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Experimental Investigation of the Effect of Spot-Welding Process Parameters on the Tensile Strength of Similar Metal Joints

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Abstract – *Resistance spot welding is commonly used in the automotive industry due to the advantage of high-speed, the high-production assembly lines, and the suitability for automation. The spot-welded joints are usually exposed to shear and tensile loads during the services, and hence these service conditions lead to the rupture of the welded joint. In this study, the effect of welding process parameters on the ultimate tensile strength and micro hardness of the AISI 304 stainless steel resistance spot welded joints are studied. Three welding parameters with three levels are used in the experimental work as welding power (current), sheet thickness, and welding time. Resistance spot welding quality mainly depends on the welding parameters. Therefore, the selection of optimal parameter levels plays an important role in the quality of the welded joints. In this research work, Surface Response Method (SRM) has been used to determine significant process parameters and their levels for optimal ultimate tensile strength and micro hardness reported and nugget diameter. SRM based L15 orthogonal array is selected for experimentation. Experiments are carried out on austenitic stainless-steel grade AISI304. The level of importance of the welding parameters on the tensile strength and micro hardness is determined by analysis of variance (ANOVA) using Minitab 17 software. The tensile test, microstructure, and Vickers hardness test have been used to evaluate the welded joints. The main findings of this study have eben that the tensile strength decreases with increasing the welding current or welding time or both, whereas the MHV increases slightly with increasing of both the thickness and on-time duration. Furthermore, nugget diameter increases with increasing the welding time.*

***Keywords**: Resistance Spot Welding, Response Surface Method, ANOVA*

I. Introduction

Resistance Spot Welding (RSW) process is commonly used in the fabrication and assembling of sheet metal, due to its advantages in welding efficiency and suitability for automation. For instance, approximately, the body of modern car needs from 7000 to 12000 spots depending on the car size [1].

Tseng [2] has discussed about based optimization method where the optimum welding condition has been created by lowering the cost of welding symbolized by consumption of power. It has been derived from the welding current, the welding pressure, and the welding time for performing favored quality of welding. Kim et al. [3] have discussed the development of response surface method in order to optimize the RSW parameters such as welding current, welding time, and forging force as input variables. In their work, the shear strength has been maximized as an objective function. A. K. Pandey et al. [4] have used the Taguchi method to optimize the RSW parameters like different pressure, welding current and welding time used to join 0.9 mm cold rolled low carbon steel. The results of Taguchi have indicated that the medium values of current, pressure and large holding time are optimum values to achieve weld joint with high quality. N. Muhammad et al. [5] have optimized and modelled the parameters of resistance spot welding with simultaneously multi-response consideration using multi-objective Taguchi method and RSM, where the experimental study has been conducted for sheet thickness of 1.5 mm from low carbon steel under different welding current, weld time and hold time. The result has showed the advanced linear RSM for expectation diameter of the weld nugget and HAZ width has been found good fitted. N. Charde and R. Rajkumar [6] have investigated RSW of AISI304. This study has been focused on the effect of welding current on the growth of nugget diameter and microhardness distribution through the welding region. The results have showed that the variation in the welding current leads to a variation in nugget growth. In other words, the increase in the welding current tends to increase the nugget diameter, but it does not affect the distribution of hardness. K. Rasheed and M. I. Khan [7] have studied the advanced comparative of responses of RSW method attained from three methodologies of genetic algorithm, design of experiments and response surface method, where the mild steel has been used in this experiment.

