Medicon Engineering Themes
Volume 8 Issue 1 January 2025
Article Type: Research Article
ISSN: 2834-7218

Experimental Study of the LSC-GMAW Welding Process Using 304 L Stainless Steel

Chetoui Ali[1]*, Ben Khalifa Ated[2], Chatmen Mouna[1] and Mzali Foued[1]*

[1]University of Monastir, Laboratory for the Study of Thermal and Energy Systems (LESTE-ENIM), Avenue Ibn El Jazzar, 5019 Monastir

[2]University of Monastir, Mechanical Engineering Laboratory (LGM-ENIM), Avenue Ibn El Jazzar, 5019 Monastir

***Corresponding Author:** Chetoui Ali and Mzali Foued, University of Monastir, Laboratory for the Study of Thermal and Energy Systems (LESTE-ENIM), Avenue Ibn El Jazzar, 5019 Monastir.

Received: November 12, 2024; **Published:** January 11, 2025

Abstract

In the recent years, numerical simulation of the welding process has become more widely used, mainly owing to advances in computer technology and the prevalence of commercial software. However, one of the main challenges of welding simulation is the accuracy of heat source modeling. This paper investigates Gas Metal Arc Welding (GMAW) with Lower Spatter Control (LSC) on an experimental basis, aiming to determine the parameters of the heat source for improved numerical prediction of weld temperature, distortion, and stress. The weld bead geometry was characterized and transient temperatures were recorded at particular points on the substrate close to the weld bead using K-type thermocouples. The results revealed that modifying welding speed can affect temperature distribution and weld bead construction. The choice of welding speed is a critical factor in determining the quality and efficiency of a welding process. The study suggests optimizing the welding process parameters, to control the heat input and cooling rate during welding, which can considerably affect the microstructure and the mechanical properties of the weld bead.

Keywords: LSC-GMAW; 304 L; temperature; macrograph; heat source

Introduction

Welding numerical simulation refers to the use of computer-based models and simulations to analyze and predict the behavior of welding processes. These models are used to evaluate the thermal and mechanical behavior of a welding joint, optimize welding parameters, and predict the final microstructure and mechanical properties of the welded joint. The simulations take into account various parameters including material properties, welding speed, and heat input, and provide valuable information for improving welding efficiency and the final welded joint quality (Khoshroyan and Darvazi, 2020).

Heat transfer analysis of the welding process highlights two zones of specific interest, the fusion zone (FZ) and the heat affected zone (HAZ), where temperatures reach their peak levels, and the heat rate is high (Iacobescu, 2006). The interaction between a heat source with a weld pool is a complicated phenomenon. As the challenge of developing a practical and efficient global welding simulation model persists, many researchers have opted to define the heat input of the arc in a simplified way. This approach involves utilizing an analytically defined welding heat source to represent the heat output delivered by the arc, thereby streamlining calculations and usability.

Giarollo et al. proposed a numerical simulation of the thermal behavior of an ASTM A36 steel plate based on gas metal arc welding GTAW (Giarollo et al., 2022). They compared a Goldak double ellipsoid heat source model with a model that uses a bi-ellipsoid curve to describe the weld pool and to identify source parameters. Chen et al. developed a modified heat source using Goldak's source that considers the changes in torch angle (Chen et al., 2014). They combined two of these modified heat sources to simulate a hybrid TIG-MIG welding process.

The present study consists in using the GMAW process in LSC mode to build two weld beads using varying welding speeds. A macrographic analysis will be carried out to identify the parameters of the Goldak heat source.

Experimental Materials and Procedure

In this experiment, an automatic welding system, as shown in Fig. 1, was carried out to build a weld bead using a 1 mm diameter SS316L filler wire which was deposited on a 304 L Stainless substrate with dimensions of 94 mm x 80 mm x 5 mm. A M12-ArC-2 (2% CO_2+ 98% Ar), as the protective gas, with a flow rate of 15 L/min is used. A Fronius "FRC-45 BASIC" welding carriage was employed to automatically move the CMT torch connected to a Fronius TPS 320i power source. Table 1 displays the chemical constituents of the filler material.

