The Effects of Resistance Spot Welding Parameters on the Mechanical Behavior of Stainless Steel

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ABSTRACT

The resistance spot welding process is a promising method for welding thin sheets of similar and dissimilar materials, principally stainless steel. Resistance spot welding is ensured using the combined effect of mechanical pressure and electric current through the thin sheets. In this experimental study, 304L stainless steel sheets were welded by resistance spot welding at various welding parameters. The welding parameters were welding effort, welding time, and welding current. Welding current varied from 10kA to 16kA, welding time varied from 10 to 13 cycles, and welding effort was fixed to 8 bars. The results showed that welding time had little effect on the mechanical properties compared to the welding current. The experimental results also showed that welding current is an important parameter for joining sheets and their mechanical strength. The external aspects of the spots were examined to determine the influence of welding parameters on the welded joints.

Keywords-RSW; welding parameters; welding current; mechanical strength; stainless steel 304L

I. INTRODUCTION

The Resistance Spot Welding (RSW) process is widely used in the manufacturing industry for joining metal sheets. Spot welding is the predominant joining process in several industries, especially in assembling automobile components. However, other products such as aerospace, furniture, and domestic equipment are joined using RSW [1]. RSW is one of the primary methods to join sheet metals on automotive components [2]. Stainless steel sheets are increasingly used in several applications due to their high corrosion resistance and good weldability [3]. The RSW process can be described by many parameters, such as time, current, and welding effort. Welding current is the most effective and common parameter to influence the welding result of a given material configuration. Welding time is important when calculating heat generation and resulting welds formation. Additionally, the force magnitude is another variable that affects the outcome of the weld.

Many RSW studies showed that the formation of nuggets in any welded material depends on the optimized combination of parameters [4-7]. Weld quality is affected by several welding parameters: current intensity, welding time, force applied by the electrodes, contact resistance, and electrode size [8]. In [7], the effect of current and weld time with constant force on nugget growth was investigated in 304 austenitic stainless steel RSW. In [9], an attempt was made to optimize the welding parameters, namely welding current and time, in the RSW of AISI 316L austenitic stainless steel sheets. The static tensile shear test is the most common laboratory test used in the determination of weld strength due to its simplicity [10]. In [11-12], the most important factor affecting the tensile shear load-bearing capacity was the size of the weld nugget, as it depended mostly on the weldin g current. The effect of welding current at constant welding time is considered in the evaluation of nugget size and tensile-shear load-bearing capacity of jointed materials. The influence of the RSW process parameters on 316 stainless steel was studied in [13]. The effects of welding parameters on the tensile shear strength of the joints were investigated in [14]. The effect of 3-9kA welding current on the structure and mechanical properties of welded joints was investigated in [5] for stainless and low-carbon steel. An increase in the tensile strength of the weld coupon was noticed when the welding current increased. Otherwise, the variation in welding current had no significant effect on the hardness value, as it mainly affected the size of the fusion zone and the heat-affected zone. In [15], the resistance of 304 stainless steel plates assembled by RSW was studied, along with the formation of nuggets under the effect of welding parameters in a DP600 dual-phase steel. In [16], the relations between nugget diameter and welding current and hardness along the welding zone of austenitic stainless steel 304 were studied. The results showed that the weld nugget increased with increasing welding current. In [17], assembled AISI-1008 steel sheets were welded by RSW, showing that the welding current was the most effective parameter controlling the weld tensile strength and the nugget diameter. In [18], weld current was the major governing factor affecting the tensile shear strength of resistance spot welded specimens in dissimilar joints formed by stainless steel 304 and galvanized steel, as it presented a high percentage compared to welding time and force. In [19-20], it was shown that using a high welding current, the material can exhibit high mechanical properties, and the tensile shear load-bearing capacity increased as the welding current increased.

This paper presents an experimental study to determine the effect of RSW parameters on tensile-shear strength of homogeneous lap joints in Stainless steel 304L with a thickness of 2mm and the geometric aspect of the welded points under the variation of welding current and time.

II. EXPERIMENTAL PROCEDURE

This study used 304L stainless steel sheets with a thickness of 2.0mm. Tables I and II show its chemical composition and mechanical properties, respectively.