The mathematical model has been presented by using regression analysis and ANOVA method. The result has showed that the welding time and the current of welding are extremely effective parameters for welding to attain maximum growth of nugget diameter and strength of weld. Both these factors should be at medium magnitudes. H. Khatib et al. have analyzed the fatigue strength of weld joints in the volume of weld bead. The results have showed the fatigue life affected by damage progression [8]. E. A. Gyasi et al. have investigated the ability of using S960QS UHSS as weldable material for structure constructions by adaptive and monitoring the current, voltage and heat input. The results have showed the good weld penetration and weld shape of the influences by joint geometry [9]. A. Vartak and N. N. Raut have investigated numerically the FSSW by using FEM. The results have showed that the FEM has good potential with coupled Eulerian-Lagrangian [10]. C. Vimalraj et al. have studied the dissimilar joining of AA 5083-H111 to AA6082 with AA5183 and AA5356 filler by using constant and pulsed current gas metal arc welding processes. The porosity and the lack of fusion have been showed in microstructure test. The hardness of joints in weld region has been similar for both filler wires of gas metal arc welding process variants [11]. V. S. Tynchenko et al. have carried out the intelligent control such fuzzy logic, artificial neural networks and a neuro-fuzzy controller for induction soldering technological process. The results have showed highest efficiency control when using artificial neural networks to weld thin-walled aluminum [12]. A. M. El-Kassas et al. have investigated the weld quality with current, nature of vertical welding and torque in friction stir welding of Aluminum 6061pipe. The experimentation has showed an increase in the penetration depth when the torque and power increase [13]. R. S. Tabar et al. have built the surrogate models of individual assemblies by using a neural network approach. The geometrical deviation and the spot-welding sequence have been used for building the surrogate model. The results have showed that the evaluation time is reduced compared to the genetic algorithm [14]. M. Multanto and S. Sulardjaka have studied the mechanical properties friction stir welding with PolyTetraFluoroEthylene for ASTM D638 and D6110 standard. The results have showed an increase in impact strength and tensile at a speed of 20 mm/min [15].

N. A. Rosli et al. have studied the effect of the gas metal arc welding, gas tungsten arc welding and plasma arc welding with 3D printer. These parameters have been used with Wire and Arc Additive Manufacturing (WAAW) in order to melt the welding wire by controlling the stand-off distance, current and speed. The layer-by-layer deposition has showed that WAAW is a good 3D structure [16]. I. Sabry et al. have investigated the underwater friction stir welding for AA 6063 pipe joints. The high tensile strength and the high hardness have been obtained when using underwater friction stir than the traditional process [17]. S. Hu et al. have studied the microstructure, the coach peel performance, and the defect distribution for the joint of aluminum alloys, AA5754-0 and AA602-T4 by using Multi-Ring Domed electrode. The improved mechanical performance with large nuggets has been obtained when using AA6022 than smaller 5754 nuggets [18]. R. Suryanarayanan and V. G. Sridhar have studied the drawback of keyhole in friction stir spot welding of Al 5754 and Al6061 alloys by optimizing many parameters such as the tool rotational and plunging speed, plunge depth, and shoulder diameter and dwell time with using response surface methodology.

The results have showed that the joint strength is affected by the crucial factor more than other shoulder diameter shape [19]. Z. Wen and W. Qing have investigated the different values of current in spot welding with steel (DP590) and aluminum (Al6061) welding joint. The results have showed the nugget diameter when the current increases [20]. Tabar, R. S. et al. have proposed the method for inspection fixture of springback calculation during the sequence evaluation, where the significant correlation is showed with the proposed method of evaluation of weld relative displacements [21]. Dong H. et al. have studied and improved the hybrid joints of carbon fiber reinforced polyether ether ketone composites and the aluminum alloy (AA5052) by friction stir spot welding [22]. Wang X. et al. have welded low carbon plates with adjustable tools of flat friction stir spot welding in order to obtain welded joints better than the conventional flat friction stir spot welding [23]. Ungureanu V. et al. have investigated the comparison between the self-drilling screw and the new technical method for the joints with spot welding of lightweight cold-formed steel beams, and the results have been that the new technical method has increased mass production of these joints [24]. Das T. et al. have studied resistance of the joints with the effect of multi-walled carbon nanotubes where the results have showed that the strength of welded joint has been improved about 45% than conventional spot-welding [25]. In this study, the tensile strength and the hardness of the spot welded joint (for AISI304 stainless steel) will be studied through controlling the input process parameters as welding power (current), sheet thickness and welding time.

This paper is organized through the subsequent sections. Section II illustrates the materials and the experimental procedures used in this study. Section III presents the mechanical tests for determining the mechanical properties such as microstructure examination and micro hardness test. Section IV presents the results of tensile test of base metal, experimental works, AVOVA experiments test and microstructures examination. Section V reports the key conclusion of this study.

