FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

ENHANCING DEPOSITION QUALITY OF ALUMINUM ALLOY 5356 THROUGH OPTIMIZATION OF WAAM PROCESS PARAMETERS

[1]Chiabuotu, C. C. *, [2]Abioye, T. E., [3]Olabanji, O. M., [4]Kusoro, O. O., [5]Adeniran, A. D.
[1]Mechanical Engineering Department, Federal University of Technology Owerri, PMB. 1526, Owerri. Imo State, Nigeria.
[2]Industrial Production Engineering Department, Federal University of Technology, Akure. Ondo State, Nigeria.
[3]Mechanical Engineering Department, Federal University of Technology, Akure. Ondo State, Nigeria.
[4]Department of General Studies, Federal School of Surveying, Oyo, Nigeria.
[5]Mechanical Engineering Department, Elizade University, Ilara-Mokin, Ondo State, Nigeria.
**Corresponding author: celine.chiabuotu@futo.edu.ng*

Chiabuotu, C. C., Abioye, T. E., Olabanji, O. M., Kusoro, O. O., Adeniran, A. D. (2026): Enhancing Deposition Quality of Aluminum Alloy 5356 Through Optimization of WAAM Process Parameters. FUTA Journal of Engineering and Engineering Technology 20(special), 124-134

Received Date: 15.01.2026 **Accepted Date: 10.03.2026**

Abstract
Wire Arc Additive Manufacturing (WAAM) gives a transformative method for fabricating components from 5356 aluminum alloy, a material which is a sought after because of its good mechanical properties and its common use in aerospace sector. WAAM technique has many advantages but parts produce through the process faces such problems as porosity, cracking, and warping. These limitations can affect the structural integrity of the produced parts and manufacturing efficiency is reduced since post-processing activities are required. This study aims at optimizing WAAM process parameters so that the geometry and quality of single-track deposits of AA5356 can be improved. The study made use of a full factorial experimental design that involves three factors at three levels to explore the process window. This was done to identify the optimal combination of parameters, which yield high dimensional accuracy and surface integrity devoid of pores, cracks and other defects. It was found out that the height of the track increased as the wire feed rate increased and the traverse speed decreased. The optimal deposition parameters that will yield material with both high dimensional accuracy and structural integrity were found out and were used for the deposition of well-defined single tracks with aspect ratios between 1.5 and 4, acute contact angles, and minimal porosity. These conditions helped to achieve a defect-free tracks with excellent dimensional consistency. These findings advertises the use of WAAM technology in the manufacturing industries as well as makes available a solid foundation for subsequent research and industrial implementation.

***Keywords**: wire arc additive manufacturing (WAAM), aluminum 5356, process optimization, track geometry, analysis of variance, multi-track deposition*

Introduction

Additive Manufacturing (AM) has come to stay as a force that revolutionizes manufacturing process as it makes easy the creation of 3-dimensional objects via adding materials in layers from digital models (Gibson et al., 2015). This technology is quite the opposite of traditional subtractive manufacturing methods where material are removed to produce the desired shape. Going by the feedstock employed, AM processes are broadly grouped under polymer-based and metal-based techniques, applications of which differ (Mazeeva et al. 2024). Polymer- based methods include Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS). These are used for creating prototypes rapidly and for producing functional parts especially in applications where there is need for high mechanical strength (Chua & Leong, 2017). The polymer- based methods make use of various polymeric materials to produce intricate designs quickly and at a moderate cost (Aminul et al., 2024). Metal-based additive manufacturing techniques, in reverse, include Electron Beam Melting (EBM), Direct Laser Metal Deposition (DLMD), and Wire Arc Additive Manufacturing (WAAM). WAAM is better suited for fabricating functional components with high-strength to be used in automotive, aerospace, and defense industries (Wang et al., 2018). WAAM has some unique advantages above other techniques which include high deposition rate that enables it to produce medium-to-large-scale metal components with high precision. WAAM uses electric arc as heat source, hence, it has lower processing cost compare to other metal-based AM techniques that utilizes laser to process the materials. This is another advantage of WAAM (Abioye et al., 2025).

AA5356 has exceptional characteristics which make it well-suited for various applications in the aerospace, marine, and automotive industries such as excellent corrosion resistance, high strength-toweight ratio, high machinability and low cost (Jiankun et al., 2021; Muthukumaran et al., 2024). Despite the fact that WAAM technique is increasingly used in the processing of aluminum alloys such as AA5356 into functional industrial components, still the process faces challenging issues like pore formation, surface cracking, and low dimensional accuracy. And, this is obtained solely because of the high heat input involved in the WAAM process.

Efforts have been made to combat the above WAAM challenges so as to improve the quality of single-track aluminum alloy deposited through the process. Some of the efforts include process optimization of the WAAM parameters, mechanical workings, and post-heat treatment. Process optimization amongst all, is the most commonly used effective method since it helps to control and refine key WAAM parameters such as wire feed rate, travel speed and shielding gas flow while deposition is taking place. This is different from post-processing methods that can be time-consuming and costly. So, optimizing the process parameters directly at the manufacturing stage reduces defects such as porosity and cracking, enhances dimensional accuracy, and reduces the need for additional finishing operations.

