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Overview on Optimization Approaches for Resistance Spot Welding Parameters and Welded Joint Quality

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Abstract

This paper presents an overview on optimization methods applied to optimize welding parameters in order to have good weld quality of mechanical characteristic of Resistance Spot Welded (RSW) joints. The qualities of the spot welded joints are defined by the mechanical properties. The aim of optimization method is to determine optimal RSW parameters associated with good mechanical performance of RSW joints. Taguchi method used S/N ratio to measure the quality characteristic deviating from the desired value. Analysis of variance “ANOVA” helps to test the significance of all main factors by comparing the mean square against an estimate of the experimental errors at specific confidence levels. Also ANOVA method permits to show out the factors which have a significant effect on the sensitivity of the process and their contribution on quality characteristics especially tensile shear strength of the Resistance spot welding joint. Additionally, presented methods are detailed to show some examples of optimization processes.

Keywords: *Resistance Spot Welding, Welded Joint, Optimization Approach, Taguchi Method, ANOVA, Moora Method.*

1. Introduction

Resistance Spot Welding (RSW) is one of the most important manufacturing processes in several industries. The main applications of RSW in industries are automobile assemblies, domestic appliances, home furniture, medical building and construction, and enclosures and, to a limited extent, aircraft components [1]. The quality is best judged by the nugget size, Heat Affected Zone (HAZ) and joint strength [2]. Welding input parameters play a very significant role in determining the quality of weld nugget and heat affected zone formation (HAZ). Therefore, it is important to select the best welding parameters to obtain optimal size of the weld nugget and to reduce HAZ. In order to input the best welding parameters, various optimization methods can be used to choose the optimal welding parameters and have the desired output variables (nugget size, HAZ, tensile shear strength…). Generally, the tensile-shear strength of the RSW can sufficiently define the joining quality. However, tensile-shear strength measurement is a destructive method and the cost of tests is very high compared with other optimized parameters. In several research works, the nugget diameter has also been used as a quality estimator in reality, because it is closely proportional to the tensile-shear strength [1, 3, 4]. Zhou and Ping have presented an overview on optimization technique of RSW and control weld quality [5]. The main optimization methods applied for improving weld quality are Taguchi method, ANOVA and MOORA [6, 7, 8].

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Additionally, to the application of Taguchi, ANOVA and MOORA methods in optimization of welding parameters, they are also applied for other optimization applications (manufacturing, economics etc.) [9, 10]. Gadakh has applied multi objective optimization method on the basis of MOORA method for solving criteria optimization problem milling process [11]. In order to improve the quality of welded joints by Gas Metal Arc Welding (GMAW) process, Achebo and Odinikuku have applied the multi-objective optimization method named MOORA Method. The analysis of the microstructure reveals that the welding joint produced by the optimized process parameters is of excellent weld quality comparatively to others used parameters [12]. In study conducted by Shanmugarajan et al. [13], laser welding process has been optimized for P92 material by using Taguchi based grey relational analysis. The optimum parameters have been derived by considering the responses such as depth of penetration, weld width and heat affected zone width. Analysis of variance (ANOVA) has been used to analyze the effect of different parameters on the responses.

In other study, Tutar et al. have applied Taguchi orthogonal array to optimize welding parameters for friction stir spot welded of non-heat treatable Al-alloy. The welding parameters, such as the tool rotational speed, tool plunge depth and dwell time, were determined according to the Taguchi method. The individual importance of each welding parameter on the tensile shear load of the friction stir spot weld was evaluated by examining the signal-to-noise ratio and analysis of variance “ANOVA” results [14]. In welded of homogeneous joint by resistance spot welding process of 301L stainless steel, Singh et al. have studied the optimization of and the effect of welding parameters on the tensile shear strength, nugget diameter, penetration and indentation. Experiment have been conducted as per Taguchi method and fixed the levels for the parameters. Moreover, Analysis Variance “ANOVA” has been used for determining most significant parameters affecting the spot weld parameters [15].