II. Materials and Experimental Procedures

The 304 stainless steel has been selected in this work.

The chemical analysis, and the mechanical properties of 304 stainless-steel are shown in Table I and Table II respectively.

TABLE I
CHEMICAL COMPOSITION 304 STAINLESS STEELS

Material	Element %								
Steel	C	Si	Mn	Cr	Ni	S	Cu	P	Bi
AISI304	0.07	0.7	1.95	17	9.7	--	--	0.035	--

TABLE II
MECHANICAL PROPERTIES OF AISI 304

Property	AISI304
Ultimate tensile strength (UTS)	505 MPa
0.2%Yield strength	215 MPa
Young modulus E	193-200 GPa
Poisson Ratio	0.29
Brinell hardness number (HB)	123
Vickers hardness number (HV)	129
G	86 GPa
Elongation	70%

The weld joint design used in this study is shown in Fig. 1. Three sheets with thicknesses of 0.5, 1 and 1.5 mm from 304 St-steel have been used in the workpiece preparation step. This step consists of three stages. Firstly, cutting the three type sheet metals into a small rectangular piece with dimensions 190 × 30 × 0.5, 190 × 30 × 1 and 190 × 30 × 1.5 mm. The second stage is the preparation of the welding samples as filling the cutting edge and surface represent to the increase the contact surfaces also, decreasing the porosity and inclusions in the weld nugget. The third stage is cleaning and levelling the weld pieces the edges of these piece drills to form supported whole with 8 mm diameter. The resistance spot welding machine (DN1-25 kVA) has been used in this study; its specifications are shown in Table III. The welding has been conducted using an electrode of 45° truncated cone with a face diameter of 5 mm. The DN1 series spot machine is designed and manufactured according to the standard B/T10101-2000.

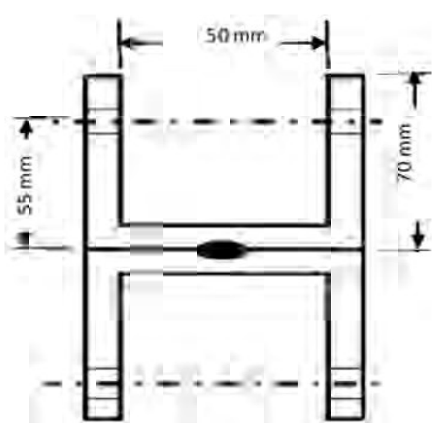


Fig. 1. Sketches illustrate the weld joint design

TABLE III
THE SPECIFICATIONS OF THE SPOT-WELDING MACHINE

Item	Specifications
Manufacturer	NASHA co., CHINA
Model	DN1-25
Transformer.	25 kVA
Power Supply	(220-380) VAC50/60 Hz
Electrode Face Diameter	5 mm
Max. Thickness (HV)	6 mm
Welding time	0–2 s

The welding parameters have been used in the different experiments for joining AISI-304 as shown in Table IV, where, the constant electrode force has been applied to produce a joint of 1kN. Electrode tip diameter has been fixed for all the experiment. In addition, squeeze time has been fixed about 50 cycles for all the welding samples.

III. Mechanical Tests

Many tests have been conducted to determine the mechanical properties and the welding quality of spot-welding joints. For determining the tensile strength of the base metal, three samples have been prepared from the raw material according to ASTM E8 – standard. Quasar 25 Advancing Universal Testing Machine has been used to determine the strength of the experiment specimens.

III.1. Microstructure Examination

The preparation of the metallographic samples has been achieved according to the standard of the metallographic procedures which consist in cutting the samples, mounting in the die contain epoxy to facilitate catching, using single disc grinding machine with speed of 250-300 rpm and different grit size of sandpaper starting from 400, 600, 800, 1000, 1500, 2000 and 2500 for 6 min each to ground the samples. After grinding process, samples have been washed by acetone and water then fine cloth disc and 1-micron diamond paste used to polish the grounded surfaces. Preparation surfaces be dried by warm air and etching process have conducted by wiped the with fresh reagent (50 ml of distillate water + 150 ml HCl + 25 g Cr_2O_3) then washed by water and acetone and dried by warm air. After that, the sample has been examined by an optical microscope in order to evaluate the microstructure of the welding zone.

