RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 7 No. 1 (2026) 195-201
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Research on Dwell Time of SS316L in Wire Arc Additive Manufacturing Using Simulation

Idham Nur Hakim Din[1], Mohd Halim Irwan Ibrahim [1*], Sarah Nadiah Mohd Ghazali [1]

[1] *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, MALAYSIA*

*Corresponding Author: mdhalim@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2026.07.01.021

Article Info

Received: 1 December 2025
Accepted: 1 February 2026
Available online: 28 February 2026

Keywords

Wire Arc Additive Manufacturing (WAAM), SS316L stainless steel, dwell time, layer count, residual stress, displacement, Simufact Welding, Taguchi method, thermal management.

Abstract

Wire Arc Additive Manufacturing (WAAM) offers an efficient and sustainable method for producing large metal components with reduced material waste. Among the materials commonly used, SS316L stainless steel is widely favored for its excellent corrosion resistance and mechanical properties, making it ideal for applications in aerospace, marine, and medical industries. However, controlling the heat generated during the layer-by-layer process remains a major challenge. One of the most influential parameters is dwell time, which refers to the pause between each deposited layer. This study explores the effect of dwell time on the thermal behaviour, deformation, and residual stress of SS316L components using numerical simulation. Simufact Welding software was used to simulate different dwell time settings across three-layer configurations. The Taguchi method was applied to design the experiments and identify optimal parameters with minimal trials. The results show that shorter dwell times, especially at lower layer counts, significantly improve dimensional accuracy and reduce residual stress. The combination of 15 seconds dwell time with 5 layers produced the most stable results. These findings highlight the importance of dwell time in controlling thermal accumulation and improving build quality. This research contributes practical insights for process optimization in WAAM and supports its broader industrial application.

1. Introduction

Wire Arc Additive Manufacturing (WAAM) is a 3D metal printing process that builds parts layer by layer using welding. It is fast and suitable for making large metal components. SS316L stainless steel is often used in WAAM because it is strong, corrosion-resistant, and easy to weld. However, heat from the welding process can build up during printing [1]. This affects the part's shape, creates residual stress, and weakens its mechanical properties. One key factor in controlling heat is dwell time, the pause between layers. If dwell time is too short, heat can build up too much, causing warping and stress. If it's too long, the bond between layers can become weak. So, it's important to find the best dwell time to reduce defects and improve part quality [2]. In this research, Simufact Welding software is used to simulate how different dwell times affect SS316L parts. The Taguchi method is used to find the best combination of dwell time and layer height using fewer simulations. This study aims to improve

the WAAM process for SS316L by finding the right dwell time to reduce stress, control heat, and improve part quality.
The technical background and previous research on SS316L stainless steel, Wire Arc Additive Manufacturing (WAAM), and the effect of dwell time on mechanical and thermal behaviour in WAAM processes are reviewed in this chapter. It emphasises how crucial process control is to reducing residual stress and displacement, particularly dwell time. WAAM is renowned for its ability to produce large metal parts and its high rate of deposition. Nevertheless, issues like heat accumulation, distortion, and internal stress may arise from the layer-by-layer process's repeated heating [3-4]. The final product's performance and quality are directly impacted by these problems. Because of its superior weldability and resistance to corrosion, SS316L is a material that is frequently used in WAAM. However, it is still impacted by thermal cycles during printing, just like other materials. Dwell time, which regulates the interval between layers and aids in controlling heat flow, is one of the most important factors. The results of earlier research and simulations are presented in this chapter to help clarify how dwell time, heat accumulation, and interlayer temperature impact the final characteristics of WAAM [5-7]-built components. The objective is to establish a solid basis for the method used in this study to optimise dwell time for SS316L through statistical analysis and simulation.

2. Methodology

This study uses Simufact Welding software to simulate the WAAM process for SS316L, focusing on the effect of different dwell times. The simulation is carried out using the finite element method (FEM), which allows modeling of temperature distribution, heat input, and thermal stress during the layer-by-layer deposition process. The wall geometry, mesh size, material properties, and process parameters are set in the software to closely mimic actual WAAM conditions as shown in Table 1.

The WAAM process is simulated with three different layer counts: 5 layers, 10 layers, and 15 layers. Each layer configuration is tested with three dwell times: 15 seconds, 60 seconds, and 120 seconds as shown in Table 2. This results in nine total simulation scenarios. The parameters such as current, voltage, welding speed, and dwell time are assigned based on previous studies and configured within the Simufact environment [8].