2. Background on Optimization Methods

2.1 Taguchi Method

Taguchi method is a statistical method, which is called a robust design method, developed by Genichi Taguchi to improve the quality of manufactured goods and more recently also applied in different domain: engineering biotechnology, marketing….etc [16]. Design experiences combined with optimization of control parameters to obtain best results can be achieved by Taguchi Method.

"Orthogonal Arrays" (OA) provide a set of well-balanced minimum experiments, reduce cost of each experiment and employ Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output and serve as objective functions for optimization, help in data analysis and prediction of optimum results. There are three Signal-to-Noise ratios of common interest for optimization defined by the equations below.

1- Smaller Better:

$$\mu = -10\,Log_{10}\left(Mean\ of\ sum\, squares\ of\ measured\, data\right) \tag{1}$$

2- Larger Better:

$$\eta = -10\,Log_{10}\left(Mean\ of\ sum\, squares\ of\ reciprocal\ of\ measured\, data\right) \tag{2}$$

3- Nominal Better:

$$\eta = -10\,Log_{10}\frac{Squares\ of\ mean}{Variance} \tag{3}$$

Where η define the S/N ratio expressed by:

$$S/N(\eta) = useful\ output/\ harmful output \tag{4}$$

2.2 Analysis of Variance (ANOVA)

ANOVA (Analysis of Variance) [17, 18] helps in formally testing the significance of all main factors by comparing the mean square against an estimate of the experimental errors at specific confidence levels. ANOVA is performed to find out the factors which have a significant effect on the sensitivity of the process and their contribution on quality characteristics; tensile shear strength and direct tensile strength of the resistance spot welded joint.

2.3 MOORA Optimization Method

The MOORA method is one of the multi objective optimization methods and it was first developed by Brauers and Zavadskas [19]. It requires a matrix of responses of the alternatives to the objectives. In the literature, the MOORA method has been applied successfully to many decision problems. The MOORA method can be functional in numerous forms of complex multi objective optimization problems. In MOORA method the recital of the diverse output responses is arranged in a decision matrix as specified in Equation (5) [20, 21, 22].

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdot\cdot & x_{1n} \\ x_{21} & x_{22} & \cdot\cdot & x_{2n} \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ x_{m1} & x_{m2} & \cdot\cdot & x_{mn} \end{bmatrix} \quad (5)$$

Where, x_{ij} is the performance measure of the *i*th alternative on *j*th attribute, *m* is the number of alternatives, and *n* is the number of attributes.

A ratio system will be formed by normalizing the data of decision matrix which can be calculated by using the equation (6).

$$x_{ij}^{*} = x_{ij} / \sqrt{\left[\sum_{i=1}^{m} x_{ij}^{2}\right]} \quad (6)$$

Where, x_{ij}^{*} represents the normalized value x which is a dimensionless number which lies between 0 and 1 i_{th} alternative on j_{th} attribute. After that, the normalized value will be added for maximization problem or subtracted in case of minimization problems. In some cases, some of the attributes have more importance than others, and to deliver even more importance to these attributes, they are multiplied by their corresponding weight. After the consideration of weight, the equation will be:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{n} w_j x_{ij}^{*} \; (j = 1,2,\ldots,n) \quad (7)$$

Where, g is the maximized number of attribute, (n-g) is the attributes to be minimized and is the weight of j_{th} attribute. y_i is the normalized assessment value of the i_{th} alternative relating to all the attributes. After calculation of normalized assessment value, ranking of y_i is done from highest to lowest value to know the best alternate among the entire attributes. Thus, highest value is the best alternative among all since ranking of the y_i is the final preference [20, 21,22].