III.2. Micro Hardness Test

Vickers microhardness (HV) method has been used to measure the hardness of the weld joint at 9.8 N and holds for 10 seconds.

TABLE IV
WELDING PARAMETERS OF EXPERIMENTAL WORK

Exp. No.	Power in *I* (kVA)	Thickness *T* (mm)	Welding time *D* (s)
1	6	0.5	1
2	4	1.5	0.6
3	4	1	1
4	2	1	0.6
5	6	1.5	1
6	4	1	1
7	2	0.5	1
8	4	1	1
9	6	1	1.4
10	4	1.5	1.4
11	6	1	0.6
12	4	0.5	0.6
13	4	0.5	1.4
14	2	1	1.4
15	2	1.5	1

The value of hardness has been averaged of three readings in different places of the nugget for all the samples except the one that has recorded maximum and minimum ultimate tensile strength. These samples have been tested from the centre of the weld and they continue in the step equal to 1 mm.

IV. Results and Discussions

In this work, the Minitab program (Minitab 17) has been used for the design of experiment (DOE). The SRM Taguchi method has been used with three input factors and three responses have been used with response surface, which have been analysed using Taguchi method.

The tensile test and fifteen experiments with different parameters have been performed by Design of Experiment (DOE) and the Surface Response in Minitab statistical program.

IV.1. Tensile Test Results of Base Metal

Three standard samples from each 304 stainless have been prepared from base material plates according to the ASTM E8-04 for the tensile test using UTM machine.

Table V represents the ultimate tensile strength results and the average of the results to obtain the ultimate strength.

The test sample preparation causes differences between the practical and the standard results.

IV.2. Experimental Works

This study includes fifteen experiments with different parameters offered by Design of Experiment (DOE) and the Surface Response in Minitab statistical program.

In this research work, three different input parameters are welding current, sheet thickness, and one-time duration and three output parameters are microhardness (MHV) for center of Fusion Zone (FZ), Nugget Diameter (ND), and Ultimate Tensile Strength (UTS). Depending on Minitab works sheet, the experiments done for the outputs UTS, ND, and MHV and the resulting data are arranged in works sheet as shown in Table VI.

IV.3. ANOVA Experiments Test

IV.3.1. Effects Spot Welding Input Parameters on UTS

The interaction plot for welding current and the sheet thickness (*T*) shows a stable decreasing of tensile strength with the increasing of pulsing current as shown in Fig. 2.

This means that UTS increases with the increasing of thickness.

TABLE V
ULTIMATE TENSILE STRENGTH OF AISI304

Material	Sample 1	Sample2	Sample 3	Average
AISI304	490.864	495.8	500.078	495.58

TABLE VI
L15 CONTROL PARAMETERS WITH LEVEL VALUES AND THE RESPONSES

Std. Order	Input Parameters *I* (kVA)	*T* (mm)	*D* (s)	*ND* (mm)	Responses F_{max} (N)	MHV
2	6	0.5	1	4.10	2339.90	178.4
10	4	1.5	0.6	1.90	3831.31	188.7
15	4	1	1	2.80	2974.50	571.9
5	2	1	0.6	1.95	2519.81	162.6
4	6	1.5	1	2.70	3986.91	195.7
14	4	1	1	2.75	2763.41	571.9
1	2	0.5	1	2.45	2420.61	151.12
13	4	1	1	2.40	2615.51	571.9
8	6	1	1.4	3.95	2948.31	185
12	4	1.5	1.4	3.40	5944.81	200.4
6	6	1	0.6	3.70	1889.51	160
9	4	0.5	0.6	2.65	2062.62	195.8
11	4	0.5	1.4	4.30	1125.60	182.7
7	2	1	1.4	3.00	2517.51	194.9
3	2	1.5	1	1.95	3548.91	151.5