TABLE I. CHEMICAL COMPOSITION OF 304L

C	Si	Mn	P	S	Cr	Ni
< 0.03	< 1.00	< 2.00	< 0.045	< 0.015	17.5-19.5	8-10

TABLE II. MECHANICAL CHARACTERISTICS OF 304L

	E (GPa)	σe (MPa)	UTS (MPa)	A%	HRB
Provider data	200	310	520-670	45	80 max
Tested specimens	190	336	655	43.2	60

Figure 1 shows the stress-strain curve of 304L stainless steel, and Figure 2 shows the shape of the specimens, which were prepared with a size of 115×20×2mm. The overlap dimension A was equal to 20mm. The spot welding machine ARO FIX TYPE MC was used to join the overlapped samples. The settings of the RSW parameters directly depend on the application and are usually determined by testing. The welding parameters used in this study were the recommended for 304L stainless steel; welding current varied from 10 to 16kA, welding time varied from 11 to 13 cycles, and the applied electrode force was equal to 8 bars with a diameter equal to 6mm.

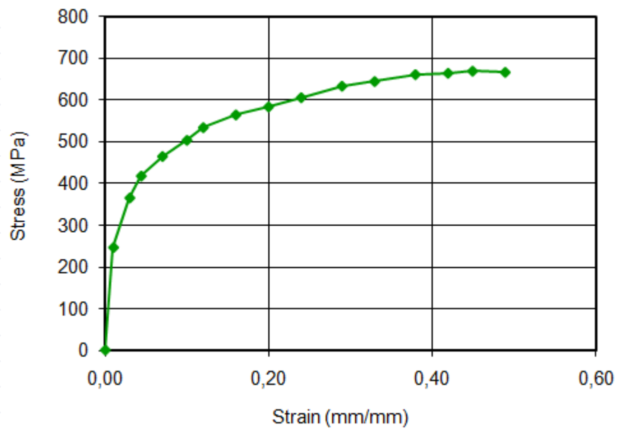

Fig. 1. Stress-Strain curve of 304L stainlees steel.

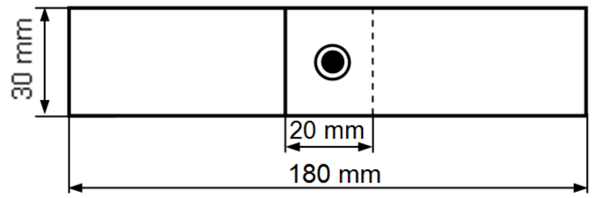

Fig. 2. Welding specimen by RSW.

III. RESULTS AND DISCUSSION

Based on tensile shear tests, this study evaluated the maximum tensile shear force value for the joint that allows a fracture to occur [21]. Moreover, the diameter's dimension and the depth of spot welded points were determined under varying welding parameters. Figure 3 shows the load versus displacement curves obtained from the tensile-shear test performed on specimens with acceptable RSW joints under varying welding currents and time. Figure 3 shows the variation of the load versus the displacement until the fracture of the welded assembly by RSW for 8 bar welding force at t=11 cycles. The increase in current intensity increased the area of plastic deformation. This figure highlights several points by type. Points A present little distorted points. At points B, rotation occurred to align the sheets in the direction of loading and necking starts. Points C show the maximum breaking loads. Points D show the maximum effort achieved when the fracture propagated across the thickness in the neck region of one of the sheets, the propagation of the fracture in the base metal, and the tear around the point of the specimen to the final fracture.

Figure 4 shows the effect of welding current and welding time on the maximum breaking load (points C) for 8 bar welding force. Welding current varied from 11 to 16kA, and the time ranged from 11 to 13 cycles. The appearance shows an increase in maximum tensile shear load bearing when increasing the welding current. Statistical tests are necessary on the fracture surfaces to better understand some interactions of welding parameters and random phenomena. In addition, the medium effect of welding time was noticed and the differences in the maximum tensile shear load-bearing for all welding currents varied from 0.18 to 2kN.