To reduce the number of simulations and analyze the impact efficiently, the Taguchi method is used with an L9 orthogonal array. Signal-to-noise (S/N) ratio analysis is applied using the "smaller-the-better" approach for both displacement and residual stress values.

Simulation outputs are then verified through comparison with known trends from existing research, ensuring reliability before data analysis.

Table 1 Simulation Parameters

Parameter	Value	Description
Welding Method	Gas Metal Arc Welding (GWAM)	Selected method for WAAM process.
Material	SS316L Stainless Steel	Workpiece material used in the study.
Layer Thickness (mm)	2	Thickness of each deposited layer.
Number of Layers	10	Total layers used in the simulation.
Dwell Time (s)	15, 60, 120	Time between successive layers to analyse the impact on residual stress
Wire Feed Rate (mm/min)	Constant 5.9	Speed of the wire feed in the process.
Heat Source Model	Gaussian	Heat source applied for the WAAM simulation.

Table 2 L9 Orthogonal Array for WAAM Simulation

Simulation Run	Number of WAAM layer	Dwell Time (s)
1	5	15
2	5	60
3	5	120
4	10	15
5	10	60
6	10	120
7	15	15
8	15	60
9	15	120

3. Result and Discussion

This chapter presents the results of the WAAM simulations for SS316L using different dwell times and layer heights. The analysis focuses on two main outputs: displacement and residual stress, which were measured across three paths (A-B, C-D, and D-E) with six data points per path. The goal is to determine how dwell time affects thermal behavior and structural stability.

3.1 Simulation Point Setup

The wall was divided into three sections: A-B (bottom), C-D (middle), and D-E (top), each consisting of six measurement points (Figure 1 & 2). This setup allows detailed observation of deformation and stress distribution at various heights.

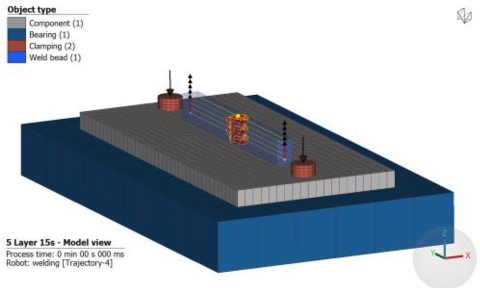

Fig. 1 Simulation setup

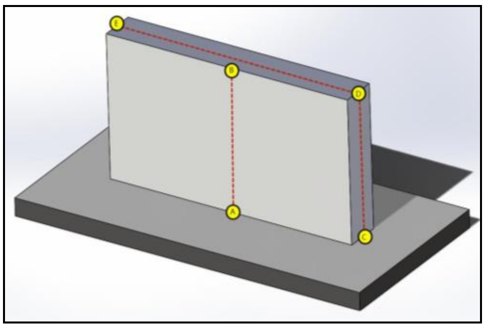

Fig. 2 Wall model indicating measurement points A, B, C, D, and E.

3.2 Displacement Results

Displacement analysis in WAAM reveals how deformation varies with layer height and dwell time across three regions: bottom (A–B), middle (C–D), and top (D–E) as shown in Figure 3 to 5. At the bottom (A–B), displacement was generally the lowest due to support from the base, with the smallest value of 0.05 mm recorded in the 5-layer build with 60s dwell time. As layers increased, especially at 10 and 15 layers, displacement rose, reaching up to 0.61 mm. In the middle region (C–D), deformation increased further due to thermal buildup, with the 10- and 15-layer builds showing values as high as 1.77 mm, particularly at longer dwell times. The top region (D–E) showed the highest overall displacement, especially in the 15-layer configuration with 120s dwell, confirming that taller structures are more prone to thermal distortion. Overall, shorter builds and moderate dwell times (like 60s) gave better dimensional stability, while taller builds suffered more from heat accumulation and increased deformation.