3. Application of Optimization Methods and Effects of Welding Parameters

In study conducted by Yi et al. [23], a mathematical model for predicting the nugget diameter and tensile shear strength of galvanized steel has been developed. The input welding parameters are preheating current, weld current, weld time and welding force. The nonlinear regression model shows the complexity of the welding of Galvanized steel sheet. Esme [24] has studied optimization of RSW process parameters for SAE 1010 steel using Taguchi method. In this investigated welding current and electrode force are main factors controlling the weld strength, i.e. the quality of RSW. Also, the author concluded that Taguchi method can be effectively used for optimization of spot welding parameters.

Thakur et al. [17] have conducted an optimization of effect of welding parameters on the tensile shear strength of spot welded galvanized steel sheets. The level of importance of the welding parameters on the tensile shear strength is defined by using ANOVA, where welding current and welding time present are the main parameters. Additionally, the experimental results confirmed the validity of Taguchi method for enhancing the welding performance and optimizing the welding parameters in resistance spot welding process.

In recent study, Vshwakarma et al. [1] have investigated the effect of welding parameters and optimized values in order to have best quality of joining. The results of this investigation indicate the welding current is the most significant parameter controlling the weld tensile strength as well as the nugget diameter. Additionally, the results indicate that the welding current represents 61% for tensile shear stress and 81% for nugget diameters in contributions effects compared with other welding parameters. In order to get desired welding quality, Jadhav et al. [25] have investigated the optimization and the effect of welding parameters on the tensile shear strength of spot welded SS202 stainless steel. Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as welding current and welding time, whereas electrode force was less effective factor. This investigation reveals that the welding current presents the main parameters for controlling the quality of welded joint. The study conducted by Shafee et al. [26] on the optimization of RSW parameters for joining of low carbon steel sheets has shown that Taguchi method presents an efficient technique to optimize the welding parameters to have best quality of joining. Analysis of variance “ANOVA” was applied to determine the significance of welding parameters on the welding quality. The ANOVA revealed that the effect of welding current and welding time was more dominant on shear tensile strength compared with the electrode force. Karad et.al. [27] have conducted experimental investigation in RSW on mild steel specimens to optimize the tensile strength. The welding input parameters were taken welding current, electrode force and welding time and the output parameter was tensile strength. Also the optimal parameters were obtained using Taguchi optimization method to get maximum tensile strength.

In recent study, Das et al. [28] have conducted experimental work for optimization of RSW dissimilar material (AA6061, Galvanized steel) by using MOORA optimization method. The effect of welding current, welding force and welding time were investigated. Optimal parameters were obtained and results shown that an increase in welding parameters decreased the ultimate tensile strength. Sreeraj [29] has optimized RSW parameters for 316 L stainless steel plates. MOORA method in combination with standard deviation (SDV) was used for optimization process. Nugget diameter, heat affected zone (HAZ) and breaking load as objectives were optimized. The obtained microstructures of the optimized welding parameters confirmed that optimization result produced the best quality of the RSW joining.

In recent research conducted by Shamsul and Hisyam [30], the relation between the nugget diameter and welding current and also hardness along welding zone for austenitic stainless steel 304 has been investigated. Results have shown that the weld nugget size increases with the increasing welding current. For other research for assemblies of stainless steel sheet, it is concluded that welding current is most effective parameter controlling the formation of nugget diameter as well as the tensile strength of spot weld [31]. The quality of the formation of the nugget depends on external geometric aspect of spot welding characterized by indentation width and indentation depth [32]. The investigation conducted by Larbi Cherif and Benachour [32] on the resistance of spot welded joint in stainless steel has shown that the increasing welding current increased the diameter of indentation width increased the nugget diameter (Figure 1). In recent experimental study of the same researchers [33], the increasing welding current increased the tensile shear stress, which improved the quality of spot welding (Figure 2).