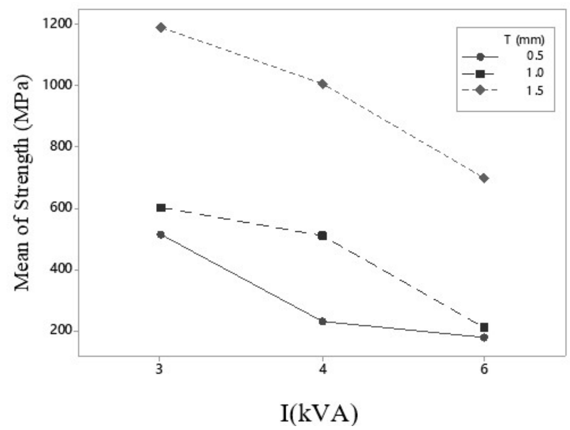


Fig. 2. Interaction plot of UTS versus I

On the other hand, the welding duration (*D*) in the interaction plot for *D* and *T* shows that the UTS drops steeply with increasing of welding duration, that means the longer current time has been more efficient because high heat input enters the weld zone as shown in Fig. 3.

Fig. 4 shows the main effects for tensile strength versus process parameters. The results show that the strength of the welded joints is affected significantly with sheet thickness (*T*).

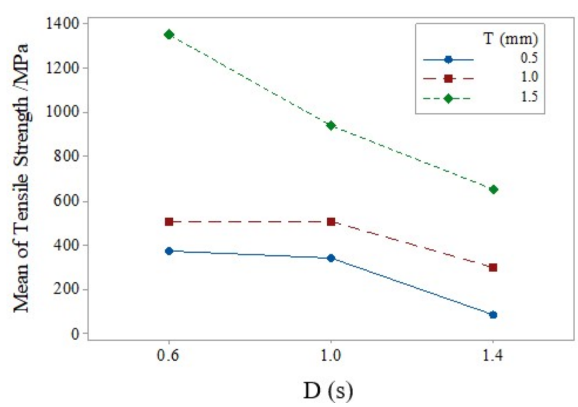


Fig. 3. Interaction plot of UTS versus welding time (D)

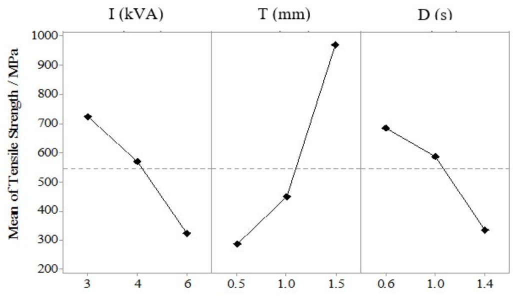


Fig. 4. Tensile strength versus process parameters

IV.3.2. Effect Spot Welding Input Parameters on ND

Fig. 5 shows the stable increasing of Nugget Diameter (*ND*) with the increasing of welding time for all the sheet thicknesses. The *ND* increases with the increasing of welding current as shown in Fig. 6. That means that the high on-time duration (*D*) in the main effects plot for ND shows higher *ND* than low *D* in the main effects plot for *ND*. It is known that the decreasing in *D* leads to decreasing in heat input and hence the resulted size of the nugget becomes small.

IV.3.3. Effect Spot Welding Input Parameters on MHV

Fig. 7 shows the main effects of process parameters. It can be noticed that the highest hardness has been achieved at current value of 4 kVA. From other sides, the MHV has increased slightly with increasing both the thickness of the plate and the on-time duration.