Srinivas et al. (2022) investigated the parametric optimization of WAAM for AA5356 aluminum alloy using the Taguchi design of experiments. The parameters, which included wire feed rate, traverse speed, and gas flow rate were varied at three levels each. It was discovered from the analysis of Variance (ANOVA) that the wire feed rate was the most significant factor that influences both the geometry and mechanical properties of the WAAM deposits. Kesarwani et al. (2025) also looked into optimization of Cold Metal Transfer (CMT)-based WAAM of aluminum alloys to reduce porosity and surface roughness. They used the Taguchi method to optimize such parameters as traverse speed, current, and type of feed wire. It was discovered from their research that AA5356 deposited at a current of 115A and a traverse speed of 6 mm/s showed the lowest levels of porosity and surface roughness.

To date, most process optimization studies on WAAM of aluminum alloys have relied on the Taguchi method. However, there is limited research employing full factorial design, which is considered more robust and statistically reliable for exploring parameter interactions and generating more accurate optimization results. Therefore, the aim of this research is to optimize WAAM process parameters for the fabrication of high-quality single-track AA5356 deposits, with a focus on achieving high dimensional accuracy and eliminating surface defects such as pores and cracks. In this study, AA5356 single tracks were deposited using the WAAM process. The resulting tracks was analyzed for geometric characteristics, and the optimal combination of parameters that yields the most suitable track quality for future multi-track builds was identified.

Methodology

Materials. AA5356 wire, a non-heat-treatable alloy, of diameter 1.2 mm was used as the feedstock material, while, AA6061 with dimensions 180 mm x 100 mm x 6 mm was used as the substrate. The wire feedstock was deposited on the substrate. The composition elements of the feedstock wire and the substrate are shown in Table 1. The substrate surface before deposition commenced, was degreased using a wire brush and emery cloth, after which it was cleansed with acetone to remove any contaminants that could reduce arcing efficiency.

WAAM Process:

A CNC machine integrated with a Gas Metal Arc Welding (GMAW) system, was used in carrying out the WAAM process. It is a setup where an automated CNC milling machine tool was interfaced with a GMAW unit configured for 3-axis motion. The WAAM-GMAW configuration enabled the single-track depositions of AA5356 alloy. By systematically varying three key process parameters: current, wire feed rate, and traverse speed, each at three distinct levels as shown in Table 2, a total of twenty-seven (27) single tracks deposits were made. There were preliminary trial experiments, which helped in the selection of parameter levels in order to ensure process stability and quality. Atmospheric contamination and oxidation could compromise the mechanical and corrosion resistance properties of the deposited tracks, hence, argon gas was employed as a shielding gas from atmospheric influence. Some trials were conducted both with and without shielding gas to ascertain its impact on the quality of the deposited tracks.

Table 1: Chemical Composition of Wire feedstock and the Substrate

Element	Al	Si	Mg	Fe	Mn	Cr	Ni	Zn	Cu
AA5356	94.5	0.18	4.9	0.27	0.03	0.08	0.02	0.01	
AA6061	97.63	0.56	0.89	0.32	0.04	0.23	0.02	0.05	0.27

Table 2: List of Combined Parameters for the Optimization of Single-Track depositions

S/N	Voltage (V)	Wire Feed Rate (m/min)	Traverse Speed (mm/min)
1	12	6.5	60
2	12	6.5	120
3	12	6.5	180
4	12	8.5	60
5	12	8.5	120
6	12	8.5	180
7	12	10.5	60
8	12	10.5	120
9	12	10.5	180
10	15	6.5	60
11	15	6.5	120
12	15	6.5	180
13	15	8.5	60
14	15	8.5	120
15	15	8.5	180
16	15	10.5	60
17	15	10.5	120
18	15	10.5	180
19	18	6.5	60
20	18	6.5	120
21	18	6.5	180
22	18	8.5	60
23	18	8.5	120
24	18	8.5	180
25	18	10.5	60
26	18	10.5	120
27	18	10.5	180

Visual Surface Inspection and Geometrical Characterization

Visual surface inspection of the AA5356 single tracks was observed to assess surface quality and identify any possible defects such as pores or cracks. Thereafter, the tracks were transversely cross-sectioned, and their geometrical features including height (H) and width (W) were measured using optical microscopy in conjunction with image processing software. The aspect ratio (AR) and wetting angle (β) for each track were then calculated using Equations 1 and 2, respectively (Abioye et al, 2024).

$$AR = \frac{W}{H} \quad (1)$$

$$\theta = 2tan^{-1}\left(\frac{2H}{W}\right) \qquad (2)$$

Analysis of Variance

Analysis of Variance (ANOVA) was carried out to statistically evaluate the influence of the selected process parameters (voltage, wire feed rate, and traverse speed) on the geometric characteristics of the deposited tracks, specifically the aspect ratio and wetting angle. The ANOVA was performed at a 95% confidence level to determine the significance and contribution of each parameter to the variation observed in the track geometry. This statistical approach made it possible to identify the most influential factors affecting the aspect ratio and wetting angle, and then, provided insights into the optimal parameter combinations for improved deposition quality.

