameter [3].

Figure 10: Welding Cycle

The welding processes in resistance spot welding have 5 cycle process as shown in the Figure 10. The first cycle is the squeeze time, where pressure from the electrode force is applied to the workpiece. The second cycle is weld time, this process where the current is on and the welding current is applied in the metal sheets to melt the sheet metal for the welding process. Then, postheat time, the current delay at the low level. The fourth cycle is cool

time. This cycle allow the melt nugget diameter to solidify before the releasing the welded parts and lastly the off time cycle, the electrode force applied on the sheets metal is released the welding process is done.

## MATERIAL PROPERTIES

Introduction of Advanced High Strength Steel (AHSS*)*

DP600 is one of the Advanced High Strength Steel (AHSS) for the automotive industry that have enhanced ductility and formability [4]. DP600 usually used in the manufacture of passenger car and commercial vehicle wheels. It is to reduce weight and increasing service life and made of the typical properties of theese materials for maximum used.

Basic Properties

**Mechanical Properties**

Table 4 : mechanical properties for DP600 [4]

**Chemical Composition**

Table 5 : Chemical Compostion for DP600 [4]

**Dimension**

Table 6 : Dimension for DP600 [4]

**Advantages of High Strength Steel (DP600)**

High strength steel (DP600) are prodominantly used in automotive industries because of many advantages such as below [4] :

1. Low ratio of yield strength to tensile stength .
2. Work-hardening capacity is high.
3. Good energy absorption characteristic to provide crash performance in structural.
4. Product stronger and safer under load.
5. Good bake hardening responce that forming the yield strength in the formed areas is significantly increased.

## RESEARCH METHODOLOGY

Methodology actually is a systematic study of method and set of procedur. In this study, there are consist of several phase. Figue 3 below showed a methodology for this project.

Detail of methodology

Information Gathering

In information gathering all related information about spot welding, and material used was collected to provide futher understanding. All the related information is obtain from the internet, journal, library and the other resources. It is important o nderstand the theory and previous step.

Design of experiment

Design of Experiment is an advance to improve design performance which to reduce cycle time to developed processes [5]. Design of experiment is a series of test to change the input variable (parameter) to study and identififying the output change in the output response. Then analyze the result of process to find the optimum value or parameters that effect to the process.

Figure 11

Figue 4 shown an example model of process that shown a number of uncontrolled factor that are discrete, such as difference machine or operators and such as ambient temperature or humidity.

**Screening Design and Full Factorial Design**

Screening design is to identify which factor and effect that are important. When have 2-4 factors and can perform a full factorial. Full factorial design in two level. Full factorial design ia a common experimental design with all input factors set at two levels each. These levels is called ¿½high¿½ and ¿½low¿½ or +1 and -1. A combination of all the input factors is called full factorial design in two level [6]. If there are k factors at 2 levels, full factorial design has 2? runs.

Table 7: Number of run 2? Full Factorial

| Number of Factors | Number of Runs |
|---|---|
| 2 | 4 |
| 3 | 8 |
| 4 | 16 |
| 5 | 32 |
| 6 | 64 |
| 7 | 128 |

Objective of factorial design as below:

1. To identify factors with significant effects on the response .
2. To identify interations among factors .
3. To identify which factors have the most importance effects on the response .
4. To decide whether further investigation of a factor¿½s effect is justified .
5. To investigate the functional dependence of a response on multiple factors simultaneously (if and only if you test many levels of each factor) .

**Response Surface Methodology**

Response surface Methodology (RSM) investigates relationships between explanatory variables and response variables. Objective of RSM is to use a sequence of designed experiments to obtain an optimal response. Below is example of RSM :

Figure 12 : Response surface ¿½Peak¿½ Figure 13 : Response surface ¿½Hillside¿½

Figure 14 : Response surface ¿½Rising ridge¿½ Figure 15 : Response surface ¿½saddle¿½

**Mathematical Method**

The mathematical model correlating process parameters and their interations with response parameter will be developed according to the experimental result. These model will be used to predict the size of weld zone which can improve the welding quality and performance in Resistance Spot Welding.

The most common models fit to the experimental data take either a linear equation. A linear model with two factors X1 and X2 such as below :

Y = ¿½0 + ¿½1X1 + ¿½2X2 + ¿½12X1X2 + experimental error

Y is the response for given levels of the main effect X1 and X2 and X1X2 is ncluded for possible interation effect between X1 and x2. Constant ¿½0 is the response of Y when both main effect are 0 [6].

The advance of using DOE is that can provides an approach organized which it possible to address both simple and tricky experimental problem. The experiment is to select appropriate objective, and then guide and perform a set of experiment. That can conclude DOE can obtain more useful and more precise information about the studies system. The joint influence of all factors is assessed [5]

*Experiment process*

The experiment is focused to get the radius of molten zone or weld nugget and Heat Affected Zone (HAZ). The diameter of weld nugget and Heat Affected Zone (HAZ) is measured by capture the image of the speciment by the microscope. All the parameter such as welding time, the diameter of tips, weld current , and force will be varied in the experiment.

All the result with different parameter will be record to investigate nugget development focused on weld nugget and Heat Affected Zone (HAZ).

The procedure for this experiment to prepare the sample of specimen are :

a) Cutting.

b) Molding.

c) Grinding.

d) Polishing.

e) Etching.

f) Invetigate weld nugget and HAZ size using microscope.

Conclusion

After get the optimum result and the hardness and strength have be confirmation by tensile test, hardness test and bending test, the conclusion from this project is verify and the project is 100% complete.

Thesis writing

After get the conclusion, to complete this project thesis writing is needed to complete the project. All the process and data from this project from the start util the end is to be record and compile as a book.

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