Materials	***C***	***Cu***	***Cr***	***Mn***	***Mo***	***N***	***Ni***	***S***	***Si***	***Ti***	***V***	***P***
Filler wire SS316L	0.03	0.76	17.83	2.43	1.63	-	10.57	-	0.63	0.267	0.3	-

Table 1: Chemical constituents of Filler wire (Ahmad et al., 2022).

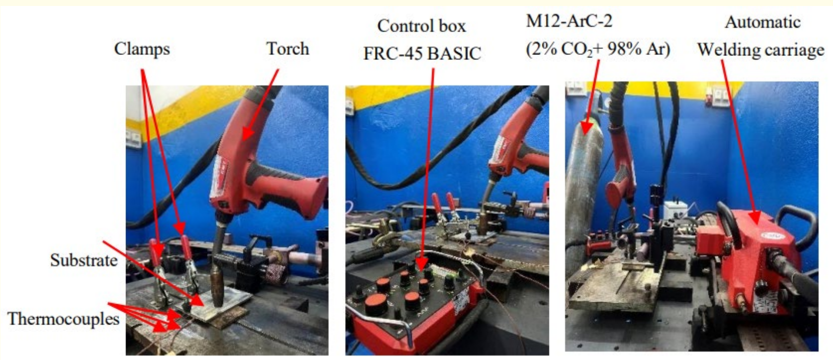

Figure 1: Experimental welding machine.

The construction of two welding beads with different speeds has been carried out using parameters listed in Table 2, which include arc current (I), voltage (V), welding speed (Ws), and wire feed rate (wfr).

To record temperature responses during the welding operation, three K-type thermocouples (TC1, TC2, TC3) were used. They are positioned and placed at the bottom of the substrate as shown in Fig. 2. Then, they were connected to an Agilent 34970A acquisition card, with a readings at intervals of 0.2 seconds. The data was then analyzed using the Bench Link Data Logger software, as illustrated in Fig. 3, which provided the temperature variation of the thermocouples.

Welding process parameters	*Value*
Current (I)	195 A
Voltage (V)	23 V
Welding speed 1 (Ws)	50cm/min
welding speed 2 (Ws)	60cm/min
Wire feed rate (wfr)	10 m/min

Table 2: Experimental welding parameters.

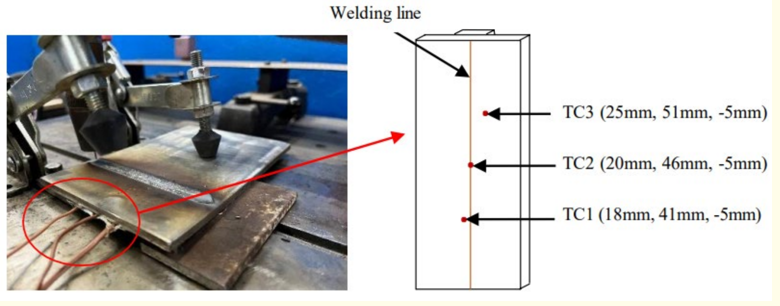

Figure 2: Schematic representation of the thermocouple's position on the substrate.

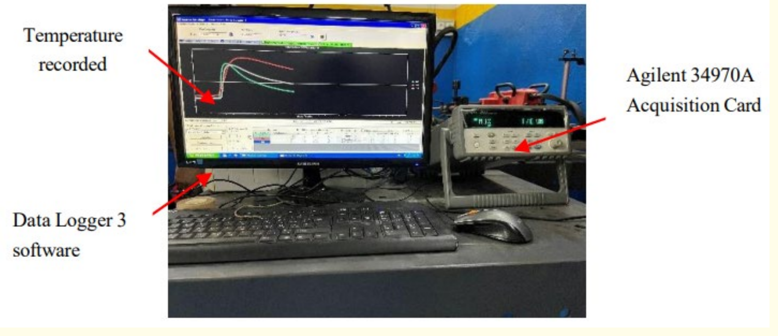

Figure 3: Post-acquisition of results.