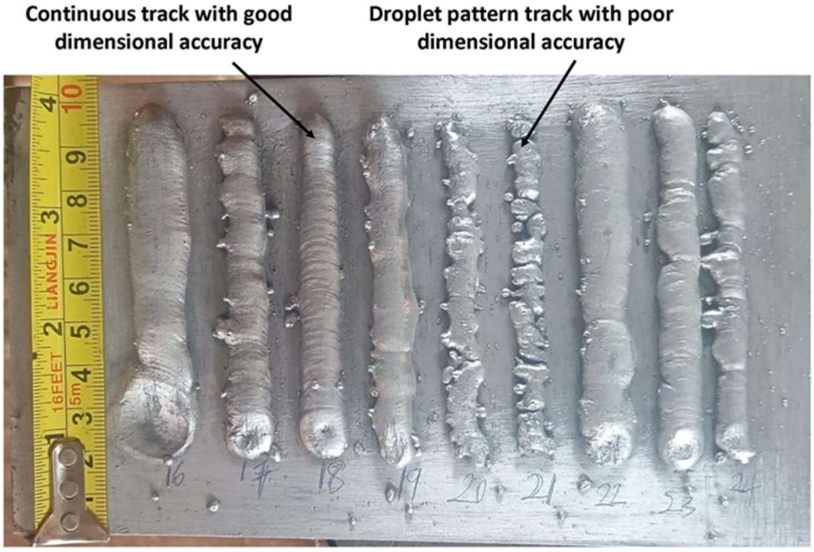

Figure 1: Some selected single track deposited via WAAM-GMAW technique

Figure 2: AA5356 single tracks deposited via WAAM-GMAW without argon shielding gas, showing poor surface finish and compromised structural integrity.

Result and Discussion

Visual Inspection and Quality Assessment of Deposited Tracks

Using a 3^3 full factorial experimental design with variations in wire feed rate, traverse speed, and voltage, a total of 27 single tracks deposits were built. Figure 1 presents selected deposited tracks. Visual inspection showed significant differences in track morphology and dimensional accuracy, which is directly influenced by the processing parameters. Tracks that were continuous and well-formed exhibited smooth surfaces and consistent widths, which suggests that they received stable metal transfer and adequate heat input, hence, are high-quality tracks. They had no pores and cracks, which indicates optimal fusion and solidification conditions.

Table 3: AA5356 WAAM deposition characteristics

S/N	Voltage (V)	Wire Feed Rate (m/min)	Traverse Speed (mm/min)	Width (mm)	Height (mm)	Aspect Ratio	Contact Angle (o)
1	12	6.5	60	10.2	7.0	1.4	108
2	12	6.5	120	9.4	6.4	1.5	107
3	12	6.5	180	8.4	6.0	1.4	110
4	12	8.5	60	11.3	7.9	1.4	109
5	12	8.5	120	10.7	7.4	1.5	108
6	12	8.5	180	10.1	6.8	1.5	107
7	12	10.5	60	12.6	9.9	1.3	115
8	12	10.5	120	11.6	8.7	1.3	113
9	12	10.5	180	10.6	7.8	1.4	112
10	15	6.5	60	10.8	6.6	1.7	101
11	15	6.5	120	9.8	6.1	1.6	102
12	15	6.5	180	9.2	4.7	1.9	92
13	15	8.5	60	12.4	7.6	1.6	101
14	15	8.5	120	11.6	6.4	1.8	96
15	15	8.5	180	10.9	5.4	2.0	90
16	15	10.5	60	13.4	8.6	1.6	104
17	15	10.5	120	14.0	8.0	1.7	98
18	15	10.5	180	12.8	7.0	1.8	95
19	18	6.5	60	11.3	6.0	1.9	94
20	18	6.5	120	10.4	5.2	2.0	89
21	18	6.5	180	9.5	4.1	2.3	81
22	18	8.5	60	13.1	6.6	2.0	91
23	18	8.5	120	12.6	6.0	2.1	87
24	18	8.5	180	11.8	5.2	2.3	83
25	18	10.5	60	14.5	7.8	1.9	94
26	18	10.5	120	14.1	7.0	2.0	90
27	18	10.5	180	13.7	6.3	2.2	85

In contrast, some tracks appeared wavy or displayed a droplet pattern, which is often a result of inadequate arc stability or mismatched process parameters particularly, excessive travel speed or low heat input. Tracks deposited without shielding gas (see Figure 2) showed pronounced porosity and brittleness, attributable to atmospheric contamination during deposition. In the absence of shielding gas, oxygen and nitrogen readily react with the molten pool, leading to gas entrapment and the formation of oxides and nitrides, which embrittle the track and compromise mechanical integrity (Bankong et al, 2024). Such defects render these tracks unsuitable for structural or loadbearing applications.

Optimization of Track Geometry

Table 3 presents the results of the width and height measurements of the single tracks. Each value is an average of 3 measurements taken around the mid-length of the tracks. The aspect ratio (AR) was calculated and recorded for each parametric combination.

The main effect plots generated using Minitab software are presented in Figures 3, 4, 5 and 6 for track width, height, aspect ratio and contact angle respectively. They illustrate the individual influence of wire feed rate, traverse speed, and voltage on the geometric characteristics of the deposited single tracks. The track width varied between 8.4 mm and 14.5 mm for all the parametric combinations used in this study. It was observed the track width increased as the wire feed rate and voltage increased, which shows that higher material feed and greater arc energy lead to wider bead formation. On the other hand, when the traverse speed is increased, the tracks become narrower, probably because of reduced heat input as well as shorter interaction time between the arc and substrate.

