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Quality Improvement for Resistance Spot Welded AHSS Steels by Using Taguchi Method

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Abstract— In this study, TRIP800-DP600 steel sheets in equal thickness which are members of advanced high strength steel (AHSS) group are joined with the resistance spot weld in various welding parameters for optimization of the strength of the weldment by the Taguchi method. For this purpose, Taguchi experimental design method and L9 orthogonal array was chosen. The experimental study was conducted under varying welding currents, welding times and electrode forces for joining DP600-TRIP800 dissimilar steel. Evaluations were made by taking the average of the data obtained by tensile shear test applied to welded joints. According to the analysis results, the welding time is determined as the most important welding parameters for the resistance spot welded TRIP800-DP600 dissimilar steels in equal sheet thickness. The welding parameter giving the highest strength by the Taguchi method was also determined. Optimum welding parameters specified by the Taqucchi method yielded the best strength in the experimental work.

Index Terms— AHSS steels, Taguchi method, Tensile shear strength, Welding parameters

1 INTRODUCTION

Nowadays, there has been a significant increase in the use of high-strength steel (AHSS) in the resistance spot welding (RSW) [1,2]. However, the AHSS sheet has limited weldability which causes a smaller fusion zone and interfacial failure of the weld nugget [3,4].

The welding current, the welding time, and the electrode force which affect the heat input are the most important parameters in spot welding [7]. Thus, the generated heat input (Q) in RSW is calculated according to the equation $Q = I^2 x\ R\ x\ t$, where I is the welding current, R is the resistance, and t is the welding time [5,6]. Variations in these parameters will cause variations in the tensile shear strength and the fracture modes. Increasing welding current leads an increment in heat input and to alter failure mode from interfacial failure mode to pullout mode [8]. Excessive heat input will cause molten metal expulsion and result in deep indentations that causes lower mechanical strength properties [9].

Therefore, it is important to select the optimal welding process parameters for obtaining the acceptable tensile shear strength. Various optimization methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables [10-12]. The Taguchi design method is a simple and robust technique for optimizing the process parameters. In this method, main parameters, which are assumed to have influence on process results, are located at different rows in a designed orthogonal array (OA)[13].

In the present paper, the Taguchi design method was applied to optimize the welding parameters for obtaining the optimum tensile strength of the weld joint for the DP600 / TRIP800 steel sheet in equal sheet thicknesses. The significant levels of the welding parameters were also obtained using an analysis of variance (ANOVA). Experimental confirmation test was also conducted to validate the predicted model.

2 MATERIAL AND METHOD

2.1 Material

The steels are used in this study are 1.5 mm equal sheet thickness in TRIP800 and DP600. The composition and mechanical properties of the steels are given in Table 1.

Table 1: Chemical composition of DP600 and TRIP800 steel (wt%)

	C	Si	Mn	Cr	Mo	Al	Fe	Yield Strength (MPa)	UTS (MPa)	Elongation (%)
DP600	0.13	0.35	1.426	0.637	0.013	0.053	Rest	418	580	19
TRIP800	0.2	1.66	1.69	0.006	0.011	0.43	Rest.	510	800	21

2.2 Resistance spot welding and experimental procedures

Test samples were spot welded in a pneumatic spot welding machine with 60 kVA capacity in 50Hz electrical circuit. Spherical tip electrodes (CuCrZr) having 5.5 mm diameter were used. A batch of sheet samples in dimensions of 100mm × 30mm × 1.5 mm in equal thickness were used for spot welding in order to determine tensile shear strength. Squeeze time (25 cycles, 1 cycle = 0.02 sec) and holding times (15 cycles) were kept constant for all the experiments. Three welding parameters such as welding current, welding time and electrode force were selected for experimentation with three levels of each factor (Table 2). Under Taguchi system having 3 parameters with 3 levels can be performed with 9 experiments. Therefore, experimental process was conducted using L9 orthogonal array in Taguchi method as shown in Table 3.

Table 2. Levels of factors

Thickness of sheets DP600-TRIP800	Symbol	RSW parameter	Unit	Level 1	Level 2	Level 3
1.5 mm	A	Electrode force	kN	4	5	6
	B	Welding current	kA	5	7	9
	C	Welding time	cycle	15	20	25
1 cycle =0.02 sec						

A set of five tensile shear test samples were joined for all weld parameters. Tests were carried out by SHIMADZU tensile test machine having 50kN capacity at the 10 mm/min constant strain rate.