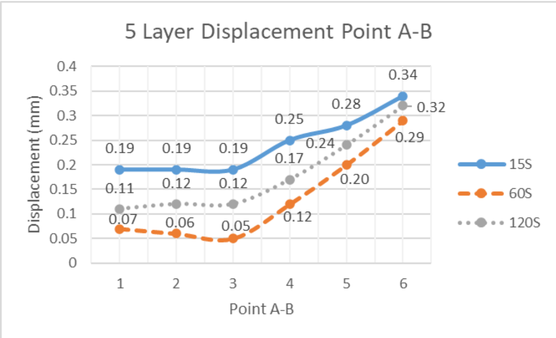

Fig. 3 5 Layer Displacement Point A-B

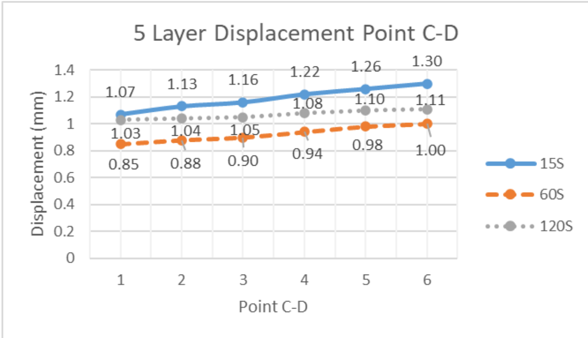

Fig. 4 5 Layer Displacement Point C-D

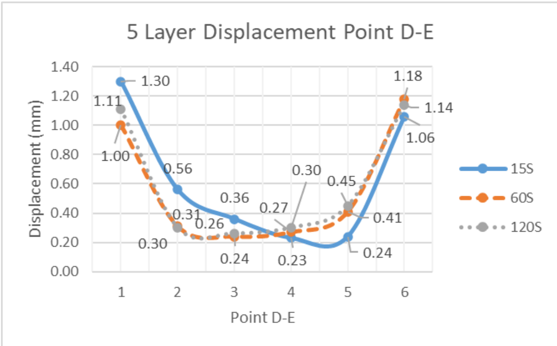

Fig. 5 5 Layer Displacement Point D-E

3.3 Residual Stress Results

Residual stress is a key concern in WAAM, as it can compromise mechanical reliability and dimensional precision as shown in Figure 6 to 8. Analysis across three vertical regions (A–B, C–D, and D–E) revealed that stress patterns vary with both dwell time and layer count. At the bottom region (A–B), the 5-layer build showed high stress at 120s dwell (209.86 MPa), but significantly lower values at 60s (31.30 MPa), indicating that moderate dwell improves thermal relief. In the 10-layer setup, 15s dwell showed moderate stress control, while the 15-layer case peaked at 184.06 MPa under 15s but dropped to just 11.40 MPa at 120s. In the middle section (C–D), shorter dwell times reduced stress more effectively in 5- and 10-layer builds, while 60s provided the smoothest drop in the 15-layer case. At the top region (D–E), the stress trends were less consistent; however, the 15-layer configuration with 15s dwell time delivered the most stable and lowest stress (25.84–38.98 MPa), while longer dwell times like 60s and 120s led to increased peaks. These results highlight that shorter dwell time is beneficial in upper layers, while moderate dwell (60s) is most effective in reducing stress accumulation in the middle and bottom of the build [9].