LSC welding process

The LSC (Low Spatter Control) process developed by Fronius is a modified dip transfer arc that offers exceptional arc stability. This process allows the user to create high quality weld beads with minimal spattering and an increased deposition rate. The LSC process is based on the short circuit that occurs at a low current level, which leads to a smooth reignition and a stable welding process.

Compared to the standard immersion transfer arc, the LSC process offers significant advantages in terms of arc control. The TPS/i power source platform, which was developed by Fronius, provides improved arc control and performance. The TPS/i platform includes features such as waveform control, a digital interface, and a range of other functions that allow for greater precision and control during the welding process (Fronius 2023). The LSC process allows metal transfer with a high peak current as shown in Fig. 4.

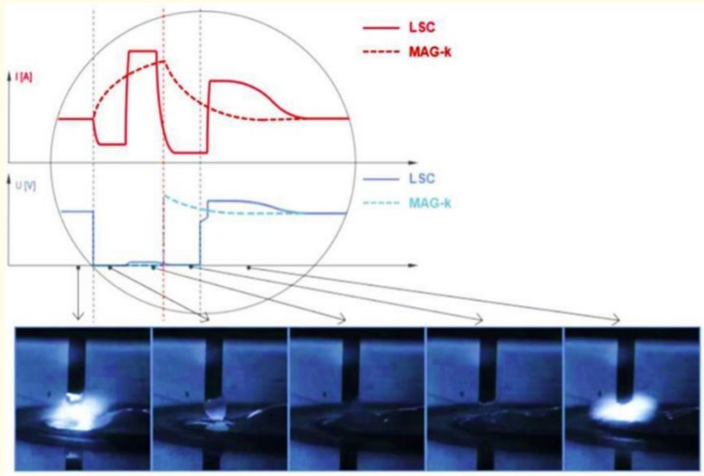

Figure 4: Current and voltage diagram for the LSC process (Fiedler et al., 2017).

Heat source model

The heat source model proposed by (Goldak et al., 1984) is widely used in arc welding simulation literature. This model delivers heat input through a double ellipsoid region that moves according to a Gaussian distribution and effectively models the shape of the weld pool. However, it doesn't take into account the proper heat distribution between the filler metal and the base material, which can result in inaccurate part distortion estimates. The Goldak parameters, which are affected by welding parameters like energy input and welding speed, play a crucial role in determining the shape and size of the double ellipsoidal heat source pattern. Adjusting these parameters can help obtain the desired thermal gradients and temperature distribution. However, the process is complex, and the main difficulty lies in adjusting a large number of parameters until the temperature distribution is appropriate. Typically, calibration is achieved through a tridimensional process due to the complexity of the model (Deng, 2009; Song et al., 2003).

The depiction of the heat source can be observed in Fig. 5, where the Z-axis corresponds to the welding motion, the Y-axis represents the depth direction, and the X-axis indicates the width direction. Equations (1) and (2) describe the heat flux distribution at the front (qf) and rear (qr) of the half ellipsoid, at a specific point in time (t) and space (x, y, z)

$$q_f(x,y,z,t) = \frac{6\sqrt{3} f_f Q}{a_f b c \pi} \exp\left(-3\left(\frac{(z-vt-z_0)^2}{a_f^2} + \left(\frac{y^2}{b^2}\right) + \left(\frac{x^2}{c^2}\right)\right)\right) \quad (1)$$

$$q_r(x,y,z,t) = \frac{6\sqrt{3} f_r Q}{a_r b c \pi} \exp\left(-3\left(\frac{(z-vt-z_0)^2}{a_r^2} + \left(\frac{y^2}{b^2}\right) + \left(\frac{x^2}{c^2}\right)\right)\right) \quad (2)$$

Where a_f, a_r, b and c are the four parameters that describe the heat source ellipsoid. a_f represents the front quadrant, ar represents the rear quadrant, b corresponds to the half- width and c indicates the depth of the ellipsoid, Q is the is the arc heat quantity (Q = η*I*V), where η is the arc efficiency and V and I are the arc voltage and current, respectively. v represents the welding speed, t signifies the welding speed time, f_f and f_r represent the proportionality coefficients at the front and rear of the ellipsoid, respectively.