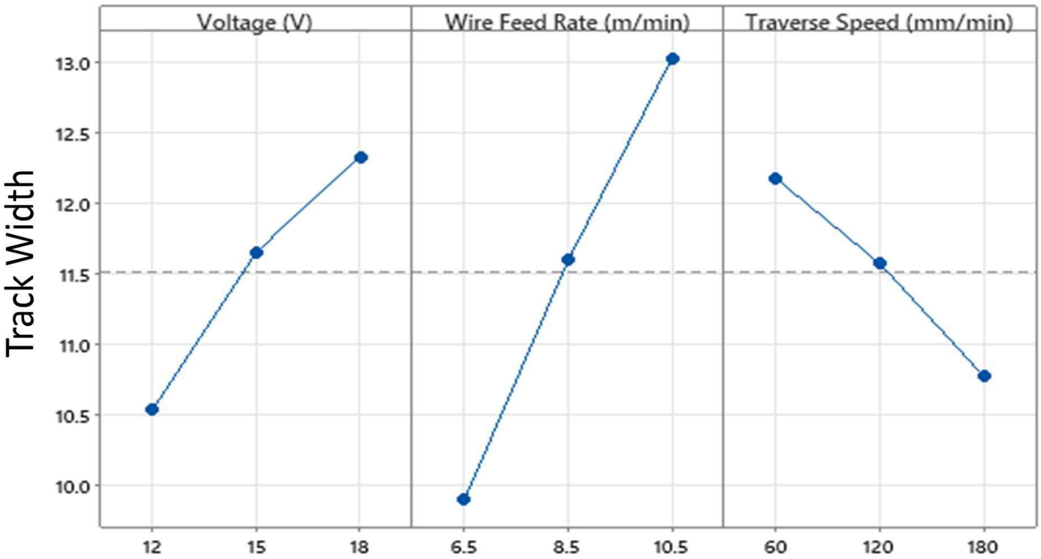

Figure 4(a): Main effect plot showing the variation of the width with the WAAM processing parameters for AA5356 single track deposition

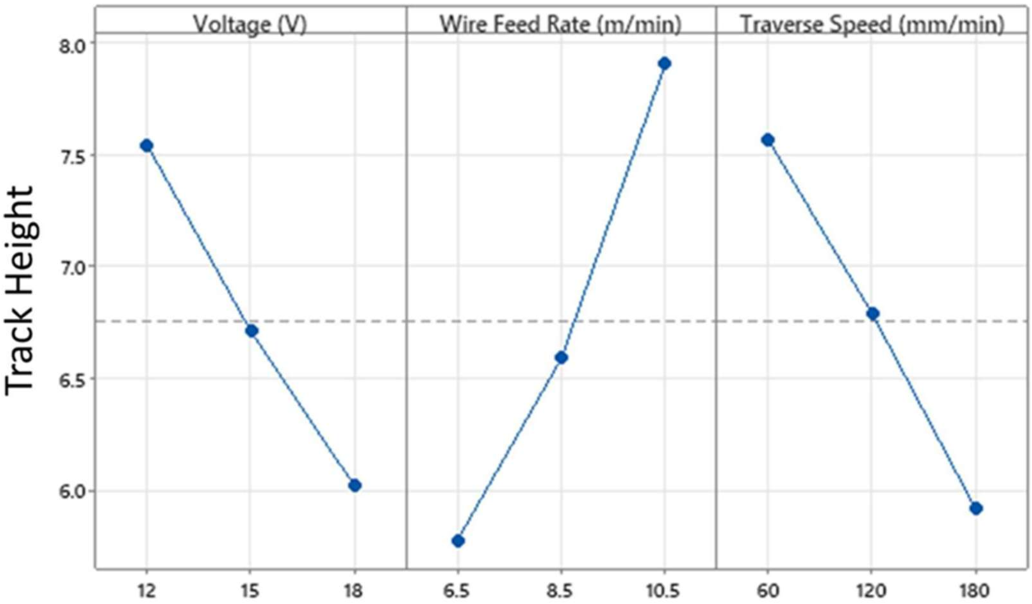

Figure 4(b): Main effect plot showing the variation of the height with the WAAM processing parameters for AA5356 single track deposition

Track height (ranging between 4.1 mm and 9.9 mm) exhibited a direct relationship with wire feed rate, as more filler material was deposited per unit time. However, height decreased with increasing traverse speed and voltage. This is attributed to faster movement and higher arc energy flattening the bead, spreading the molten pool, and reducing vertical buildup. The aspect ratio (width-to-height) ranged between 1.3 and 2.3. The ideal aspect ratio for WAAM deposition has been established to range between 1.5 < AR < 4 (Abioye et al., 2017; Abuabiah et al., 2024; Benoit et al., 2021; Gufran et al., 2022). Aspect ratio is a critical parameter in multi-track and multi-layer WAAM builds. A better aspect ratio enables adjacent tracks to overlap correctly without excessive bulging or under-filling. And, this condition is important for achieving, uniform fusion consistent layer height, and dimensional accuracy. Maintaining an optimal aspect ratio is the basis to achieving structural soundness and surface quality in WAAM- fabricated components. When it is low (< 1.5), it may lead to poor vertical growth and layer discontinuity, and when it is excessively high (> 4), it can result in poor track-to-track fusion and surface irregularities. It was discovered in this study, that the aspect ratio increases with both voltage and traverse speed. However, with respect to wire feed rate, the aspect ratio displayed a nonlinear behavior: it initially increased as the wire feed rate rose from 6.5 to 8.5 m/min, but decreased beyond 8.5 m/min up to 10.5 m/min. This trend indicates that there is an optimal wire feed rate for achieving balanced track geometry.