The Taguchi method converts objective function values to the signal-to-noise (S/N) ratio (η, dB), which represents the quality characteristics of the experimental data in the Taguchi design of experiments (DoE) [13,14]. In this study, for obtaining the maximum tensile shear strength, S/N ratio was chosen according to criterion, "larger the-better", as shown in Equation (1) [15-17]:

$$\eta = S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right), \quad i=1,2 \ldots k \qquad (1)$$

Where, yi (mean) is the observed data during the experiment and n is the number of trials.

The relative effect of the different welding parameters was determined with the analysis of the variance (ANOVA) table. Confirmation tests were done by Taguchi optimization method with using the optimum resistance spot welding conditions for obtaining the tensile shear strength of DP600-TRIP800 steel couple. Thereby the experimental test was applied with the optimum welding parameters to validity (to compare) of the optimization. Optimization process based on the Taguchi method is performed by Minitab 17 software.

3 EXPERIMENTAL RESULTS & DISCUSSION

3.1 S/N ratio results

The average values of tensile shear strength values were measured after tensile shear test of the resistance welded DP600-TRIP800 steels. The experimental results and S/N ratios are shown in Table 3 according to the L9 orthogonal array.

Table 3. Resistance spot welding parameters and L9 orthogonal array

RSW parameters for DP600-TRIP800 weldment (1.5 mm - 1.5 mm)				**Tensile shear test results**	
Experiment number	**Electrode force (kN)**	**Welding current (kA)**	**Welding time (cycle)**	**Average Tensile shear strength (MPa)**	**S/N ratios (dB)**
1	4	5	15	19,03	25,5888
2	4	7	20	19,48	25,7918
3	4	9	25	20,37	26,1798
4	5	5	20	19,52	25,8096
5	5	7	25	20,14	26,0812
6	5	9	15	19,73	25,9025
7	6	5	25	20,34	26,1670
8	6	7	15	18,67	25,4229
9	6	9	20	20,39	26,1883

S/N ratios of the tensile shear strength for weldments in equal sheet thicknesses obtained from the experimental results, which will be used to determine the optimal levels (higher-the-better) of each variable, were calculated according to the Eq. (1) (Table 3). In addition, the total mean of the S/N ratio for the 9 experiments and delta (Δ) between the maximum and the minimum S/N values are also calculated and listed in Table 4. Figure 1 illustrates the graphs of S/N ratios that were calculated for tensile shear strength for weldments.

Table 4: S/N responses for the tensile shear strengths and energy absorptions of joints.

Results	Symbol	RSW parameters	Unit	Level 1	Level 2	Level 3	Total mean S/N(dB)	Delta (Δ)
Tensile shear strengths (MPa)	A	Electrode force	kN	25,85	25,93*	25,93*	25,90	0,08
	B	Welding current	kA	25,86	25,77	26,09*		0,32
	C	Welding time	cycle	25,64	25,93	26,14*		0,50
Equal sheet thickness (1.5 mm-1.5mm)								

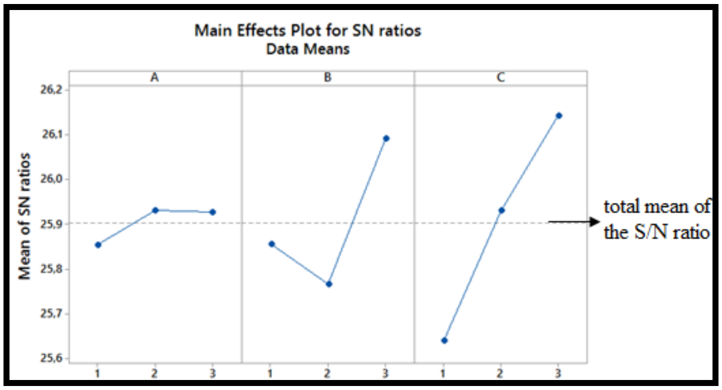

Figure 1. Graphs of S/N ratios with levels A (electrode force), B (welding current) and C (welding time).

Table 4 and Fig. 1 show the S / N ratios of the tensile shear strengths of welds for different welding parameters. As shown in Table 4, the (*) marked S / N ratio values are obtained for the maximum tensile shear strengths. As a result, the maximum S/N ratio values are obtained as A2B3C3 and A3B3C3 for the DP600-TRIP800 spot weldment in same thickness (1.5mm - 1.5mm sheet thickness). This means the maximum value of tensile shear strengths were obtained for 5 kN and 6kN electrode force, 9kA welding current and 25 cycle welding time. Fig. 1 shows the S/N ratio graph where the centre dote line is the value of the total mean of the S/N ratio. It can be seen from Fig. 1, the tensile shear strength value increases as the electrode force (kN) is increased from A1 to A2 (4kN to 5kN). The tensile shear strength value was not affected after a certain electrode force value (for A3, 6kN). It could be high heat generation and splashing higher amount of the molten metal from the weld nugget that reduces the weld area. On the other hand, the electrode indentation depth also increases. From the Fig. 1B, no significant relation is observed for weldments for the weld time with factor of B. From Fig. 1C, with increase in welding time from C1 to C3, the tensile shear strength increases. The tensile shear strength reaches the maximum values at maximum welding current with factor of B3 and maximum welding time with factor C3.