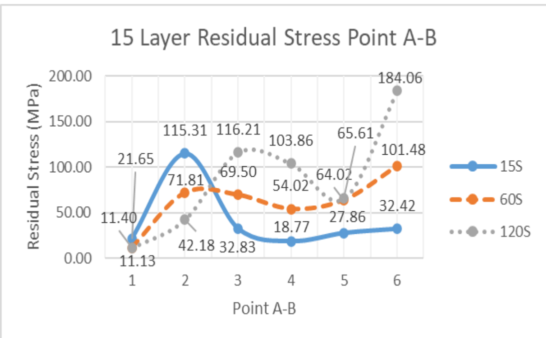

Fig. 6 15 Layer Residual Stress Point A-B

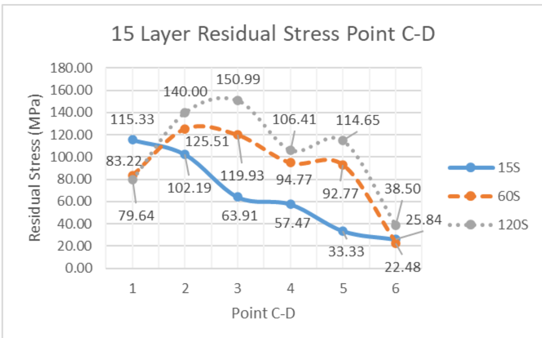

Fig. 7 15 Layer Residual Stress Point C-D

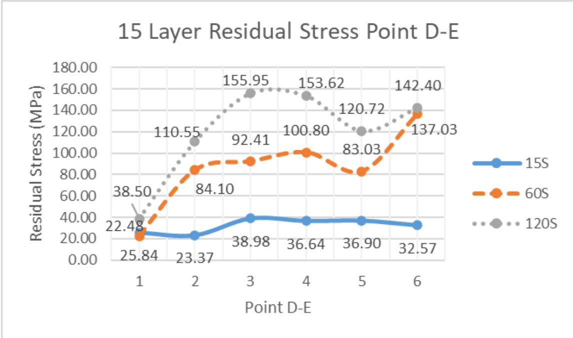

Fig. 8 15 Layer Residual Stress Point D-E

3.4 Taguchi Analysis

Taguchi analysis was applied to statistically evaluate how dwell time and layer count influence both displacement and residual stress in SS316L parts fabricated by WAAM as shown in Figure 9 to 12. Using the "smaller is better" approach, the analysis showed that layer count has a greater effect than dwell time on both responses. For displacement, the signal-to-noise (S/N) ratio and mean values indicated that the 5-layer configuration resulted in the lowest deformation, especially when paired with a 15s dwell time. As the number of layers increased to 10 and 15, displacement also increased due to accumulated heat and geometric distortion. Similarly, for dwell time, shorter intervals like 15s led to better displacement control, likely because they prevented excessive heat buildup. In the case of residual stress, the 5-layer build again performed best, showing the highest S/N ratio and the lowest stress variability, while 15-layer parts showed increased stress due to extended thermal cycling. Dwell time had a secondary but noticeable effect: shorter dwell times such as 15s reduced residual stress, while longer times like 120s led to stress accumulation due to uneven cooling. The main effects plots for both displacement and residual stress supported these trends, showing clear increases in both values with longer dwell times and higher layer counts. In conclusion, the Taguchi method confirmed that the optimal setup for minimizing both displacement and residual stress is 5 layers with a 15-second dwell time, which provides a more balanced heat distribution and minimizes thermal distortion throughout the WAAM process [10].

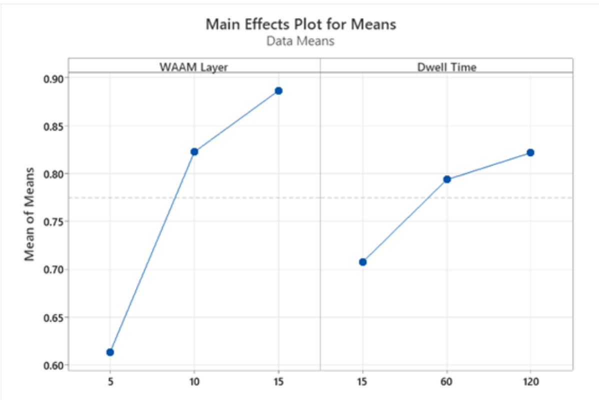

Fig. 9 Main Effects Plot for Means – Displacement.

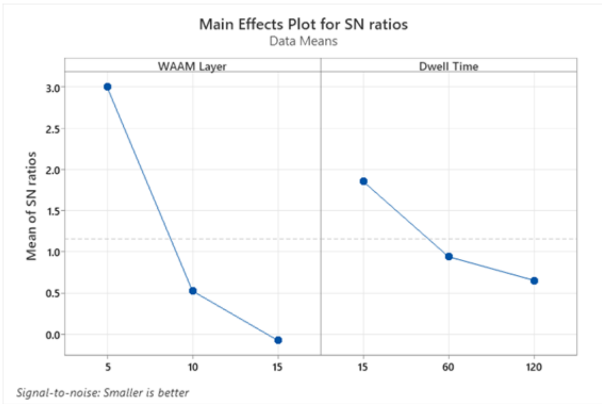

Fig. 10 Main Effects Plot for Signal-to-Noise Ratios – Displacement.

Fig. 11 Main Effects Plot for Means – Residual Stress.

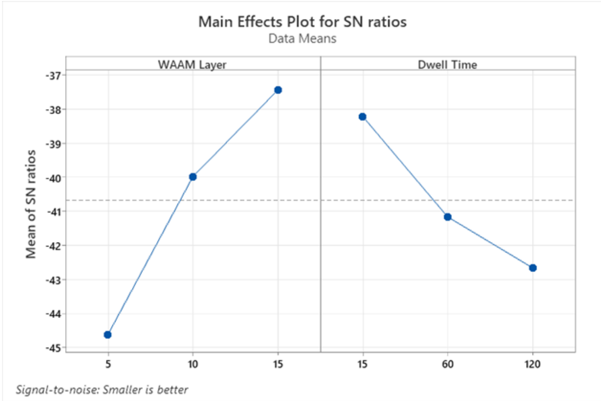

Fig. 12 Main Effects Plot for Signal-to-Noise Ratios – Residual Stress.