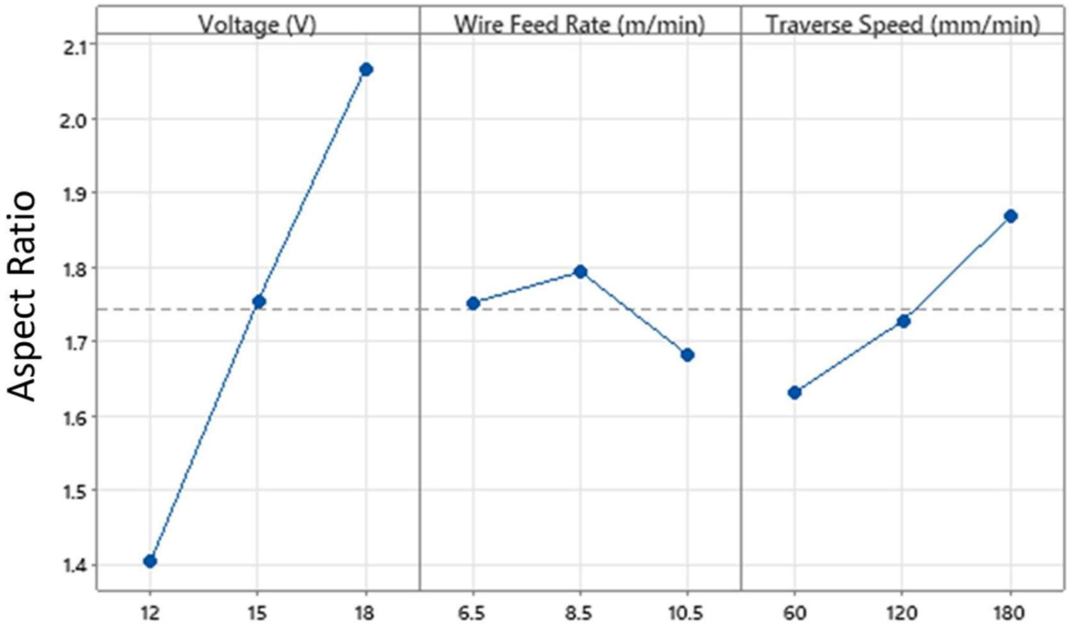

Figure 5: Main effect plot showing the variation of the aspect ratio with the WAAM processing parameters for AA5356 single track deposition.

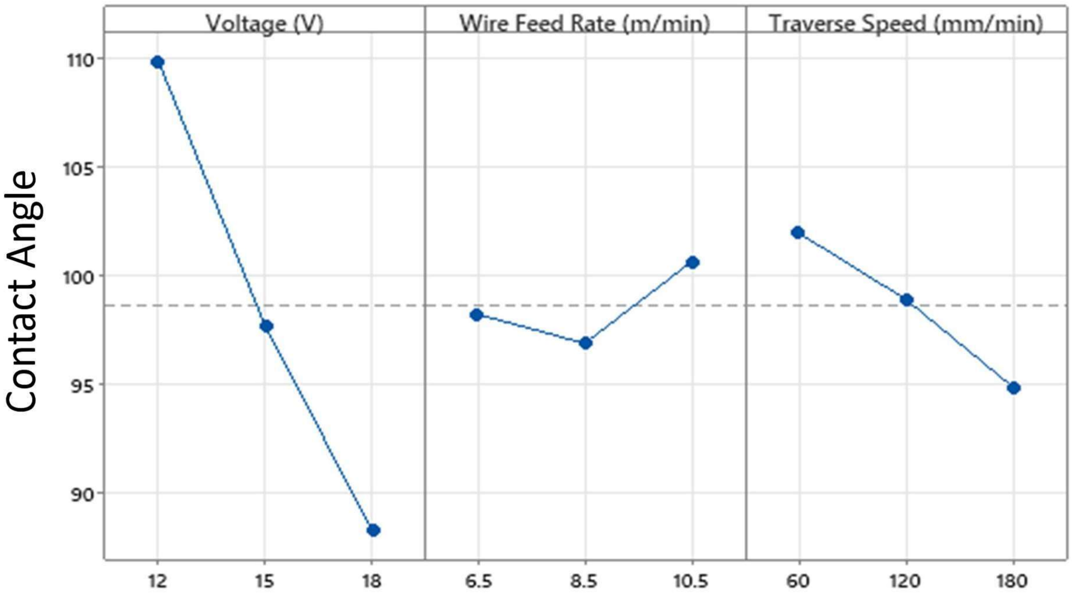

Figure 6: Main effect plot showing the variation of the contact angle with the WAAM processing parameters for AA5356 single track deposition

Table 4: Analysis of Variance for Width (mm)