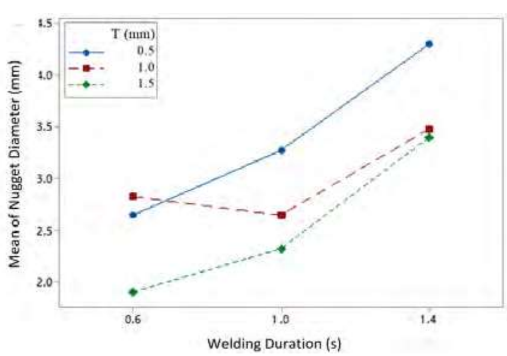


Fig. 5. Interaction plot of D versus welding duration

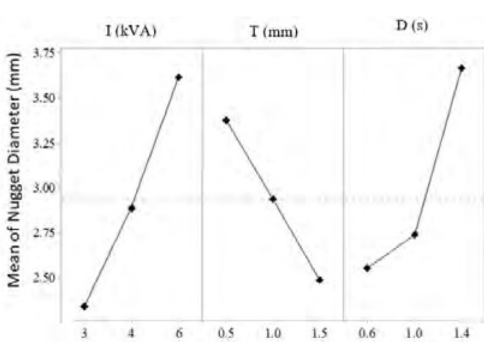


Fig. 6. Nugget diameter versus process parameters

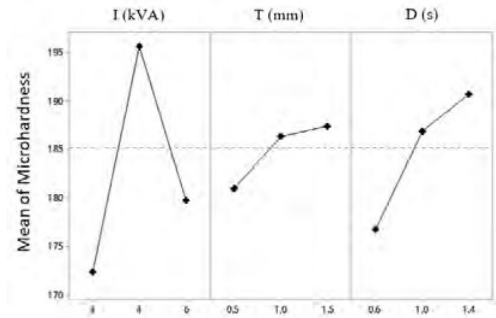


Fig. 7. MHV versus process parameters

The MHV has increased with the increases of sheet thickness as shown in Fig. 8. In the same way, the MHV has increased with the increases of welding time as shown in Fig. 9.

IV.4. Microstructures Examination Results

Figs. 10 illustrate the different metallurgical zones of the high tensile strength specimen. These zones have been equated region represented by the fine grains its lay in the centre of weld nugget as shown in Fig. 10(a). The adjacent zone is the longitudinal grain region, which has grown basically from the base metal toward the fusion zone as shown in Fig. 10(b), and the third zone represents the Heat Affected Zone (HAZ), which displays grain growth more than the base metal as shown in Fig. 10(c).

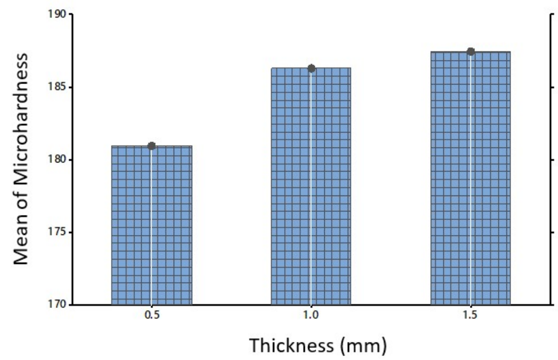


Fig. 8. Relation between MHV and thickness

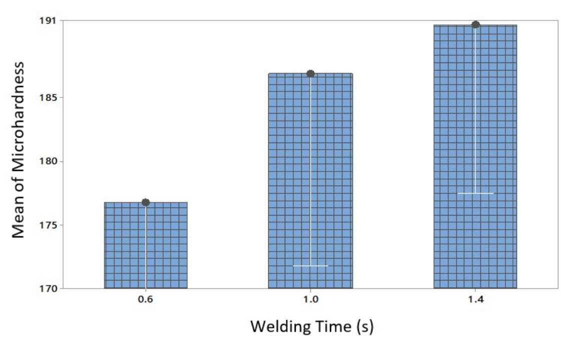
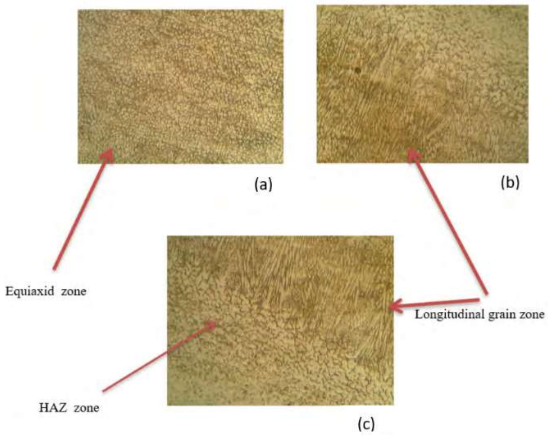


Fig. 9. Relation between MHV and welding time



Figs. 10. Microphotographs of the different metallurgical zones

V. Conclusion

The spot-welded joints usually during the services expose to mechanical stresses as shear and tensile loads lead to the rupture of the welded joint. The effect of welding process parameters on the ultimate tensile strength and micro hardness of the AISI 304 stainless steel resistance spot welded joints are investigated in this study as the welding power (current), the sheet thickness, and the welding time with three levels, where the resistance spot welding quality mainly depends on the welding parameters. The significant process parameters and their levels for optimal ultimate tensile strength and micro hardness reported and nugget diameter have been determined by using SRM. SRM based L15 orthogonal array is selected for experimentation the austenitic stainless-steel grade AISI304. The results have showed that the tensile strength decreases with increasing the welding current or welding time or both. Furthermore, the nugget diameter increases with increasing the welding time, whereas the MHV increases slightly with increasing of both the thickness and on-time duration.