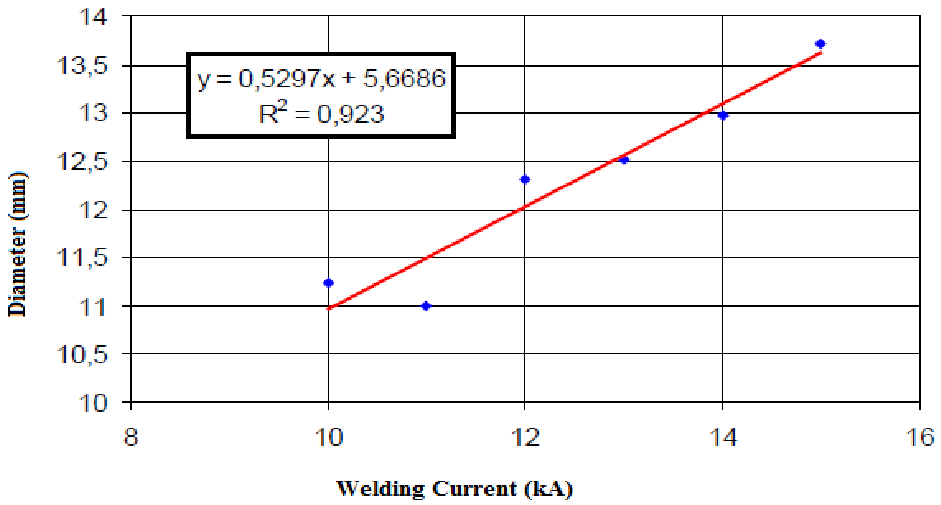

Figure 1. Effect of welding current on indentation width in spot of welding [32]

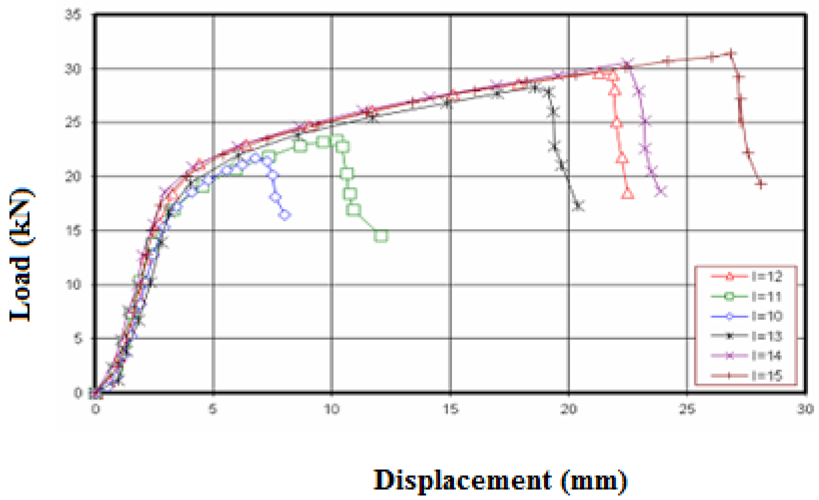

Figure 2. Effect of welding current I (kA) on tensile shear [33]

4. Conclusion

The experiments carried out on two turn different, a conventional turn and a turn with numerical controlThe work presented in this paper is an overview of optimization methods applied in evaluation of optimal of resistance spot welding parameters and parameters effects. From above presentation it can be concluded that:

- ⇨ Taguchi or Moora methods and analysis variance (ANOVA) extensively used in optimization of RSW presents an efficient technique to optimize the welding parameters in order to have best quality of joining.
- ⇨ In optimization process, welding current presents high percentage in input parameters, which affect the quality of RSW.
- ⇨ Welding current is the main parameter controlling the tensile shear strength and diameter nugget.
- ⇨ The size of the nugget (nugget diameter) depends on welding parameters, i.e. indentation width and indentation depth.
- ⇨ The welding time presents an average effect on tensile shear strength and nugget diameter.
- ⇨ Results of output parameters shown that optimal results are confirmed by conducted experimental results.

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