Source	**DF**	**SS**	**MS**	**F**	**P**
Wire Feed Rate (m/min)	2	44.2867	22.1433	14.297	0.005
Traverse speed (mm/min)	6	9.2926	1.5488	1.563	0.215
Voltage (V)	18	17.8308	0.9906		
Total	26	71.4101			

Table 5: Analysis of Variance for Height (mm)

Source	**DF**	**SS**	**MS**	**F**	**P**
Wire Feed Rate (m/min)	2	20.7731	10.3865	5.088	0.005
Traverse speed (mm/min)	6	12.2492	2.0415	3.219	0.025
Voltage (V)	18	11.4176	0.6343		
Total	26	44.4399			

Table 6: Optimal parametric setting for multi-track AA5356 WAAM deposition

Voltage (V)	**Wire Feed Rate (m/min)**	**Traverse Speed (mm/min) (mm/min**	**Width (mm)**	**Height (mm)**	**Aspect Ratio**	**Contact Angle (o)**
18	6.5	180	9.5	4.1	2.3	81
18	8.5	180	11.8	5.2	2.3	83
18	10.5	180	13.7	6.3	2.2	85
18	8.5	120	12.6	6	2.1	87
18	6.5	120	10.4	5.2	2	89

The contact angle of the deposited single tracks ranged from 81° to 115°. The contact angle is defined as the angle formed at the interface between the deposited molten track and the substrate surface. It is a key factor for indicating the wetting behavior during deposition. If it is low, it shows improved wetting and spreading of the molten pool over the substrate, and this leads to stronger metallurgical bonding and enhanced fusion with the substrate or with the earlier deposited layers. Generally, acute contact angles (< 90°) are preferable in WAAM, as lack of fusion or voids. It was observed in this study, that the contact angle varied inversely with voltage and traverse speed, which suggests that higher arc energy or faster torch movement reduces the ability of the pool to spread. It was also noticed that the contact angle initially decreased with increasing wire feed rate, which is suggestive of improved wetting. However, beyond a wire feed rate of 8.5 mm/min, the contact angle began to increase, up to a higher value at 10.5 mm/min, probably as a result of excess material input or instability in molten pool dynamics the hinder optimal spreading.

In multi-track deposition, the contact angle plays a vital role in inter-track fusion and surface continuity. For instance, one produces more convex bead shapes with higher contact, which limits lateral spreading and reduces overlap between adjacent tracks (Abioye et al., 2023). This condition can lead to incomplete fusion and the formation of inter-run porosity, voids or gaps trapped between runs due to poor wetting or insufficient heat input. On the other hand, lower contact angles favour better spreading, leading to improved track coalescence, minimized inter-run porosity, and enhanced structural integrity of the deposited wall.

Analysis of variance

The ANOVA results for the width and height of the deposited tracks are shown in Tables 4 and 5, respectively. At a 95% confidence level, a process parameter is taken to possess a statistically significant effect if its p-value is less than or equal to 0.05. For the width of the track, only the wire feed rate was found to be statistically significant having a p-value of 0.005, an indication that the wire feed rate has a strong influence on the width of the deposited track, may be because of the direct role it plays in controlling the volume of material fed into the molten pool in a unit time.

For the height, both the wire feed rate ($p = 0.050$) and the traverse speed ($p = 0.025$) significantly affected the track height. The significance of wire feed rate in this context can be as a result of the increased deposition volume that gave rise to taller bead profiles. Meanwhile, the traverse speed influences the height by controlling the residence time of the heat source over a particular location. The slower the traverse speeds, the more accumulated materials and deeper penetration, which leads to increased track height, whereas higher traverse speeds yields thinner layers because of shorter interaction time.

Optimal Parametric Setting for Multitrack Deposition

Table 6 presents the sets of optimal WAAM process parameters suitable for depositing multitrack AA5356 structures that would have minimal defects like inter-run porosity, surface porosity, and ensuring excellent dimensional accuracy. The parameters have been shown to produce single tracks with aspect ratios ranging from 1.5 to 4, together with acute contact angles that promote effective wetting and fusion. Also, the resulting tracks demonstrate high dimensional consistency, a proof that the set of parameter gotten are suitable for high-quality, defect-free WAAM builds.

Conclusion

This study has demonstrated that the key process parameters like wire feed rate, voltage, and traverse speed determines the quality of AA5356 single tracks deposited via WAAM- GMAW. Optimal WAAM process parameter combinations produce continuous tracks with good dimensional accuracy, minimal defects, and favorable contact angles indicative of effective wetting and metallurgical bonding. It is established that the wire feed rate significantly affects both the track width and height, whereas traverse speed has a notable influence on the height. Obviously, the contact angle and aspect were proven to be key indicators of track stability and deposition quality. The optimal parameter settings identified in this study enabled the formation of well-defined single tracks with aspect ratios between 1.5 and 4, acute contact angles, and minimal porosity, which resulted in high dimensional accuracy and structural integrity. These findings support the advancement of defect-free, high-quality WAAM builds using AA5356 and establish a strong foundation for future research on multi-layer deposition, mechanical performance assessment, and post-processing strategies for diverse structural applications.

