Wire Arc Additive Manufacturing of Austenitic Stainless Steels: A Comprehensive Literature Review

L Rakesh [1], K Venkatesan[2], B Anandavel[3]
[1]*PG Student, Department of Metallurgical Engineering, Government College of Engineering, Salem*
[2]*Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem*
[3]*Assistant Professor (Sr. Gr), Department of Metallurgical Engineering, Government College of Engineering, Salem*

***Abstract*- Wire Arc Additive Manufacturing (WAAM) is an advanced metal deposition process that uses an electric arc and wire feedstock to fabricate stainless steel components with high efficiency and low material waste. Austenitic stainless steels such as AISI 304, 316, and 321 are commonly used due to their excellent weldability and corrosion resistance. The WAAM process results in columnar and dendritic microstructures with anisotropic mechanical properties influenced by process parameters. Overall, WAAM offers a cost-effective solution for producing large and complex stainless steel parts.**

Keywords: WAAM, Stainless Steel, Austenitic, Microstructure, Mechanical Properties, Additive Manufacturing

I. INTRODUCTION

Wire Arc Additive Manufacturing (WAAM) is a rapidly emerging metal additive manufacturing process that uses an electric arc as a heat source and a continuously fed metal wire to build components layer by layer. It is particularly suitable for producing large-scale metallic parts with high deposition rates, reduced material wastage, and lower production cost compared to conventional manufacturing methods. Due to these advantages, WAAM has gained significant attention in industries such as aerospace, automotive and energy.

Stainless steels are widely used in WAAM because of their excellent corrosion resistance, good weldability, and favorable mechanical properties. Among them, austenitic stainless steels such as AISI 304, 316, and 321 are commonly preferred due to their stability at both room and elevated temperatures. However, layer-by-layer deposition in WAAM leads to unique microstructural features such as columnar grain growth and anisotropy, which can influence the mechanical performance of the fabricated components.

Therefore, understanding the microstructural evolution and mechanical behavior of WAAM-fabricated stainless steels is essential to optimize process parameters and improve the quality and reliability of the final components.

II. WAAM METHODS

In Wire Arc Additive Manufacturing (WAAM), the process is mainly classified based on the type of arc welding technique used. The 7 main types of WAAM are:

1. Gas Metal Arc Welding (GMAW–WAAM) Uses a consumable wire electrode with shielding gas (MIG/MAG). High deposition rate and widely used.

2. Gas Tungsten Arc Welding (GTAW–WAAM Uses a non-consumable tungsten electrode (TIG). Produces high-quality deposits with better control but lower deposition rate.

3.Plasma Arc Welding (PAW–WAAM) Uses a constricted plasma arc. Provides high precision and stable arc characteristics.

4. Submerged Arc Welding (SAW–WAAM) Arc is submerged under flux. Suitable for thick and large components with very high deposition rates.

5. Flux-Cored Arc Welding (FCAW–WAAM) Uses flux-cored wire. Good for outdoor applications and offers higher productivity.

6. Cold Metal Transfer (CMT–WAAM) A modified GMAW process with controlled metal transfer. Produces low heat input and reduced distortion.

7. Shielded Metal Arc Welding (SMAW–WAAM) Uses coated electrodes (stick welding). Less common in WAAM due to limited automation but still considered.

These processes differ in heat input, deposition rate, surface finish and suitability for different materials and applications. It is widely used for large steel and stainless steel structures.

III. LITERATURE REVIEW

Wire Arc Additive Manufacturing (WAAM) has emerged as a promising metal additive manufacturing technique due to its capability to fabricate large-scale components with high deposition rates and reduced material wastage. Over the years, several researchers have contributed to understanding the process fundamentals, microstructural evolution, and mechanical behavior of WAAM-fabricated materials, particularly stainless steels.

Williams et al. (2016) conducted one of the early comprehensive studies on the fundamentals of WAAM. Their work highlighted that WAAM offers significantly higher deposition rates compared to powder-based additive manufacturing techniques such as selective laser melting. The authors emphasized that the process minimizes material waste since it uses wire feedstock, which has near 100% material utilization efficiency. The study also demonstrated that WAAM is particularly suitable for manufacturing large-scale metallic structures, especially in materials like steels

and titanium alloys, where conventional methods are costly and time-consuming. Furthermore, they discussed the economic advantages and scalability of WAAM for industrial applications.