From the finding of this work, it can be recommended to use dissimilar stainless steel materials or investigate the austenitic stainless-steel grade AISI304H and AISI304L for further impovements.

References

[1] Yuh J. Chao, Ultimate Strength and Failure Mechanism of Resistance Spot-weld Subjected to Tensile, Shear, or Combined Tensile/Shear Loads, *Journal of Engineering Materials and Technology,* Vol. 125, n. 2, pp. 124-132, 2003.

[2] H. Y. Tseng, Welding parameters optimization for economic design using neural approximation and genetic algorithm, *International Journal of Advanced Manufacturing Technology,* Vol. 27, n. 1, pp. 897-901, 2006.

[3] Kim, T., Park, H., and Rhee, S., Optimization of Welding Parameters for Resistance Spot Welding of TRIP Steel with Response Surface Methodology, *International Journal of Production Research,* Vol. 43, n. 21, pp. 4643-4657, 2007.

[4] A.K. Pandey, M. I. Khan, K. M. Moeed, Optimization of Resistance Spot Welding Parameters Using Taguchi Method, *International Journal of Engineering Science and Technology,* Vol. 5, n. 2, pp. 234-241, 2007.

[5] N. Muhammad, Y. Manurung, M. Hafidzi, S. K. Abas, G. Tham and E. Haruman, Optimization and Modelling of Spot-Welding Parameters with Simultaneous Multiple Response Consideration Using Multi-Objective Taguchi Method And RSM, *Journal of Mechanical Science and Technology,* Vol. 26, n. 8, pp. 2365-2370, 2012.

[6] Nachimani Charde and Rajprasaad Rajkumar, Investigating Spot Welding Growth on 304 Austenitic Stainless Steel (2mm) Sheets, *Journal of Engineering Science and Technology,* Vol. 8, n. 1, pp. 69-76, 2013.

[7] K. Rasheed and M.I. Khan, A Review on Different Optimization Techniques Used to Optimize the Process Parameters of Resistance Spot Welding, *International Journal of Engineering Technology, Management and Applied Sciences,* Vol. 2, n. 5, pp. 65-72, 2014.

[8] Khatib, H., Mansouri, K., Salhi, B., Yeznasni, A., Hachim, A., Effect of Notch and Residual Stresses on the Fatigue Strength of the Weld Joints - Local Approach Analysis, (2017) *International Review of Mechanical Engineering (IREME)*, 11 (8), pp. 602-612. doi: https://doi.org/10.15866/ireme.v11i8.11689

[9] Gyasi, E., Kah, P., Handroos, H., Layus, P., Lin, S., Adaptive Welding of S960QC UHSS for Arctic Structural Applications, (2018) *International Review of Mechanical Engineering (IREME)*, 12 (4), pp. 371-381. doi: https://doi.org/10.15866/ireme.v12i4.14991

[10] A. Vartak and N. N. Raut, Numerical Analysis of Friction Stir Spot Welding (FSSW) Using ABAQUS, *International Journal of Research and Analytical Reviews,* Vol.6. n 2, pp. 710-717, 2019.