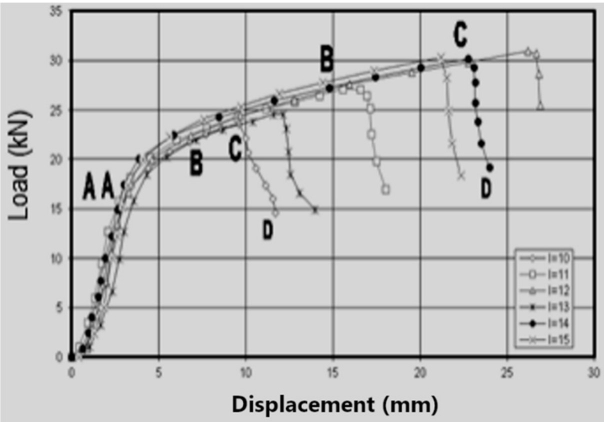

Fig. 3. Effect of welding current on the mechanical behavior of the welded assembly by RSW at 8 bar welding force and 10 cycles welding time.

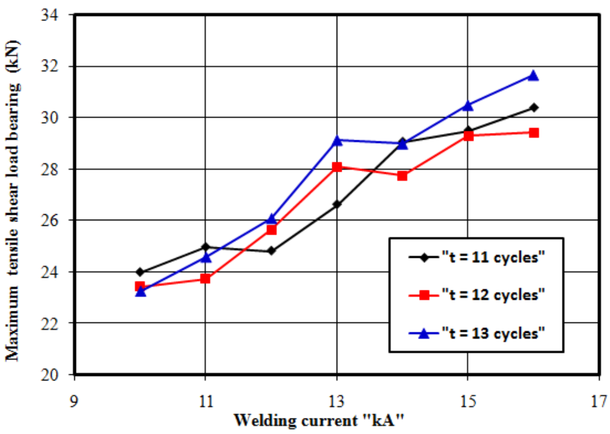

Fig. 4. Effect of welding current and welding time on maximum tensile shear load bearing for welding force F=8 bar.

Figure 5 shows the effect of the welding current on the external diameter of the RSW point. An increase in weld current increases the external diameter of RSW for all welding times. For all welding currents and times, the maximum difference of the external diameter was 0.4mm, observed at welding current I=11kA, while the minimum was observed at I=16kA. This result shows that the effect of welding time is very small.

Figure 6 shows the effect of welding current and welding time. A minimum depth, equal to 0.6mm, was produced at I=10kN and t=12 cycles, and the maximum depth of 1.12mm was produced at 13 cycles. This graph shows a random effect. Statistical analysis is required to investigate the effect of welding parameters on the geometric parameters of RSW. Figure 7 shows the fracture of welded 304L steel sheets plate by RSW under tension/shear loads. The fracture was initiated in the heated affected zone and propagated in the base metal. This propagation was made according to the mode I of fracture.

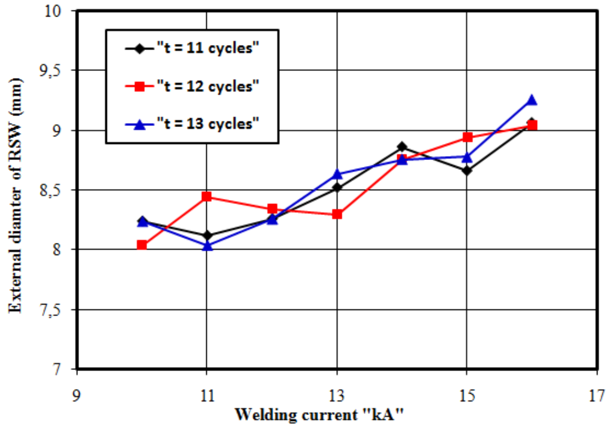

Fig. 5. Effect of welding current and welding time on the external diameter of RSW for welding force F=8 bar.