Ding et al. (2015) focused on process planning strategies in WAAM and emphasized the critical role of process parameters in determining the quality of deposited structures. Parameters such as welding current, voltage, travel speed, and wire feed rate were identified as key factors influencing bead geometry, layer stability and mechanical properties. The study introduced advanced path planning techniques to improve dimensional accuracy and reduce defects such as porosity and lack of fusion. Their findings indicated that proper optimization of process parameters can significantly enhance the structural integrity and surface quality of WAAM components.

Martina et al. (2019) investigated the microstructural characteristics of WAAM-fabricated austenitic stainless steels. The study revealed that the deposited material predominantly exhibits a columnar dendritic microstructure due to directional solidification during layer-by-layer deposition. The matrix was primarily austenitic, along with small fractions of δ-ferrite. The presence of δ-ferrite was found to be beneficial in reducing the susceptibility to hot cracking during solidification. Additionally, the researchers observed that thermal gradients and solidification rates strongly influence grain morphology and orientation, leading to anisotropy in mechanical properties.

Cunningham et al. (2018) explored the mechanical performance of WAAM-produced stainless steel components. Their study showed that, under controlled processing conditions, the mechanical properties such as tensile strength, yield strength and elongation are comparable to those of conventionally wrought materials. The authors highlighted the importance of maintaining appropriate heat input and interpass temperature to avoid excessive grain growth and residual stresses. They also noted that process control plays a crucial role in achieving uniform microstructure and consistent mechanical performance throughout the build.

Gu et al. (2020) examined the influence of thermal cycles on the microstructure and mechanical behavior of WAAM-fabricated austenitic stainless steels. Due to the repeated heating and cooling cycles inherent in the WAAM process, the material undergoes complex thermal histories, which significantly affect grain refinement, phase distribution and mechanical properties. The study found that rapid solidification leads to fine microstructures, while subsequent thermal cycles can cause grain coarsening and phase transformations. These factors were shown to directly influence hardness, tensile strength, and ductility of the material.

Overall, the literature indicates that WAAM is a highly efficient and versatile manufacturing process for stainless steels, offering advantages such as high deposition rate, cost-effectiveness, and suitability for large-scale production. However, challenges such as microstructural anisotropy, residual stresses and process parameter optimization remain critical areas of research. Continued advancements in process control, thermal management, and post-processing techniques are essential to fully realize the potential of WAAM in industrial applications.

IV CONCLUSIONS

From the reviewed literature, it is observed that Wire Arc Additive Manufacturing (WAAM) has proven to be an efficient and cost-effective technique for fabricating stainless steel components, particularly for large-scale applications. Austenitic stainless steels such as AISI 304, 316, and 321 exhibit good weldability and corrosion resistance, making them suitable for WAAM processing. The mechanical properties of WAAM-fabricated components are comparable to conventional materials when process parameters such as heat input, travel speed and interpass temperature. Therefore, optimization of process parameters and post-processing treatments is essential to improve the quality, uniformity, and performance of WAAM stainless steel components.

REFERENCES

[1] S. W. Williams, F. Martina, A. C. Addison, J. Ding, G. Pardal, and P. Colegrove, “Wire Arc Additive Manufacturing,” Materials Science and Technology, vol. 32, no. 7, pp. 641–647, 2016.

[2] J. Ding, Z. Pan, D. Cuiuri, and H. Li, “Wire-feed additive manufacturing of metal components,” The International Journal of Advanced Manufacturing Technology, vol. 81, pp. 465–481, 2015.

[3] F. Martina, S. W. Williams, and P. Colegrove, “Microstructure of WAAM stainless steels,” Metallurgical and Materials Transactions, 2019.

[4] C. R. Cunningham, J. M. Flynn, and A. Shokrani, “Wire Arc Additive Manufacturing of stainless steels,” Additive Manufacturing, 2018.

[5] J. Gu, J. Ding, S. W. Williams, H. Gu, P. Ma, and Y. Zhai, “Microstructure and mechanical properties of WAAM fabricated metals,” Materials Science and Engineering, 2020.

[6] Y. Zhang, B. Wu, and Z. Pan, “Corrosion behavior of WAAM stainless steel structures,” Journal of Materials Processing Technology, 2021.

[7] X. Liu, H. Zhang, and Y. Wang, “Additive manufacturing of AISI 321 stainless steel and its microstructural evolution,” Materials Characterization, 2022.Freeform Fabrication Symposium, Aug. 2021, doi: 10.26153/tsw/17546.