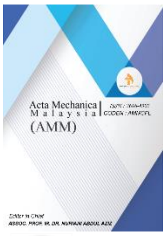
ZIBELINE INTERNATIONAL PUBLISHING

Acta Mechanica Malaysia (AMM)

DOI: http://doi.org/10.26480/amm.02.2020.40.45

ISSN: 2616-4302 (Online)
CODEN: AMMCFL



RESEARCH ARTICLE

EFFECTS OF WELDING CURRENT AND SPEED ON RESIDUAL STRESS AND DISTORTION OF JOINING ST52 ROLLED PLATE IN DIFFERENT WELDING SEQUENCES

Ali Aminifar, Alireza M. Haghighi*

Faculty of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran.
**** Corresponding Author email: alireza.m.haghighi@eng.uk.ac.ir; m.haghighi.alireza@gmail.com***

ARTICLE DETAILS

Article History:

Received 18 September 2020
Accepted 20 October 2020
Available online 17 November 2020

ABSTRACT

Welding is a process of permanent joining parts by different welding methods. Residual stress and distortion are the most common phenomena of this process. Reduction of the residual stresses, distortion and improving the quality of welding are the important subjects of this field. Determining and analyzing the residual stresses and distortion is the main step for these purposes. Welding sequences, speed and current are the most effective parameters of this process. In this study, effects of welding parameters such as welding speed and current, in order to reduce residual stress and distortion of welding ST52 rolled plate in different welding sequences have been studied with three-dimensional thermo-mechanical finite element model by means of ANSYS APDL. By comparing different considered situations, the most efficient welding methods with the least residual stress and distortion by considering different welding sequences have been suggested. It obtains that welding the ST52 rolled plate from edge to edge with higher current and lower speed is the best option in fatigue and load-bearing situations, and welding from the center to both sides simultaneously with lower current and higher speed is the best option for assembly problems.

KEYWORDS

ST52 Rolled Plate, Residual Stress, Distortion, ANSYS APDL, Finite Element Method

1. INTRODUCTION

Welding is a common method of permanent joining in various industries such as power plants, oil and gas pipelines, and construction. Industrial welding needs a high-quality joining, but non-uniform high temperature field cause plastic strain in parts and appearance of residual stress. These stresses create internal forces that leads to appearance of distortion in the product which has negative effects on shape of the parts, assembly and on resistance of materials again fatigue, corrosion and failure (Teng et al., 2001; Haghighi and Samani, 2020). The pattern of residual stress is different based on manufacturing process, materials and combination of service structure. In rolled plates, tensile stress spread near the edges and compressive stresses spread in the internal regions (Brust and Kim, 2005). There are six stress variables of σ_x, σ_y, σ_z, τ_{xy}, τ_{xz}, τ_{yz} that in the plane stress, there are only σ_x, σ_y and τ_{xy}. Strain ($\in_x$, $\in_y$ and $\in_{xy}$) is summation of elastic ($\in'_x$, $\in'_y$ and $\in'_{xy}$) and non-elastic ($\in''_x$, $\in''_y$ and $\in''_{xy}$) strains. Non-elastic strains include plastic and thermal strains. For the thermal strain (Haghighi and Samani, 2020):

$$\in''_x = \in''_y = \alpha\Delta T \tag{1}$$

$$\in''_{xy} = 0 \tag{2}$$

These relations are for isotropic materials. α is the linear thermal expansion coefficient and ΔT is the difference of recent and initial temperature. In plane stress, Hooke's law between stress and elastic strains are:

$$\in'_x = \frac{1}{E}(\sigma_x - \vartheta\sigma_y) \tag{3}$$

$$\in'_y = \frac{1}{E}(\sigma_y - \vartheta\sigma_x) \tag{4}$$

$$\in'_{xy} = \frac{1}{G}(\tau_{xy}) \tag{5}$$

That E is the elasticity modulus, ϑ is the Poisson's ratio and G is the shear modulus. Stress parameters should satisfy the stability conditions of:

$$\frac{\partial\sigma_x}{\partial x} + \frac{\partial\tau_{xy}}{\partial y} = 0 \tag{6}$$

$$\frac{\partial\tau_{xy}}{\partial x} + \frac{\partial\sigma_y}{\partial y} = 0 \tag{7}$$