Acknowledgements

Our profound gratitude goes to God Almighty, the greatest enabler. We also want to acknowledge the efforts of the chief supervisor of this work who is also one of the authors, and the technologists who assisted in some machine shop exercises. Lastly, we thank the pre-paper reviewers for their tireless efforts in reviewing this paper.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

Abioye, T. E., Bankong, B. D., Ogundipe, O. J., Kusoro, O. O., & Ogedengbe, T. I. (2024). A parametric study on the stability, geometry and hardness of AISI 308LSi WAAM-GMAW. Materials Science Forum, 1131, 49–60.

Abioye, T. E., Chuah, Y. W., Zuhailawati, H., & Abdullah, A. B. (2023). Enhancing the single-track deposition quality of AISI 308L wire arc additive manufacturing via process optimization and cold forging treatment. Proceedings of the Institution of Mechanical Engineers. 239(5), 1 - 17

Abioye, T. E., Bankong, B. D., Ogedengbe, T. I., Odumuwagun, A., Zuhailawati, H., & Mbohwa, C. (2025). Enhancing mechanical, wear and corrosion properties of wire arc additively manufactured 308LSi stainless steel structures through cold forging and annealing processes. The International Journal of Advanced Manufacturing Technology, 139, 603–616.

Abuabiah, M., Weidemann, T. C., Elahi, M. A., Shaqour, B., Day, R., Plapper, P., & Bergs, T. (2024). Investigating the Impact of Process Parameters on Bead Geometry in Laser WireFeed Metal Additive Manufacturing. Journal of Manufacturing and Materials Processing, 8(5), 204.

Avery Bend, Venkata A.S. Kandadai, Jacob B. Petersen, Bharat K. Jasthi (2025). Effect of deposition pressure on the microstructure, mechanical, and corrosion properties of tantalum nitride thin films deposited by reactive pulsed laser deposition, Vacuum. 238, 114228,

Bankong, B. D., Ogundipe, O. J., Abioye, T. E., Ogedengbe, T. I., Zuhailawati, H., Adamolekun, T. M., Osasona, A. B., & Hassan, M. H. (2024). Cold forging and annealing of wire arc additively manufactured AISI 308LSi stainless steel. Advances in Science and Technology, 154, 41–47.

Benoit, M., Sun, S. D., Brandt, M., & Easton, M. A. (2021). Processing window for laser metal deposition of Al 7075 powder with minimized defects. Journal of Manufacturing Processes, 64, 1484–1492.

Blakey- Milner, B., Gradl, P., Snedden, G., Brooks, M., Pitot, J., Lopez, E., Leary, M., Berto, F., & du Plessis, A. (2021). Design freedom in additive manufacturing: Opportunities for aerospace applications. Additive Manufacturing, 39, 101771.

Campatelli, G.; Montevecchi, F.; Venturini, G.; Ingarao, G.; Priarone, P.C. Integrated WAAM-Subtractive Versus Pure Subtractive Manufacturing Approaches: An Energy Efficiency Comparison. Int. J. Precis. Eng. Manuf. Green. Technol. 2020, 7, 1–11

Celine C. Chiabuotu, Victor M. Mbachu, Uche, U. Opara, Daniel A. Ekpechi, Stanley C. Kanu (2024). Effect of Bio-Digester's Shape on Biogas Production: A Comparative Analysis Of 3d- Printed Triangular And Hexagonal Shaped Biodigesters. International Journal of Advances in Engineering and Management (IJAEM), 6(4) 1198-1209.

Chua, C. K., & Leong, K. F. (2017). 3D printing and additive manufacturing: Principles and applications. World Scientific.

Dhinakaran, V.; Ajith, J.; Fathima Yasin Fahmidha, A.; Jagadeesha, T.; Sathish, T.; Stalin, B. Wire Arc Additive Manufacturing (WAAM) process of nickel based superalloys—A review. Mater. Today Proc. 2020, 21, 920–925.

Du, W., Sun, G., Li, Y., & Chen, C. (2023). Process Optimization, Microstructure and Mechanical Properties of Wire Arc Additive Manufacturing of Aluminum Alloy by Using DP-GMAW Based on Response Surface Method. Materials, 16(16), 5716.

Frazier, W. E. (2014). Metal additive manufacturing: A review. Journal of Materials Engineering and Performance, 23(6), 1917-1927.

Gadagi, J. R., & Lekurwale, R. (2020). Defects in wire arc additive manufacturing and their mitigation. Materials Today: Proceedings, 27, 800-804.

Gibson, I., Rosen, D. W., & Stucker, B. (2015). Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing. Springer.

Gufran, M., Mishra, A., Singh, R. K., Sharma, A. K., Dixit, A., & Shah, A. (2022). Dependence of process planning strategy on deposition ratio in wire arc additive manufacturing. Materials Today: Proceedings, 62(Part 6), 3468–3472.

Habib, N., Vafadar, A. & Guzzomi, F. (2025). A comparative study of aluminium properties manufactured using additive friction stir deposition (AFSD) and wire arc additive manufacturing (WAAM). Progress in Additive Manufacturing, 10, 8963–8983.

Hauser, A., et al. (2021). The impact of shielding gases on the quality of WAAM. Journal of Materials Processing Technology, 288, 116847.

Huang, Y., et al. (2020). The influence of process parameters on the mechanical properties of WAAM. Materials Science and Engineering: A, 772, 138859.