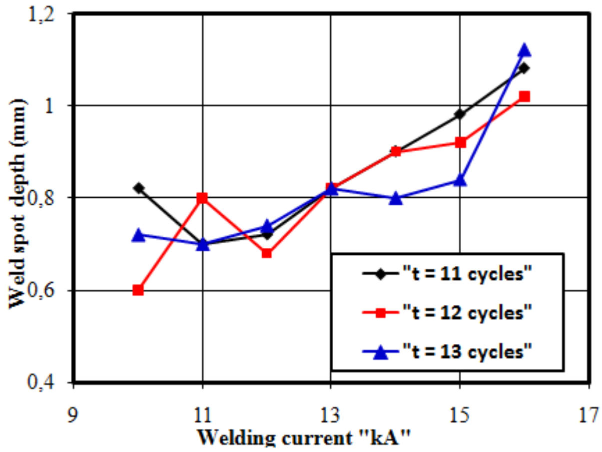

Fig. 6. Effect of welding current on maximum tensile shear load bearing for welding force F=8 bar.

(a) (b) (c)

Fig. 7. Effect of welding parameters on the fracture modes in RSW for applied load F= 8 bar: (a) I=10kA, t=10 cycles, (b) I=10kA, t=11 cycles, and (c) I=10kA, t=13 cycles.

IV. CONCLUSION

An RSW process was applied on 304L stainless steel to experimentally investigate the external parameters of the RSW joints and the maximum tensile shear load bearing of the joints. Furthermore, the influence of welding parameters, including welding current and welding time at fixed welding force, on the maximum tensile shear load bearing of the joints was studied using a factorial test. The conclusions deduced from this study are summarized as follows:

- The diameters of the RSW joints increased with increasing welding current and time.
- Welding time has a medium effect on the external diameter and the depth of RSW.
- An increase in welding current allows the increasing the depth of RSW.
- Tensile/shear tests show that the welding current is the dominant parameter in the evolution of the load/displacement curves.
- Increasing welding intensity increases the plastic deformation zone and the maximum tensile shear load bearing of joints.

REFERENCES

[1] D. Tanmoy, "Resistance Spot Welding: Principles and Its Applications," in *Engineering Principles*, K. O. Cooke and R. C. Cozza, Eds. London, UK: IntechOpen, 2022.

[2] N. Becker, J. Gilgert, E. J. Petit, and Z. Azari, "The effect of galvanizing on the mechanical resistance and fatigue toughness of a spot welded assembly made of AISI410 martensite," *Materials Science and Engineering: A*, vol. 596, pp. 145–156, Feb. 2014, https://doi.org/10.1016/j.msea.2013.12.008.

[3] D. Özyürek, "An effect of weld current and weld atmosphere on the resistance spot weldability of 304L austenitic stainless steel," *Materials & Design*, vol. 29, no. 3, pp. 597–603, Jan. 2008, https://doi.org/10.1016/j.matdes.2007.03.008.

[4] F. A. Ghazali, Y. H. P. Manurung, M. A. Mohamed, S. K. Alias, and S. Abdullah, "Effect of Process Parameters on the Mechanical Properties and Failure Behavior of Spot Welded Low Carbon Steel," *Journal of Mechanical Engineering and Sciences*, vol. 8, pp. 1489–1497, Jun. 2015, https://doi.org/10.15282/jmes.8.2015.23.0145.

[5] M. R. A. Shawon, F. Gulshan, and A. S. W. Kurny, "Effect of Welding Current on the Structure and Properties of Resistance Spot Welded Dissimilar (Austenitic Stainless Steel and Low Carbon Steel) Metal Joints," *Journal of The Institution of Engineers (India): Series D*, vol. 96, no. 1, pp. 29–36, Apr. 2015, https://doi.org/10.1007/s40033-014-0060-6.

[6] O. Andersson and A. Melander, "Prediction and Verification of Resistance Spot Welding Results of Ultra-High Strength Steels through FE Simulations," *Modeling and Numerical Simulation of Material Science*, vol. 5, no. 1, pp. 26–37, Jan. 2015, https://doi.org/10.4236/mnsms.2015.51003.

[7] N. Charde and R. Rajkumar, "Investigating Spot Weld Growth on 304 Austenitic Stainless Steel (2 mm) Sheets," *Journal of Engineering Science and Technology*, vol. 8, no. 1, pp. 69–78, 2013.

[8] M. Eshraghi, M. A. Tschopp, M. Asle Zaeem, and S. D. Felicelli, "Effect of resistance spot welding parameters on weld pool properties in a DP600 dual-phase steel: A parametric study using thermomechanically-coupled finite element analysis," *Materials & Design (1980-2015)*, vol. 56, pp. 387–397, Apr. 2014, https://doi.org/10.1016/j.matdes.2013.11.026.