Also, strain should satisfy the compatibility condition of:

$$\frac{\partial\in'_x}{\partial y^2} + \frac{\partial^2\in'_y}{\partial x^2} + \frac{\partial^2\in'_{xy}}{\partial x\partial y} + \frac{\partial^2\in''_x}{\partial y^2} + \frac{\partial^2\in''_y}{\partial x^2} - \frac{\partial^2\in''_{xy}}{\partial x\partial y} = 0 \tag{8}$$

Summation of forces and momentums of residual stress should be zero in absence of external forces and should satisfy:

$$\int \sigma.dA = 0 \tag{9}$$

$$\int dM = 0 \tag{10}$$

Quick Response Code	Access this article online	
	Website: www.actamechanicamalaysia.com	**DOI:** 10.26480/amm.02.2020.40.45

Cite the Article: Ali Aminifar, Alireza M. Haghighi (2020). Effects Of Welding Current And Speed On Residual Stress And Distortion Of Joining St52 Rolled Plate In Different Welding Sequences. *Acta Mechanica Malaysia, 3(2): 40-45.*

That dA is surface element and dM is the momentum element (Haghighi and Samani, 2020).

There are some studies on the effects of welding parameters and investigating distortion and residual stress of welding. In an article, researchers study effects of different welding parameters on residual stresses and distortion of the Cr18Ni90 pipe with thickness of 6 mm and by changing the inserted heat, the most displacement of the pipe obtained (Xie et al., 2020). In another research, effects of welding parameters such as preheating, welding speed and current on residual stress and distortion of joining an ST52 T-shape stiffener ring in an Aisi4130 thin-walled tubular shell by numerical method has been analyzed. It obtained that welding simultaneously both sides of the ring in the same way with preheating is the best method with less residual stresses and distortion between considered methods (Haghighi and Samani, 2020). Some researchers calculate the residual stress in P91 steel by studying surface deformation by means of CMM method and stress-strain relations (Suman et al., 2020). In a research, the residual stress of multi-layer welding of steel pipes by birth-death element method has been studied.

In this study, by studying an elastoplastic model, relation of stress and distortion had been presented for the model by means of Ansys software (Ponomareva, 2010). Some researchers investigate the residual stress and distortion of welding SAE1020. Results show that by increasing the input heating, more distortion appears (Teng et al., 2001). In another article, researchers investigate the multi-pass welding residual stress distribution in medium thick-walled austenitic stainless steel SUS304 pipe by finite element and experimental method and presented the influence of yield strength of the weld metal on the residual stress (Deng et al., 2008). Researcher in an article simulate two axisymmetric butt welds of stainless-steel pipes with different radius and thickness in order to investigate the effects of pipe diameter on residual stress (Yaghi et al., 2006). Two researchers use experimental and numerical method by means of Ansys software and birth-death method to study residual stress of butt welding two similar plates (Dragi and Ivana, 2009).

In another research, the effects of welding sequences on residual stress and distortion of welding by thermo-mechanical finite element method have been studied and the results show that welding sequences have a significant effect on magnitude and distribution of residual stress and distortion of welding (Fu et al., 2016). Some researchers investigate the distribution of residual stress, temperature and distortion of stiffened aluminum alloy Al6061-T6 plates by thermo-mechanical finite element model. They figured out that increasing the welding current increased the residual stress and distortion and changing the welding sequence change the distribution of distortion (Khoshroyan and Darvazi, 2020). Two researchers investigate the effects of welding sequences on magnitude and distribution of temperature, residual stress and distortion of stiffened plates by nonlinear thermo-elasto-plastic and experimental method. Results show that welding sequences have a significant effect on distortion and longitudinal residual stress. Also, welding from the middle of the plate to the edges has smaller distortion and residual stress (Chen and Soares, 2016).

Stresses and distortions in welding parts caused by non-uniform distribution of heat in the welding heat zone and local deformation in the part, which are directly related to effective welding parameters. There are several welding parameters effect on greatness of the residual stress and displacement of the product. Welding speed, sequences and current are the main effective parameters of the joining process. Welding current is the most effective parameter of this process that control the melting rate of the filler material which has a direct effect on the quality of final product. Welding speed determine the real time and cost of the process and welding sequence can reduce the distortion of the product (Mandal, 2004). In this paper, effect of welding speed and current on residual stress and distortion of an ST52 rolled plate in different welding sequences has been studied and the best method with the least residual stress and distortion has been presented.

