Optimization of spot welding process parameters on dissimilar and unequal thickness of metal sheets by using Taguchi technique

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Abstract. The objective of the present work is to optimize the process parameters of Resistance Spot Welding (RSW) of dissimilar steel sheets with unequal thickness used in automotive industry through evaluation of the responses in order to get the better mechanical properties. Various combination of applied current, weld time and electrode force as the selected parameters which have three levels each, have been investigated to obtain the optimal condition of a welding process. In this work all experiments were carried out based on Taguchi experimental design of L9 orthogonal array. The values of spot weld tensile strength were decided as the response character to be optimized. Signal to noise ratio analysis and analysis of variance (ANOVA) were also conducted to determine the main significant effect of those parameters and the contribution percentage of each parameter. It has been found that the current welding time plays the most important/significant factor in welding process to control the spot weld performance. The experimental results confirm the validity of robust design by Taguchi method for parameter optimization and possible increasing of efficiency in resistance spot welding processes.

Keywords: parameter optimization, resistance spot welding, Taguchi method, S/N ratio, ANOVA

I. Introduction

Resistance Spot Welding (RSW) has become an essential process in metal industries which prerequisite the metal joining process for their products. In automotive industry, RSW is a common method applied for combining many metal parts to be used in creating the vehicle’s white body. Benefiting from the characteristics of inexpensive processes, the flexibility of RSW could possibly join different types of sheets with unequal thicknesses and also due to its susceptibility process to be
automated with robotic systems to speed up the production. Generally, more than 4000 points of spot welds are needed to assure the production of a vehicle.

Automotive industries with a large number of production consider that weld quality is one of the criteria that should be guaranteed. Weld quality is responsible for the judgment of joining quality whether it fails or not through the loads and fatigue experiences during durability of vehicle. The weld quality itself is the result or the response of the adjusted weld parameters. Through the selected welding parameters, the appropriate quality of weld could be predicted to ensure the adequate level of quality. In order to achieve the minimum target of quality weld diameter ($4\sqrt{t}$), three main welding parameters such as current, weld time and electrode force are chosen to be the adjusted parameters that affect the weld quality [1][2]. In obtaining the best parameters setting to optimize the spot welding process, many methods have been developed and implemented. In many field of industries, especially automotive industries, the optimization process becomes a big concern not only due to the secured quality matter, but also the considerable impact on cost minimization. One of the conventional approaches is the “One factor at a time” method. Through this method, optimization process was conducted by changing one factor at a time while the other factors held constant [3][4]. The experiments should be repeated till the effect of all factors is obtained. This method is quite simple to be implemented; however, it is highly times and costs consuming due to the preparation of material and so many experiments must be conducted. The other approach is the full factorial (design of experiment) which provides a set of experiments in which all of input factors are varied simultaneously in a systematic way and offers possible interactions of multiple independent variables to evaluate the effect of each factor [5]. Nevertheless, this method has a large number of experiments to be done, which increase exponentially to the increasing of the amount of the factors and/or the levels affected to the response during the optimization process [6][7].

The improved method of design of experiment is Taguchi design which reduces the number of experiments by arranging the number of experiments through an orthogonal array and identifies the key parameters which has the most effect on the response [8][9]. The orthogonal array developed in Taguchi allows this method to study the entire parameters effectively [10]. Optimal combination of the parameters was predicted by signal to noise (S/N) ratio analysis. Responses of the experiments are measured by S/N ratio to obtain the variability of the responses. This S/N ratio is characterized to three categories i.e., nominal-the better, lower-the better, larger-the better. In this research the larger-the better is used in order to get find the highest value of response [11]. A statistical analysis of variance (ANOVA) is performed to check the statistical process parameters.

The present study focuses on optimizing the process parameters of resistance spot welding (RSW) of dissimilar steel sheets with unequal thickness which used in automotive industry. Evaluation of the tensile strength was done as a response of the quality characteristic, in order to get the better mechanical properties of the joined sheets.

2. Experimental

2.1 Material

The low carbon steels of material that used in this experiment were SPC 440 (0.9 mm thick) and SPH 440 (2.9 mm thick). They were selected due to their widely use and one of the most popular materials in the production of automobile white’s bodies. The data of each chemical composition and mechanical properties of the used materials can be seen in the Table 1. The sheets were cut into the specimen with the dimension of 110 x 20 mm. The samples were cleaned with acetone before processed, and then overlapped for the purpose of tensile shear test. Figure 1 shows the dimension of specimen for spot weld tensile tests.
Table 1. Chemical composition and mechanical properties of the used low carbon steel material

| Material | C  | S  | P  | Mn | Yield Strength (MPa) | Tensile Strength (MPa) |
|----------|----|----|----|----|---------------------|-----------------------|
| SPC 440  | 0.16 | 0.013 | 0.019 | 0.82 | 337                | 468                   |
| SPH 440  | 0.14 | 0.005 | 0.022 | 0.68 | 335                | 483                   |

Figure 1. Dimension of specimen for spot weld tensile tests

2.2 Experiment Procedure

KDX type of OBARA Welding Machine that was coupled with a pair of water cooled copper alloy electrodes was performed in this experiment. In order to remove some dirt and oily material, all of the steel samples were cleaned by using a cloth and acetone before welding. Based on literature study and internal practical experience [1][2], the welding parameters that have major impact to the weld quality are: welding current, welding time and electrode force. They are chosen to be the parameters that should be optimized in this experiment. Each parameter has 3 levels to accommodate the optimization of RSW by utilizing Taguchi method as arranged in Table 2.

| Exp. Number | Level 1 | Level 2 | Level 3 |
|-------------|---------|---------|---------|
| Weld Current (kA) | 7.0    | 7.5    | 8.0    |
| Weld Time (cycles)   | 15    | 20    | 25    |
| Electrode Force (N)  | 2500  | 3000  | 3500  |

Tensile shear strength tests as an evaluation to the responses were performed with a HungTa HT3002 Universal Testing Machine by maintaining the crosshead speed of 50 mm/min. The tensile-shear test was carried out using 100 kN (max capacity) tensile testing machine to determine the strength of spot welded specimens.