3.5 Summary of Findings and Suitable Parameter Selection

This study examined how different dwell times (15s, 60s, 120s) and layer counts (5, 10, 15 layers) affect residual stress and displacement in WAAM-fabricated SS316L parts. Simulations across three vertical paths (A–B, C–D, and D–E) showed that increasing the number of layers generally leads to higher stress and deformation, especially at the top. Similarly, longer dwell times cause more heat buildup and stress. The Taguchi analysis confirmed that layer count had a stronger effect than dwell time. The best overall result came from using 5 layers with a 15s dwell time, which minimized both stress and displacement. For taller builds, a 60s dwell time gave better balance between cooling and thermal input. The recommended combinations are:

- 5 layers: 15s dwell time, best for minimizing stress and deformation.
- 10 layers: 60s dwell time, best for balanced thermal behavior and dimensional accuracy.
- 15 layers: 60s dwell time, most effective in controlling both stress and displacement in tall builds.

In short, low dwell times suit smaller builds, while moderate dwell times (60s) are better for taller structures to prevent excessive stress and warping. These insights help guide WAAM process optimization for stronger, more accurate components.

4. Discussion and Conclusion

This study examined how dwell time and layer count affect residual stress and displacement in the WAAM process for SS316L using thermal-mechanical simulations in Simufact Welding and Taguchi analysis. The results showed that higher dwell times and more layers led to increased deformation and residual stress, especially in the upper region of the building due to heat accumulation and limited cooling. The bottom section (A–B) consistently had lower values because of base support. The 5-layer configuration with 15s dwell time showed the best performance in minimizing displacement, while stress reduction varied depending on region, with 60s dwell time performing well in both 5-layer and 15-layer builds. Taguchi analysis confirmed that layer count was the most influential factor, followed by dwell time. These findings emphasize the importance of thermal control in WAAM, showing that shorter dwell times and fewer layers can effectively reduce internal stress and distortion. The study offers practical guidance for improving the mechanical quality of stainless-steel parts made through WAAM by selecting suitable process parameters [11].

Acknowledgement

This author expresses their gratitude to the Faculty of Mechanical Manufacturing Engineering at Universiti Tun Hussein Onn Malaysia for their valuable support and opportunity to conduct this study.

References

[1] Srivastava, M., et al. (2023). "Wire arc additive manufacturing of metals: A review on processes, materials and their behaviour." Materials Chemistry and Physics.

[2] Jhavar, S. (2021). "Wire arc additive manufacturing: approaches and future prospects." In Additive Manufacturing.

[3] Gürol, U., et al (2023). "A comparative study on the microstructure, mechanical properties, wear and corrosion behaviors of SS 316 austenitic stainless steels manufactured by casting and WAAM technologies." CIRP Journal of Manufacturing Science and Technology.

[4] Ma, D., et al. (2023). "Enhanced strength-ductility synergy in a wire and arc additively manufactured Mg alloy via tuning interlayer dwell time." *Journal of Magnesium and Alloys*.

[5] N Farias, et al. (2021). "Prediction of the interpass temperature of a wire arc additive manufactured wall: FEM simulations and artificial neural network." *Additive Manufacturing*.

[6] Wang, C., et al. (2020). "Study on microstructure and tensile properties of 316L stainless steel fabricated by CMT wire and arc additive manufacturing." Materials Science and Engineering.

[7] Zhong, Y., et al. (2021). "Fabrication of 316L nuclear nozzles on the main pipeline with large curvature by CMT wire arc additive manufacturing and self-developed slicing algorithm." *Materials Science and Engineering.*

[8] Montevecchi, F., et al. (2018). "Idle time selection for wire-arc additive manufacturing: A finite element-based technique." Additive Manufacturing.

[9] Goviazin, G. et al. (2023). "Achieving high strength with low residual stress in WAAM SS316L using flow-forming and heat treatment." Materials Science and Engineering.

[10] Ramalho, A., et al. (2022). "Effect of contaminations on the acoustic emissions during wire and arc additive manufacturing of 316L stainless steel." Additive Manufacturing

[11] Rodrigues, T. A., et al. (2021). "Effect of heat treatments on 316 stainless steel parts fabricated by wire and arc additive manufacturing: Microstructure and synchrotron X-ray diffraction analysis." Additive Manufacturing.