2. PROBLEM EXPLANATION, INNOVATIONS & AIMS OF THE PAPER

A 300×1884 mm plate with thickness of 12 mm has been rolled and edges joined by welding filler of ER70S-2, by means of birth-death method. Figure 1 shows the model of rolled plate designed by Ansys APDL.

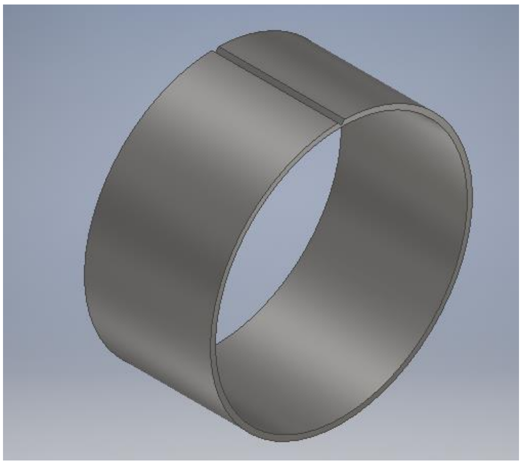


Figure 1: 3D model of rolled plate designed by Ansys APDL.

ST52-3N (DIN 1.0570) is high strength steel and good weldability with lot of applications in the industry and construction that has been used in bridge structures, railway track, wind turbines, the hull of the ship, tanks and etc. the properties of ST52 is mentioned in table 1 as follow (Zargar et al., 2012):

3. RESEARCH METHOD AND ASSUMPTIONS

a validated article has been calculated stress of welding two ASTM 36 carbon steel plates by experimental and finite element methods (Dragi and Ivana, 2009). To validate the results of simulation of Ansys APDL, welding simulated in an identical situation and results compared with results of that research. Figure 2 shows the geometrical model of the article.

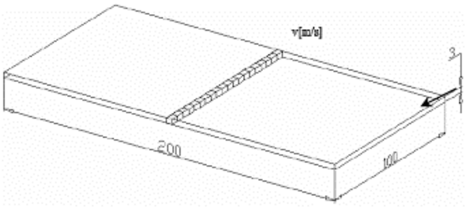


Figure 2: Geometric model of the valid article (Dragi and Ivana, 2009).

Welding speed is $5mm/s$, current of 180 A, 24 V voltage with efficiency rate of 85%. By a thermal and then a mechanical analysis, longitudinal effective stress of the weld line exploited. Figure 3 shows the comparison of the simulation with results of the article (Dragi and Ivana, 2009).

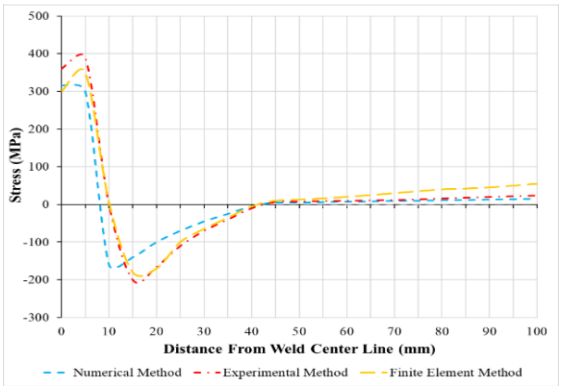


Figure 3: Comparison of the results of the finite element method with the valid article (Dragi and Ivana, 2009).

The model designed and meshed by Ansys APDL. The model meshed by 5400 cubic elements and 38430 nodes as shown in figure 4. Figure 5 shows the mesh concentration in regions near the weld line for more accuracy and reducing the error rate.

Figure 4: The model meshed by 5400 cubic element and 38430 nodes.

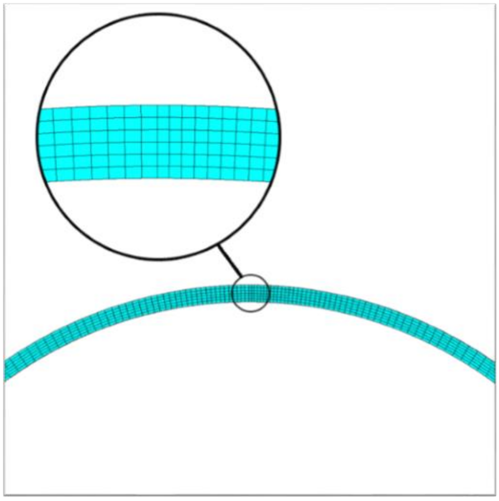


Figure 5: Mesh concentration near the weld line

The Goldak's double ellipsoid model used in this paper for inserting and modeling heat source of welding is the closest situation with the least error rate to the experimental process. Figure 6 shows the Goldak's double ellipsoid model.