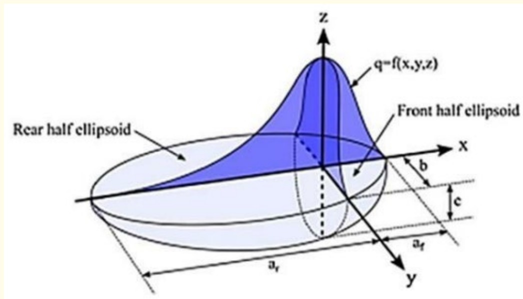

Figure 5: Double ellipsoidal heat source.

Results and discussions

Weld bead characterization

Weld bead characterization refers to the analysis and evaluation of the physical and mechanical characteristics of the weld bead created during welding. This process involves examining the geometry, microstructure, and macrostructure of the weld bead, as well as its chemical composition and hardness. In addition to characterizing the weld bead, several solutions can be implemented to improve its quality and performance. One approach is to optimize the welding processes parameters, such as the welding speed, current, voltage, and electrode size. By adjusting these parameters, the heat input and cooling rate during welding becomes possible to influence significantly the microstructure and mechanical characteristics of the weld bead. Figure 6 shows a front weld bead macrograph, on which the weld bead half lengths and width (a_f, a_r, and w) are measured for different welding speeds.

In Figure 7, the weld bead height is measured using a welding caliper. The corresponding values are noted in table 2. From this table, it is clear that all these parameters decrease by increasing welding speed.

On the other hand, figure 8 shows a transverse weld bead macrograph, on which the weld bead depth and width are measured using Micro Capture Pro software.

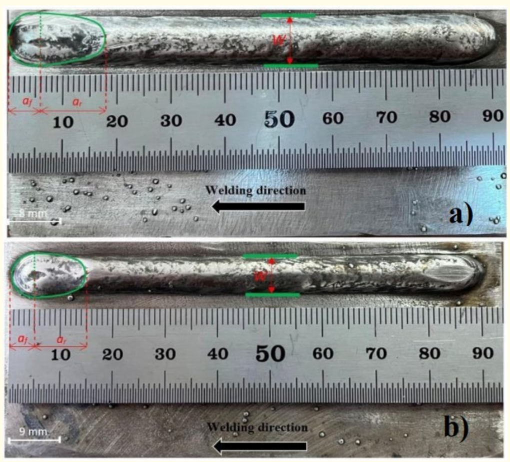

Figure 6: Measurement of the front weld bead geometrical parameters (a_r, a_f and w) for different welding speeds: a) 50 cm/min, b) 60 cm/min.

Figure 7: Measurement of weld bead height using welding caliper.

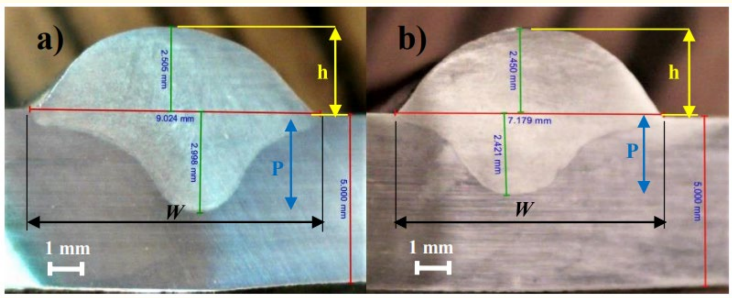

Figure 8: Measurement of the weld bead height on a transverse weld Macrograph for different welding speeds a) 50cm/min, b) 60cm/min.

Parameters	***Value***	
	WS= 50 cm/min	***WS= 60 cm/min***
Front quadrant (af)	6 mm	5 mm
Rear quadrant (ar)	12 mm	10
Width (w)	9,0 mm	7,2 mm
Height (h)	2,5 mm	2,45 mm
Penetration of wels (P)	3 mm	2,4 mm

Table 3: Weld bead geometry measurement.