[9] D. Kianersi, A. Mostafaei, and A. A. Amadeh, "Resistance spot welding joints of AISI 316L austenitic stainless steel sheets: Phase transformations, mechanical properties and microstructure characterizations," *Materials & Design*, vol. 61, pp. 251–263, Sep. 2014, https://doi.org/10.1016/j.matdes.2014.04.075.

[10] M. Zhou, S. J. Hu, and H. Zhang, "Critical specimen sizes for tensile-shear testing of steel sheets," *Welding Journal*, vol. 78, no. 9, Sep. 1999.

[11] A. Hasanbaşoğlu and R. Kaçar, "Resistance spot weldability of dissimilar materials (AISI 316L–DIN EN 10130-99 steels)," *Materials & Design*, vol. 28, no. 6, pp. 1794–1800, Jan. 2007, https://doi.org/10.1016/j.matdes.2006.05.013.

[12] J. P. Kong, T. K. Han, K. G. Chin, B. G. Park, and C. Y. Kang, "Effect of boron content and welding current on the mechanical properties of electrical resistance spot welds in complex-phase steels," *Materials & Design (1980-2015)*, vol. 54, pp. 598–609, Feb. 2014, https://doi.org/10.1016/j.matdes.2013.08.098.

[13] Jagadeesha T. and T. J. S. Jothi, "Studies on the influence of process parameters on the AISI 316L resistance spot-welded specimens," *The International Journal of Advanced Manufacturing Technology*, vol. 93, no. 1, pp. 73–88, Oct. 2017, https://doi.org/10.1007/s00170-015-7693-y.

[14] R. Qiu, Z. Zhang, K. Zhang, H. Shi, and G. Ding, "Influence of Welding Parameters on the Tensile Shear Strength of Aluminum Alloy Joint Welded by Resistance Spot Welding," *Journal of Materials Engineering and Performance*, vol. 20, no. 3, pp. 355–358, Apr. 2011, https://doi.org/10.1007/s11665-010-9703-4.

[15] M. Behulova and M. Nagy, "Numerical simulation of the resistance spot welding of parts from the AISI 304 steel," Slovakia.

[16] J. B. Shamsul and M. M. Hisyam, "Study Of Spot Welding Of Austenitic Stainless Steel Type 304," *Journal of Applied Sciences Research*, vol. 3, no. 11, pp. 1494–1499, 2007.

[17] A. G. Thakur, T. E. Rao, M. S. Mukhedkar, and V. M. Nandedkar, "Application of Taguchi Method for Resistance Spot Welding of Galvanized Steel," *ARPN Journal of Engineering and Applied Sciences*, vol. 5, no. 11, pp. 22–27, Nov. 2011.

[18] F. Ternane, M. Benachour, F. Sebaa, and N. Benachour, "Regression Modeling and Process Analysis of Resistance Spot Welding on Dissimilar Steel Sheets," *Engineering, Technology & Applied Science Research*, vol. 12, no. 4, pp. 8896–8900, Aug. 2022, https://doi.org/10.48084/etasr.5059.

[19] A. Alzahougi, M. Elitas, and B. Demir, "RSW Junctions of Advanced Automotive Sheet Steel by Using Different Electrode Pressures," *Engineering, Technology & Applied Science Research*, vol. 8, no. 5, pp. 3492–3495, Oct. 2018, https://doi.org/10.48084/etasr.2342.

[20] M. Elitas and B. Demir, "The Effects of the Welding Parameters on Tensile Properties of RSW Junctions of DP1000 Sheet Steel," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3116–3120, Aug. 2018, https://doi.org/10.48084/etasr.2115.

[21] S. Kim, I. Hwang, M. Kang, J. Park, and J. Yu, "Prediction of Indentation Depth of Resistance Spot Welding Using Electrode Displacement Signal," *Journal of Welding and Joining*, vol. 39, no. 3, pp. 314–322, Jun. 2021, https://doi.org/10.5781/JWJ.2021.39.3.10.