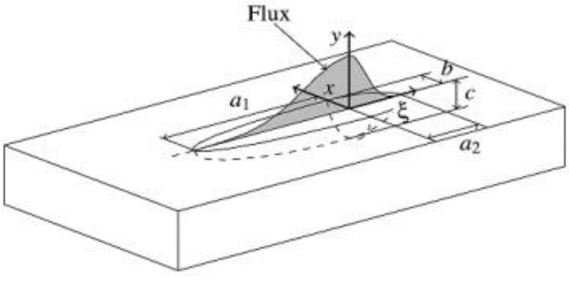


Figure 6: Goldak's double ellipsoid heat source model (Lorin et al., 2014).

The rate of inserted heat for melting the base parts, to the whole inserted heat, is the efficiency rate of the welding process:

$$\eta = \frac{Q}{Q_{Nominal}} = \frac{Q}{E \times I} \tag{6}$$

That Q is the efficient heat, $Q_{Nominal}$ is the nominal inserted heat, E is the voltage and I is the welding currency.

4. RESULTS AND DISCUSSION

Welding has been designed and programmed in different conditions with welding current of 130 and 150 A, voltage of 25 V, speed of 1.5 and 2 mm/s, and efficiency rate of 85% in different situations in order to study effective stress and distortion of welding ST52 rolled plate in different welding sequences as shown in Figure 7. Figure 8 shows different welding sequences have been considered in this paper.

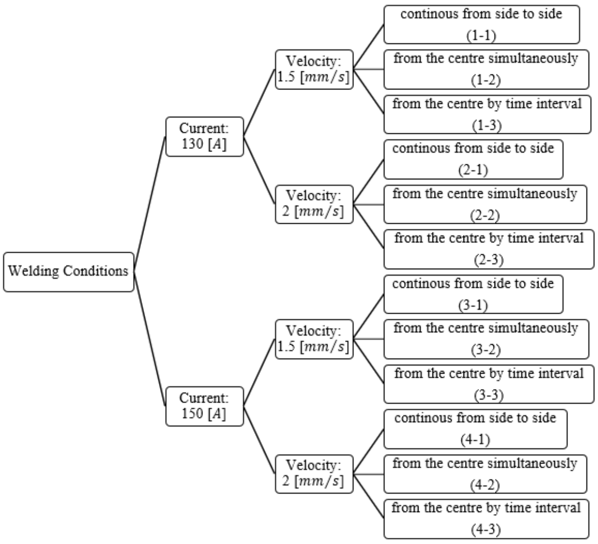
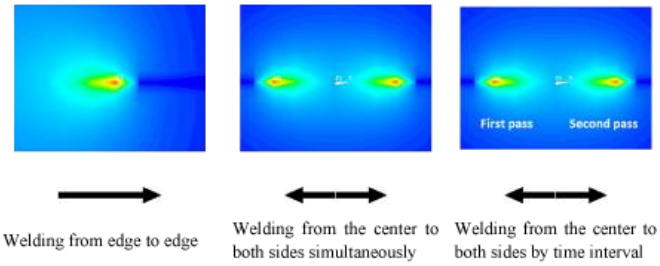


Figure 7: Considered conditions in order to study effects of welding speed and current on residual stress and distortion of different welding sequences.



Welding from edge to edge

Welding from the center to both sides simultaneously

Welding from the center to both sides by time interval

Figure 8: Different considered welding sequences

Effective stress and distortion exploited in longitudinal and transverse directions in the heat affected zone on the node lines as shown in Figure 9.

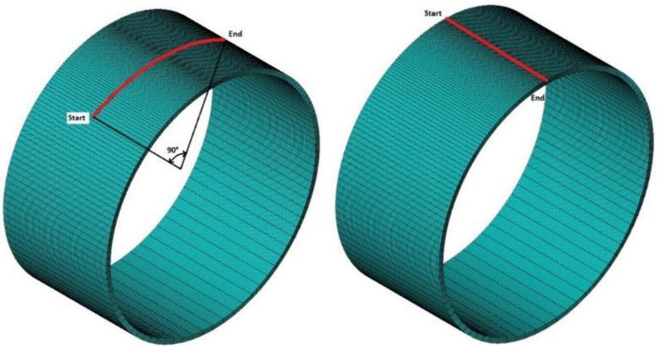


Figure 9: Longitudinal and transverse node lines in heat affected zone for exploiting results.