Temperature measurement

The temperature distribution during welding is an important factor to consider in ensuring the quality and strength of the welded joint. However, the welding speed plays a crucial role in determining the temperature distribution during the welding process. The temperature evolution was measured by the TC2 thermocouple located on the welding line at the bottom of the substrate using the Data Logger 3 software during the passage of the filler metal.

As shown in Fig. 9, the maximum temperature is reached with a welding speed equal to 50 cm/min, approximately 470 °C. While with a welding speed equal to 60 cm/min, the highest temperature achieved is 367 °C. Lower welding speed allows more time for the heat to be absorbed by metal, resulting in a more uniform temperature distribution. While a higher welding speed can increase the risk of defects such as cracks or distortion due to thermal stresses. Thus, selecting the appropriate welding speed for a given application is an important consideration for achieving a high quality welded joint.

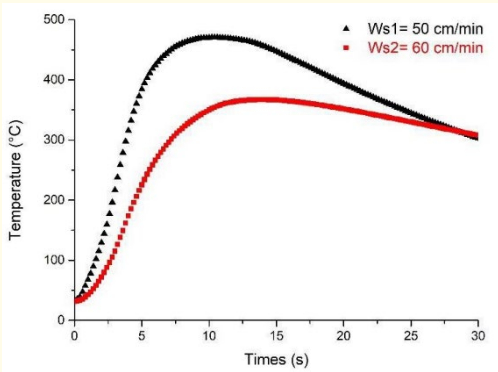

Figure 9: Temperature distribution for two different welding speeds.

Conclusion

In this study, a thorough examination of the LSC-GMAW welding process was performed. Two weld joints with different welding speeds were performed on the A304 L steel substrate. Based on a front and transverse macrograph, geometrical parameters of the weld bead are measured and used as heat source parameters. These parameters will be used for further numerical predictions to match the reality of the welding process more closely.

In addition, it was found that modifying the welding speed can affect the temperature distribution and the construction of weld beads. The choice of welding speed is a critical factor in determining the quality and efficiency of a welding process. Therefore, finding the optimal welding speed is essential to achieving a robust, high-quality weld while minimizing distortion.

References

1. Ahmad SN., et al. “Experimental validation of numerical simulation on deformation behaviour induced by wire arc additive manufacturing with feedstock SS316L on substrate S235”. Int. J. Adv. Manuf. Technol 119 (2022): 1951-1964.
2. Chen J, Wu CS and Chen MA. “Improvement of welding heat source models for TIG-MIG hybrid welding process”. J. Manuf. Process 16 (2014): 485-493.
3. Deng D. “FEM prediction of welding residual stress and distortion in carbon steel considering phase transformation effects”. Mater. Des 30 (2009): 359-366.
4. Fiedler M., et al. “Control of mechanical properties for high strength steels through optimized welding process”. Engineering technologies in manufacturing of welded constructions and products (2017).
5. Fronius. “LSC.” (2023).
6. Giarollo DF, Mazzaferro CCP and Mazzaferro JAE. “Comparison between two heat source models for wire-arc additive manufacturing using GMAW process”. J. Braz. Soc. Mech. Sci. Eng 44 (2022): 7.
7. Goldak J, Chakravarti A and Bibby M. “A new finite element model for welding heat sources”. Metall. Trans. B 15 (1984): 299-305.
8. Iacobescu G. “A Theoretical Model for Welding Process with Gaussian Heat Source - Part. 1”. UPB Scientific Bulletin, Series D:

Mechanical Engineering 68.4 (2006): 45-50.

9. Khoshroyan A and Darvazi AR. “Effects of welding parameters and welding sequence on residual stress and distortion in Al6061-T6 aluminum alloy for T- shaped welded joint”. Trans. Nonferrous Met. Soc. China 30 (2020): 76-89.
10. Song J., et al. “Sensitivity analysis of the thermomechanical response of welded joints”. Int. J. Solids Struct 40 (2003): 4167-4180.

Volume 8 Issue 1 January 2025