3.2. ANOVA results

Table 5 shows the results of the analysis of variance (ANOVA) for tensile shear strength of welded samples. This table also shows the degree of freedom (DF), the sum of squares (SS), the mean square (MS), the F-values (F), the probability (P) and the percentage-contribution ratio (PCR) of each factor. The F-ratios and their PCR were taken into consideration to identify the significance levels of the variables. The PRC of each factor and the residual error was shown in the Fig. 2.

Table 5. ANOVA results for S/N ratios

Thickness	Source	DF	Seq SS	Adj MS	F	P	PCR
(1.5mm-1.5mm)	A	2	0,05896	0,02948	0,27	0,789	1,9
	B	2	0,86222	0,43111	3,92	0,203	27,77
	C	2	1,96329	0,98164	8,92	0,101	63,25
	Residual Error	2	0,22002	0,11001			7,08
	Total	8	3,10449				100

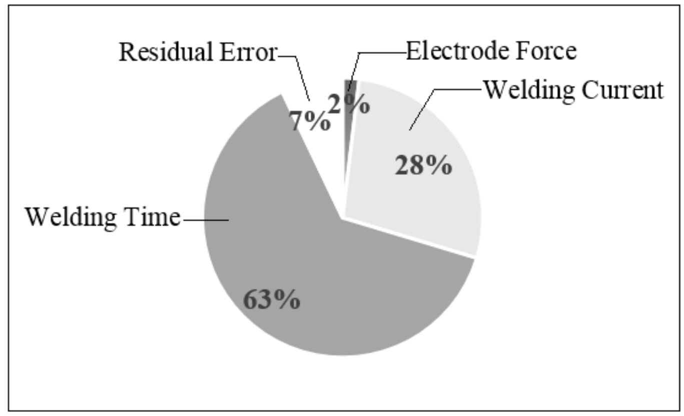

Figure 2. Percentage contribution ratio (PCR) of welding parameters

Table 5 and Figure 2 show that the most effective variable for the tensile shear strength value is the welding time with the PCR of 63%. The other variables have an effect on the tensile shear strength of the welding current with a PCR of 28% and the electrode force of a PCR of 2%. The electrode has not had a significant effect of the tensile shear strength.

3.3 Confirmation tests results

Confirmation tests were made at the optimum factor levels for welding parameters including welding force, welding current and welding time. These parameters give the optimum results by Taguchi method. The confirmation test and the experimental results of tensile shear strength and S/N ratio values are given in Table 6.

Table 6. Comparison between predicted test results and experimental test value

	Optimum parameters		Differences
	Predicted 1	Experimental 1	
Level	A2B3C3	A2B3C3	
Tensile shear strength (kN)	20,7611	20,47	0,2911
S/N Ratio (dB)	26,3569	26,2224	0,1345
	Predicted 2	Experimental 2	
Level	A3B3C3	A3B3C3	
Tensile shear strength (kN)	20,7644	20,47	0,2944
S/N ratio (dB)	26,3519	26,2224	0,1295

Table 6 gives a comparison of the results of the confirmation tests conducted according to the optimum levels of the variables with Taguchi analysis program and the experimental tensile shear test value. As shown in Table 6, there is a small difference of 0,2911 kN tensile shear strength and 0,1345 dB for A2B3C3 (5 kN electrode force, 9 kA welding current and 25 cycle welding time). Similarly, there is also a slight difference of 0,2944 kN and 0,1295 dB for A3B3C (6 kN electrode force, 9 kA welding current and 25 cycle welding time).

4 CONCLUSIONS

In this study, the welding parameters for the optimum tensile shear strength of the welded spot welded TRIP800-DP600 steel sheets in equal thicknesses were optimized with the Taguchi method. The results obtained from this study are presented below:

- The most significant welding parameters for tensile shear strength were found in the welding time with a PCR of 63%.

- The optimum levels of the welding parameters for optimizing the tensile shear strength and S/N ratios were determined. The optimum welding parameters for the acceptable tensile shear strengths were obtained with 5kN electrode force, 9kA welding current and 25cycle welding time (A2B3C3) and 6kN electrode force, 9kA welding current and 25 cycle welding time (A3B3C3).