4.1 Welding from Edge to Edge

By considering different conditions in welding continuously from edge to edge, welding with higher current of 150 A and lower speed of 1.5 mm/s (condition number 3-1) has the least effective stress with max amount of 331 MPa in longitudinal and transverse direction. Welding with lower current of 130 A and higher speed of 2mm/s (2-1) has the least longitudinal distortion with Max of 0.39 mm and transverse distortion with Max of 0.45 mm as shown in figure 10.

Cite the Article: Ali Aminifar, Alireza M. Haghighi (2020). Effects Of Welding Current And Speed On Residual Stress And Distortion Of Joining St52 Rolled Plate In Different Welding Sequences. *Acta Mechanica Malaysia, 3(2): 40-45.*

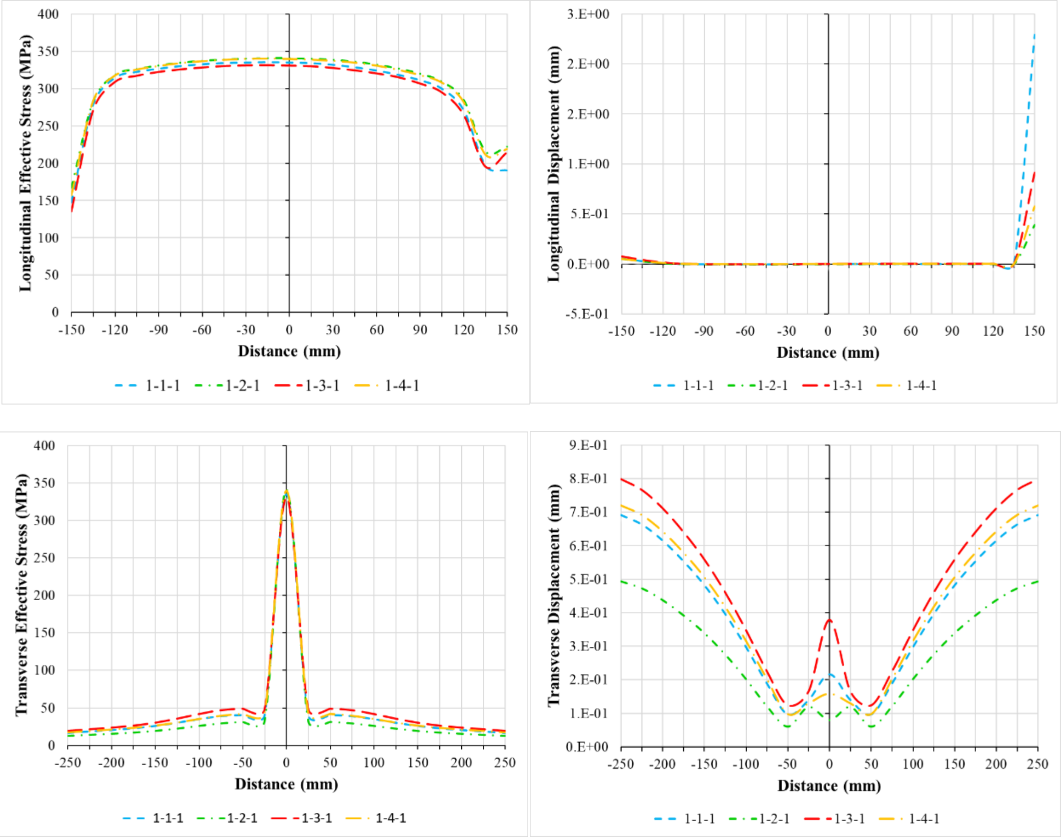


Figure 10: Longitudinal and transverse effective stress and distortion of welding from edge to edge

4.2 Welding from The Center to Both Sides Simultaneously

Welding from the center to the both sides simultaneously by higher current and lower speed (3-2) has the least residual stress by Max of 342MPa and welding with lower current and higher speed (2-2) has the least distortion with Max of 0.35 mm in longitudinal direction. Welding with lower current and higher speed (2-2) has the least residual stress and distortion with Max of 342 MPa and 0.21 mm in transverse direction respectively as shown in figure 11.