Islam, M. A., Mobarak, M. H., Rimon, M. I. H., Al Mahmud, M. Z., Ghosh, J., Ahmed, M. M. S., & Hossain, N. (2024). Additive manufacturing in polymer research: Advances, synthesis, and applications. Polymer Testing, 132, 108364.

Jiankun Wang; Qingkai Shen; Xiangdong Kong; and, Xizhang Chen (2021). Arc Additively Manufactured 5356 Aluminum Alloy with Cable-Type Welding Wire: Microstructure and Mechanical Properties. Journal of Materials Engineering and Performance, **30**(10), 7472–7478

Kesarwani, S., Yuvaraj, N. (2025). Optimization of CMT-WAAM process parameters to minimize the porosity and surface roughness in bimetallic wall of aluminium alloys. Weld World, 69, 989–1002

KDM Steel. (2024). 5356 Aluminum – Chemical Composition. Retrieved July 20, 2024, from https://www.kdmsteel.com/5356-aluminum/

Lewandowski, J. J., & Seifi, M. (2016). Metal additive manufacturing: A review of the state of the art. Journal of Materials Science & Technology, 32(7), 633-645.

Manu Srivastava, Sandeep Rathee, Ankit Tiwari, Mehul Dongre (2022). Wire arc additive manufacturing of metals: A review on processes, materials and their behavior. Materials Chemistry and Physic, 294(5), 126988.

Mark Armstrong, Hamid Mehrabi, Nida Naveed (2022). An overview of modern metal additive manufacturing technology. Journal of Manufacturing Processes, 84, 1001-1029.

Mazeeva, E. V., Popovich, A. A., Kramar, L. Y., & Sufiiarov, V. S. (2024). Multi-metal additive manufacturing by extrusion-based

3D printing for structural applications: A review. Metals, 14(11), 1296.

Mohamed Dekis, Mahmoud Tawfik, Mohamed Egiza, Montaser Dewidar (2025). Challenges and developments in wire arc additive manufacturing of steel: A review. Results in Engineering, 26, 104657.

Murzin, S. P. (2024). Artificial Intelligence-Driven Innovations in Laser Processing of Metallic Materials. Metals, 14(12), 1458.

Muthukumaran A; Sowmiya Jeyakumar; K Jayakumar (2024). Metallurgical and mechanical properties of marine grade AA5356 using wire arc additive manufacturing. Materials Research Express, 11(7).

Myśliwiec, P., Kubit, A., & Szawara, P. (2024). Optimization of 2024-T3 Aluminum Alloy Friction Stir Welding Using Random Forest, XGBoost, and MLP Machinee 16 of 17 - AI Writing Submission Learning Techniques. Materials (Basel, Switzerland), 17(7), 1452.

Srinivas, M. N., Vimal, K. E. K., Manikandan, N., & Sritharanandh, G. (2022). Parametric optimization and multiple regression modelling for fabrication of aluminium alloy thin plate using wire arc additive manufacturing. International Journal on Interactive Design and Manufacturing.

Nguyen, V.-T., Minh, P. S., Uyen, T. M. T., Do, T. T., Ngoc, H. V. T., Le, M.-T., & Tien Nguyen, V. T. (2023). WAAM Technique: Process Parameters Affecting the Mechanical Properties and Microstructures of Low-Carbon Steel. Metals, 13(5), 873.

Satyaki Sinha, Tuhin Mukherjee (2024). Mitigation of Gas Porosity in Additive Manufacturing Using Experimental Data Analysis and Mechanistic Modeling. Materials, 17(7):1569.

T. DebRoy, H.L. Wei, J.S. Zuback, T. Mukherjee, J.W. Elmer, J.O. Milewski, A.M. Beese, A. Wilson-Heid, A. De, W. Zhang (2018). Additive manufacturing of metallic components – Process, structure and properties. Progress in Material Science, 92, 112-224.

Tiago A. Rodrigues, V. Duarte, R.M. Miranda, Telmo G. Santos and J.P. Oliveira (2019). Current Status and Perspectives on Wire and Arc Additive Manufacturing (WAAM). Materials. 12, 1121.

Vafadar, A., Guzzomi, F., Rassau, A. and Hayward, K. (2021). Advances in metal additive manufacturing: a review of common processes, industrial applications, and current challenges. Applied Sciences, 11(3): 1213.

Wang, P., et al. (2018). Overview of metal additive manufacturing technologies. Materials Science and Engineering: A, 726, 790-806.

Williams, S. W., Martina, F., & Colegrove, P. (2016). Wire arc additive manufacturing. Materials Science and Technology, 32(11), 1207-1215.

Wiltgen, F. (n.d.). Prototypes are important. Transformations/Transformacje. Retrieved from EBSCOhost.

Yu, Q., Meng, Y., Xu, J., Wu, X., Guo, X., Xie, Y., Yang, Z., & Chen, H. (2025). Study on forming characteristics and process stability in wire arc additive manufacturing of 5356 aluminum alloy. Journal of Materials Engineering and Performance, 34(20), 23249–23263.

Wong, K. V., & Hernandez, A. (2012). A review of additive manufacturing. ISRN Mechanical Engineering, 2012, 1–10. Retrieved September 23, 2024, from https://openurl.ebsco.com/contentitem/gcd:162314538?sid=ebsco:plink:crawler&id=ebsco:gcd:162314538