[11] Vimalraj, C., Kah, P., Mvola Belinga, E., Layus, P., Eskelinen, H., Investigation on Microstructure and Mechanical Properties of Gas Metal Arc Welded Dissimilar Aluminium Alloys, (2019) *International Review of Mechanical Engineering (IREME)*, 13 (2), pp. 126-132. doi: https://doi.org/10.15866/ireme.v13i2.15829

[12] Tynchenko, V., Milov, A., Tynchenko, V., Bukhtoyarov, V., Kukartsev, V., Intellectualizing the Process of Waveguide Tracks Induction Soldering for Spacecrafts, (2019) *International Review of Aerospace Engineering (IREASE)*, 12 (6), pp. 280-289. doi: https://doi.org/10.15866/irease.v12i6.16910

[13] El-Kassas, A., Sabry, I., Mourad, A., Thekkuden, D., Characteristics of Potential Sources - Vertical Force, Torque and Current on Penetration Depth for Quality Assessment in Friction Stir Welding of AA 6061 Pipes, (2019) *International Review of Aerospace Engineering (IREASE)*, 12 (4), pp. 195-204. doi: https://doi.org/10.15866/irease.v12i4.16362

[14] R. S. Tabar, Kristina Warmefjord and R. Soderberg, A New Surrogate Model-Based Method for Individualized Spot-Welding Sequence Optimization with Respect to Geometrical Quality, *The International Journal of Advanced Manufacturing Technology,* Vol. 106, n. 4, pp. 2333-2346, 2020.

[15] Mulyanto, M., Sulardjaka, S., Mechanical Properties of Friction Stir Welding Joining of PolyTetraFluoroEthylene, (2020) *International Review of Mechanical Engineering (IREME)*, 14 (4), pp. 253-257. doi: https://doi.org/10.15866/ireme.v14i4.18037

[16] Rosli, N., Alkahari, M., Ramli, F., Sudin, M., Maidin, S., Single Layer Formation of Plasma Based Wire Arc Additive Manufacturing, (2020) *International Journal on Engineering Applications (IREA)*, 8 (3), pp. 89-95. doi: https://doi.org/10.15866/irea.v8i3.17953

[17] Sabry, I., Mourad, A., Thekkuden, D., Comparison of Mechanical Characteristics of Conventional and Underwater Friction Stir Welding of AA 6063 Pipe Joints, (2020) *International Review of Mechanical Engineering (IREME)*, 14 (1), pp. 64-70. doi: https://doi.org/10.15866/ireme.v14i1.17483

[18] S.HU, A. S. Haselhuhn, Y.Ma, Y.Li, B. E. Carlson and Z. Lin, Comparison of the Resistance Spot Weldability of AA5754 and AA6022 Aluminum to Steels, *Welding Journal,* Vol. 99, n. 4, pp. 2333-2346, August 2020.

[19] R. Suryanarayanan and V.G. Sridhar, Effect of Process Parameters in Pinless Friction Stir Spot Welding of Al 5754-Al 60661 Alloys. *Metallography, Microstructure, and Analysis Journal,* Vol. 9, pp. 261-272, 2020.

[20] Z. Wen and W. Qing, Effect of Welding Current on the Morphology and Properties of Steel-Aluminum Dissimilar Metal Spot Welding Joint, *Design Engineering Journal,* Vol.2, pp. 380-387, 2020.

[21] Tabar, R.S., Lorin, S., Cromvik, C., Lindkvist, L., Wärmefjord, K. and Soderberg, R., Efficient spot welding sequence simulation in compliant variation simulation, *Journal of Manufacturing Science and Engineering,* Vol. 143, n. 7, pp. 1-12, 2021.

[22] Dong, Honggang, Zuyang Tang, Peng Li, Baosheng Wu, Xiaohu Hao, and Chaoqun Ma., Friction stir spot welding of 5052 aluminum alloy to carbon fiber reinforced polyether ether ketone composites, *Materials & Design,* Vol. 201, pp. 109495, 2021.

[23] Wang, X., Morisada, Y. and Fujii, H., Flat friction stir spot welding of low carbon steel by double side adjustable tools, *Journal of Materials Science & Technology,* Vol. 66, pp. 1-9, 2021.

[24] Ungureanu, V., Both, I., Burca, M., Radu, B., Neagu, C. and Dubina, D., Experimental and numerical investigations on built-up cold-formed steel beams using resistance spot welding, *Thin-Walled Structures,* Vol. 161, pp. 107456, 2021.

[25] Das, T., Rawal, S., Panda, S.K. and Paul, J Resistance spot-welding of AISI-1008 steel joints with MWCNT coating interlayer, *Materials and Manufacturing Processes,* Vol. 36, n. 4, pp. 448-456, 2021.

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