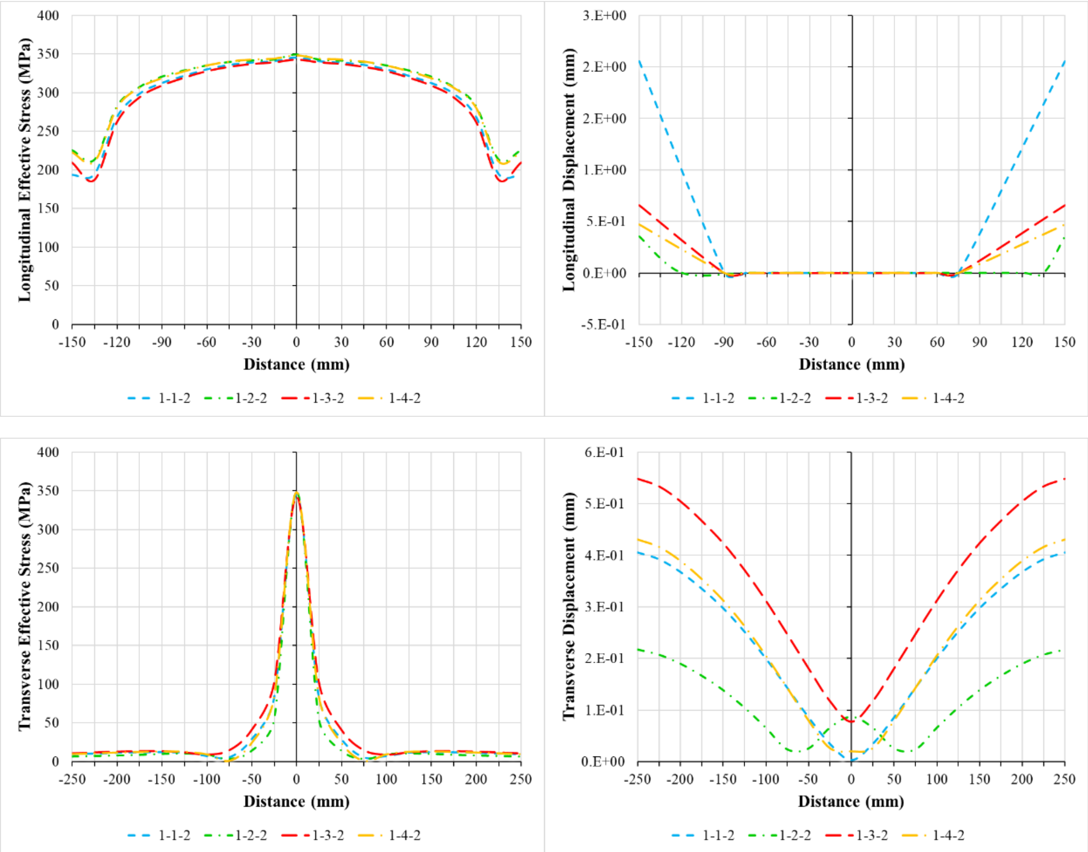


Figure 11: Longitudinal and transverse effective stress and distortion of welding from the center to both sides simultaneously

4.3 Welding from The Centre To the Both Sides by Time Interval

Welding with higher current and lower speed (3-3) with Max residual stress of 362 MPa in longitudinal direction and 355 MPa in transverse direction has the least residual stress in the considered conditions. Welding with lower current and higher speed (2-3) with Max distortion of 0.35 mm in longitudinal direction and 0.36 mm in transverse direction are the best conditions with the least distortion as shown in figure 12.