3. Result and Discussion

The setting design of RSW process parameters were determined by using Taguchi’s experimental method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to find the optimal levels and to analyze the effect of the RSW process parameters with the response of tensile shear strength values. Settings of parameters were determined by the orthogonal array L9. Experiments were conducted by following the settings of
parameters and tensile strength was the response measured. Combinations of parameters were performed and the experiment runs were carried out 3 times in every combination. The S/N ratio of the larger the better was applied with the intention of achieving the greatest tensile strength.

S/N ratio for the criteria of the larger the better [12]:

$$\text{SNR}_{\text{Exp}} = -10 \log \left( \frac{1}{3} \sum_{i=1}^{3} \frac{1}{y_i^2} \right)$$

| No. | Current (Amp) | Time (Cycles) | Pressure (kN) | Tensile Strength (kN) | TS (kN) | Average | S/N Ratio (dB) |
|-----|---------------|---------------|---------------|-----------------------|---------|---------|----------------|
| 1   | 7000          | 15            | 2.5           | 8.45                  | 8.43    | 8.59    | 8.49           | 18.57          |
| 2   | 7000          | 20            | 3             | 8.62                  | 8.55    | 8.53    | 8.57           | 18.66          |
| 3   | 7000          | 25            | 3.5           | 8.64                  | 8.85    | 8.70    | 8.73           | 18.82          |
| 4   | 7500          | 15            | 3             | 8.74                  | 8.92    | 8.88    | 8.85           | 18.93          |
| 5   | 7500          | 20            | 3.5           | 9.33                  | 9.23    | 9.18    | 9.24           | 19.32          |
| 6   | 7500          | 25            | 2.5           | 9.26                  | 9.23    | 9.18    | 9.22           | 19.29          |
| 7   | 8000          | 15            | 3.5           | 9.04                  | 9.00    | 8.92    | 8.99           | 19.07          |
| 8   | 8000          | 20            | 2.5           | 9.48                  | 9.22    | 9.14    | 9.28           | 19.35          |
| 9   | 8000          | 25            | 3             | 9.51                  | 9.56    | 9.46    | 9.51           | 19.56          |

The S/N ratios for each factor were calculated to minimize the variances in the value [13] S/N ratio has a good capability in quality prediction and evaluation, S/N ratio able to reflect the variations of the quality attributes and adjust average values to the target values with the purpose of comparing the quality performance [14].

Figure 2. S/N ratio graphs for the tensile strength as responses of dissimilar thickness spot welding
The highest plots of each parameter were chosen to be the best levels to be applied on RSW. The obtained optimum condition are as follows: Current = 8000 A, WeldingTime = 25 cycles, Pressure = 2.5 N. The pressure’s plot shows no variation between each level. The flat trend of the pressure’s plot explains that the changing level of pressure does not effect the tensile strength.

Table 4. S/N analysis of parameter effect on tensile strength of spot welds.

| Level | Current (kA) | Time (Cycles) | Pressure (kN) |
|-------|--------------|---------------|---------------|
| 1     | 18.68        | 18.86         | 19.07         |
| 2     | 19.18        | 19.11         | 19.05         |
| 3     | 19.33        | 19.22         | 19.07         |
| Delta | 0.64         | 0.36          | 0.02          |
| Rank  | 1            | 2             | 3             |

The result of S/N ratio of our experiments has been shown in Table 3. In S/N analysis, the delta value shows how the parameter is significantly affecting the response. The higher the delta value signifies the greater contribution of its parameter.

Table 5. ANOVA result for parameter contribution on quality characteristics

| No. | Factor  | DoF | SS    | MS   | F Ratio | % Contribution |
|-----|---------|-----|-------|------|---------|----------------|
| 1   | Current | 2   | 0.684 | 0.342| 19.260  | 73.7           |
| 2   | Time    | 2   | 0.208 | 0.104| 5.858   | 22.4           |
| 3   | Pressure| 2   | 0.001 | 0.000| 0.020   | 0.1            |
| 4   | Error   | 2   | 0.035 | 0.018|         |                |
| 5   | Total   | 8   | 0.928 |      |         |                |

A statistically decision-making tool, ANOVA detects any differences in the average performance and tests the significance of all main factors [15]. We found that the weld current is affecting the response significantly while the least affecting factor is pressure. The percentage of contribution was obtained as seen in Table 5, the current parameter has the highest contribution on the tensile strength with the percentage of contribution 73.7%, followed by welding time with the percentage of contribution of 22.4% and pressure gave almost no contribution at all.

4. Conclusion

By utilizing Taguchi method and ANOVA we obtained the optimum level and the percentage of contribution for each parameter. Based on optimization results, the following conclusions can be drawn:

1. Among of all important parameters, weld current plays the most significant variable towards the quality characteristics of tensile strength in spot welding process, with the percentage of 73.7%, followed by the weld time (22.4%). The electrode force become the less effective variable to control the quality of welding strength.

2. The optimal parameter combination for the maximum tensile shear strength in these experiments is: Current: 8000 A, Weld time: 25 cycles, and at force 3500 N, obtained as the result from S/N analysis.
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