- Confirmation tests and experimental tests were carried out for optimum welding parameters. According to the confirmation test results, the measured tensile shear strength values were changed 0,2911kN and 0,2944kN as compare to the experimental test results. This result indicates that the optimal test results for the optimum welding parameters are very close to the predicted values of the Taguchi method.

- The welding time is the most important welding parameter for the acceptable tensile shear strength. The welding current is the second significant effect on the strength. However, the electrode strength was found to have little effect.

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REFERENCES

[1] Sawhill, J.M., Jr., and Baker, J.C., ‘‘Spot Weldability of High-Strength Sheet Steel,’’ Welding Journal 59(1): 19s–30s (1980).

[2] H.-L. Lin, T. Chou, and C.-P. Chou, “Optimization of Resistance Spot Welding Process Using Taguchi Method And A Neural Network” September/October 2007 Experimental Techniques 30-36.

[3] Cary, H.B., Modern Welding Technology, 3rd ed., Prentice Hall, Upper Saddle River, NJ (1994).

[4] Han, Z., Indacochea, J.E., Chen, C.H., and Bhat, S., ‘‘Weld Nugget Development and Integrity in Resistance Spot Welding of High-Strength Cold-Rolled Sheet Steels,’’ Welding Journal 72(5):209s (1993).

[5] Williams, N.T.; Parker, J.D. Review of resistance spot welding of steel sheets-Part 2 Factors influencing electrode life. Int. Mater. Rev. 2014, 49, 77–108.

[6] Prof. A. A. Karad, Mr. V. S. Shete, Mr. N. V. Boraste, “Optimization of Resistance Spot Welding Process Parameter by Taguchi Method”, International Journal of Engineering Research and General Science Volume 4, Issue 2, March-April, 2016 ISSN 2091-2730, pp.679-684.

[7] Tumuluru M, “Resistance spot weld performance and weld failure modes for dual phase and TRIP steels”. Failure Mechanisms of Advanced Welding Processes A, In: Woodhead Publishing Series in Welding and Other Joining Technologies, Edited by: X. Sun, ISBN: 978-1-84569-536-1, pp 43–64, (2010).

[8] Pouranvari, M, “Analysis of Fracture Mode of Galvanized Low Carbon Steel Resistance Spot Welds”, International Journal of Multidisciplinary Sciences and Engineering,2:6:36-40, 2011.

[9] Ertek Emre H., Kaçar R, “Development of weld lobe for resistance spot welded TRIP800 steel and evaluation of fracture mode of its weldment” The International Journal of Advanced Manufacturing Technology, 83, Issue 9–12, pp 1737–1747, 2016.

[10] Mr. Niranjan Kumar Singh, Dr. Y. Vijayakumar, “Application of Taguchi method for optimization of resistance spot welding of austenitic stainless steel AISI 301L” Innovative Systems Design and Engineering www.iiste.org ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online) Vol 3, No 10, 2012 pp.50-62.

[11] Norasiah Muhammad, Yupiter HP Manurung, Mohammad Hafidzi, Sunhaji Kiyai Abas, Ghalib Tham and Esa Haruman, “Optimization and modeling of spot welding parameters with simultaneous multiple response consideration using multi-objective Taguchi method and RSM”, Journal of Mechanical Science and Technology, 2012, Volume 26, Issue 8, pp 2365–2370.

[12] M. Boy, İ. Ciftci, M. Günay, F. Ozhan, “Application of the Taguchi method optimize the cutting conditions in hard turning of a ring bore”, Materials and technology, 49(5), 765–772, (2015).

[13] M. Günay, E. Yücel, “Application of Taguchi method for determining optimum surface roughness in turning of high-alloy white cast iron”, Measurement, 46: 913–919 (2013).

[14] H. Eisazadeh, M. Hamedi, “New parametric study of nugget size in resistance spot welding process using finite element method”, Material and design ,Vol.31, pp149-157, 2010.

[15] A.G. Thanur, V.M. Nandedkar, “Application of Taguchi method to determine resistance spot welding conductions of austenitic stainless AISI 304”, Journal of scientific & Industrial research, 69 (2010) pp. 680-68.

[16] J.S. Kwak, “Application of taguchi and response surface methodologies for geometric in surface grinding process”, International Journal of Machine Tools & Manufacture, 45 (2005), 327-334.

[17] Srinivas Athreya, Y.D.Venkatesh, “Application Of Taguchi Method For Optimization Of Process Parameters In Improving”, The Surface Roughness Of Lathe Facing Operation International Refereed Journal of Engineering and

Science (IRJES), ISSN (Online) 2319-183X, (Print) 2319-1821,Volume 1, Issue 3 (November 2012), PP.13-19.