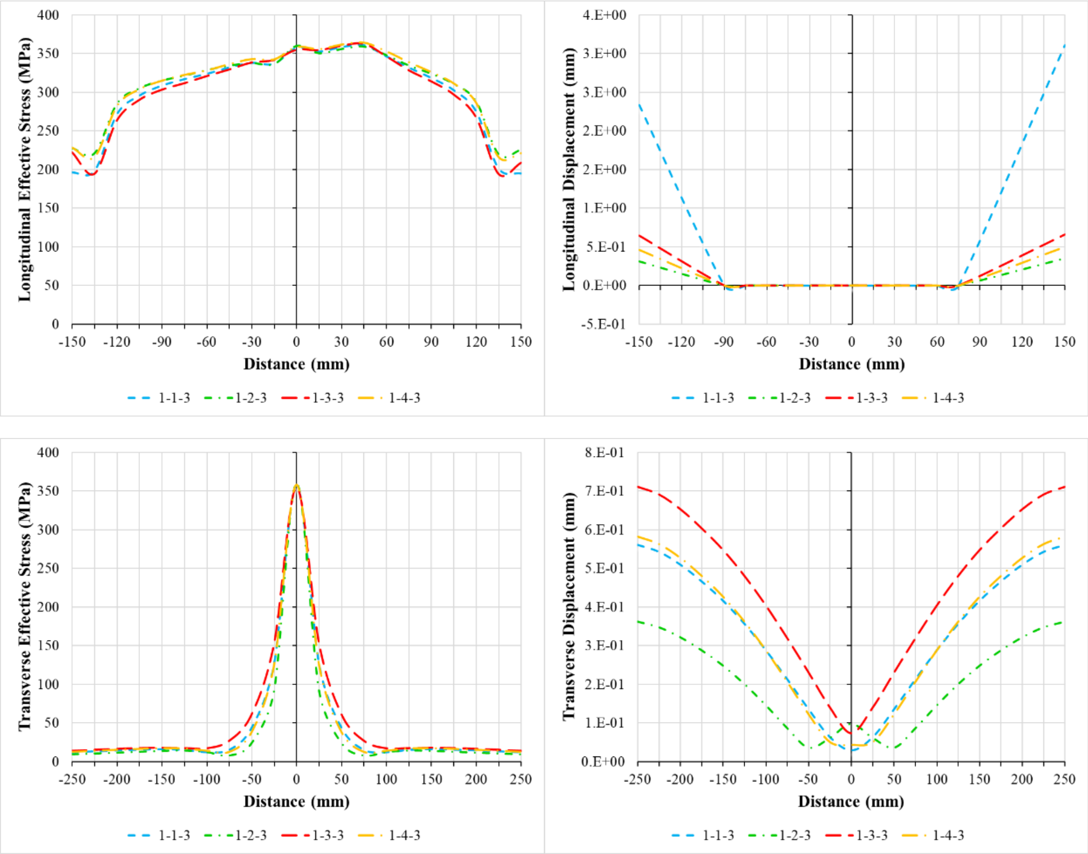


Figure 12: Longitudinal and transverse effective stress and distortion of welding from the center to both sides by time interval.

Table 2 shows the effective stress and total distortion in longitudinal and transverse direction in the considered conditions of Figure 7.

Table 2: Effective stress and distortion results in different welding conditions

Welding Sequences	Condition Num.	Max Longitudinal Effective Stress [MPa]	Max Transverse Effective Stress [MPa]	Max Longitudinal Distortion [mm]	Max Transverse Distortion [mm]
Continuous Welding from Edge to Edge	1-1	336	335	2.30	0.70
	2-1	341	341	0.39	0.45
	3-1	331	331	0.91	0.79
	4-1	340	340	0.57	0.70
Welding from the center to both sides simultaneously	1-2	345	345	2.05	0.70
	2-2	349	349	0.35	0.21
	3-2	342	342	0.65	0.54
	4-2	348	348	0.46	0.43
Welding from the center to both sides by time interval	1-3	360	357	3.10	0.56
	2-3	360	360	0.35	0.36
	3-3	362	355	0.66	0.70
	4-3	363	358	0.50	0.58

Welding from the center to both sides by time interval with higher current and speed (4-3) with Max of 363 MPa has the highest longitudinal effective stress and welding from edge to edge continuously with higher current and lower speed (3-1) with Max of 331 MPa has the least longitudinal effective stress. The highest transverse effective stress is for welding from the center to both sides by time interval with lower current and higher speed (2-3) with Max of 360 MPa, and welding from edge to edge with lower current and speed (1-1) has the least transverse effective stress with Max of 335 MPa between considered situations. Welding with lower current and speed (1-3) has the highest longitudinal distortion with Max of 3.10 mm, and welding with lower current and higher speed (2-2) has the least longitudinal distortion with Max of 0.35 mm in the longitudinal direction. The highest transverse distortion is for welding from edge to edge with higher current and lower speed (3-1) with Max of 0.79, and welding from the center to both sides simultaneously with lower current and higher speed has the least distortion with Max of 0.21 in transverse direction.

5. CONCLUSION

By study the longitudinal and transverse effective stresses and distortions for welding ST52 rolled plate from edge to edge, from the center to the both sides simultaneously and from the center to both sides by time interval, welding from edge to edge with higher current and lower speed, because it has the least residual stresses between considered conditions, is the best option in fatigue and load-bearing situations, and welding from the center to both sides simultaneously with lower current and higher speed, because it has the least distortion, is the best option for assembly problems.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Brust, F.W., Kim, D.S., 2005. Processes and mechanisms of welding residual stress and distortion. Cambridge: Woodhead Publishing, Pp. 264-294.

Chen, B., Guedes, S.C., 2016. Effect of welding sequence on temperature distribution, distortions, and residual stress on stiffened plates. The International Journal of Advanced Manufacturing Technology, 86 (9-12), Pp. 3145-3156. Available: 10.1007/s00170-016-8448-0.

Deng, D., Murakawa, H., and Liang, W., 2008. Numerical and experimental investigations on welding residual stress in multi-pass butt-welded austenitic stainless-steel pipe. Computational Materials Science, 42 (2), Pp. 234-244. Available: 10.1016/j.commatsci.2007.07.009.

Dragi, S., Ivana, V., 2009. Finite element analysis of residual stress in butt welding two similar plates. Scientific Technical Review, 59 (1), Pp. 57-60.

Fu, G., Lourenço, M., Duan, M., Estefen, S., 2016. Influence of the welding sequence on residual stress and distortion of fillet welded structures. Marine Structures, 46, Pp. 30-55. Available: 10.1016/j.marstruc.2015.12.001.

Haghighi, M., Samani, A.S., 2020. Effects of Welding Parameters, Time Interval and Preheating on Residual Stress and Distortion of Joining St52 Stiffener Ring in An Aisi 4130 Tubular Shell. Acta Mechanica Malaysia, 4 (1), Pp. 11-15.

Khoshroyan, A., Darvazi, A., 2020. Effects of welding parameters and welding sequence on residual stress and distortion in Al6061-T6 aluminum alloy for T-shaped welded joint. Transactions of Nonferrous Metals Society of China, 30 (1), Pp. 76-89. Available: 10.1016/s1003-6326(19)65181-2.

Lorin, S., Cromvik, C., Edelvik, F., Lindkvist, L., Söderberg, R., 2014. Variation Simulation of Welded Assemblies Using a Thermo-Elastic Finite Element Model. Journal of Computing and Information Science in Engineering, 14 (3), Pp. 031003. Available: 10.1115/1.4027346.

Mandal, N., 2004. Welding and distortion control. New Dehli: Narosa Pub. House, Pp. 1-120.

Ponomareva, I., 2010. Residual welding stresses in multipass welding of circumferential joints in pipelines. Welding International, 24 (8), Pp. 631-634.

Suman, S., Biswas, P., Patel, S., Singh, V., Kumar, A., Kuriachen, B., 2020. Measurement of residual stresses in submerged arc welded P91 steel using surface deformation. Materials Today: Proceedings, 21, Pp. 1707-1712.

Teng, T., Fung, C., Chang, P., Yang, W., 2001. Analysis of residual stresses and distortions in T-joint fillet welds. International Journal of Pressure Vessels and Piping, 78 (8), Pp. 523-538.

Teng, T., Fung, C., Chang, P., Yang, W., 2001. Analysis of residual stresses and distortions in T-joint fillet welds. International Journal of Pressure Vessels and Piping, 78 (8), Pp. 523-538.

Xie, Y., Zhuang, J., Huang, B., Chen, Q., Li, G., 2020. Effect of different welding parameters on residual stress and deformation of 20/0Cr18Ni9 dissimilar metal arc-welding joint. Journal of Adhesion Science and Technology, 34 (15), Pp. 1628-1652.

Yaghi, A., Hyde, T., Becker, A., Sun, W., Williams, J., 2006. Residual stress simulation in thin and thick-walled stainless-steel pipe welds including pipe diameter effects. International Journal of Pressure Vessels and Piping, 83 (11-12), Pp. 864-874.

Zargar, S., Farahani, M., Givi, M., 2012. Numerical and experimental investigation on the effects of submerged arc welding sequence on the residual distortion of the fillet welded plates. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230 (4), Pp. 654-661.

Cite the Article: Ali Aminifar, Alireza M. Haghighi (2020). Effects Of Welding Current And Speed On Residual Stress And Distortion Of Joining St52 Rolled Plate In Different Welding Sequences. *Acta Mechanica Malaysia, 3(2): 40-45.*