

Experimental Investigation of the Mechanical Properties of GTAW-Based WAAM-Fabricated Inconel 718

Bhaskar Chaubey¹ Dr. Nitesh Kumar Dixit² Er. Shweta Mishra³

¹M.tech Student, Mechanical Engineering, Dr. Ram Manohar Lohia Avadh

University U.P

²Assistant Professor, Mechanical Engineering, Dr. Ram Manohar Lohia Avadh

University U.P

³Assistant Professor, Mechanical Engineering, Dr. Ram Manohar Lohia Avadh

University U.P

Corresponding Author Email: arkbchaubey@gmail.com

Abstract

Wire Arc Additive Manufacturing (WAAM) has emerged as an efficient manufacturing technique for producing large metallic components with reduced material wastage and improved production economy. In the present investigation, an Inconel 718 plate was fabricated using a manually operated Gas Tungsten Arc Welding (GTAW)-based WAAM process under an argon shielding environment. Deposition was carried out with a 3 mm Inconel 718 filler wire employing a welding current of 115–130 A, an arc voltage of 10–13 V, an argon flow rate of 12–15 L/min, and a travel speed ranging from 90 to 150 mm/min. The fabricated plate was subsequently evaluated through tensile, Rockwell hardness, Charpy impact, and Izod impact tests performed according to relevant ASTM standards. The material exhibited an ultimate tensile strength of 1441.72 MPa, a yield strength of 1020.54 MPa, an average hardness of 44.2 HRC, an average Charpy impact energy of 148.67 J, and an average Izod impact energy of 136.67 J. These experimental findings demonstrate that the adopted manual GTAW-based WAAM approach is capable of producing Inconel 718 components possessing a well-balanced combination of strength, hardness, and impact toughness, indicating its potential for demanding engineering applications.

Keywords: Wire Arc Additive Manufacturing (WAAM), Gas Tungsten Arc Welding (GTAW), Inconel 718, Additive Manufacturing, Tensile Properties, Rockwell Hardness, Impact Testing.

I. INTRODUCTION

The growing demand for lightweight, high-strength, and complex metallic components has accelerated the adoption of additive manufacturing (AM) across several engineering sectors. Unlike conventional subtractive manufacturing, additive manufacturing builds components layer by layer, resulting in improved material utilization, reduced manufacturing waste, and greater design flexibility. These advantages have made AM an attractive solution for producing parts used in aerospace, power generation, automotive, marine, and defence applications.

Among the various metal additive manufacturing technologies, Wire Arc Additive Manufacturing (WAAM) has gained considerable attention because of its high deposition rate, low production cost, and capability to manufacture medium- and large-scale components. The process utilizes a welding arc as the heat source and metallic wire as the feedstock, making it more economical than powder-based additive manufacturing techniques while

maintaining high material efficiency. Owing to these advantages, WAAM has become a practical manufacturing route for fabricating structural metallic components where productivity and cost are important considerations.

Gas Tungsten Arc Welding (GTAW) is one of the welding processes successfully employed in WAAM. The stable arc characteristics, precise heat-input control, and comparatively low spatter associated with GTAW enable the production of deposits with improved surface quality and good metallurgical integrity. These features make GTAW-based WAAM particularly suitable for experimental investigations aimed at understanding the relationship between processing conditions and mechanical performance.

Among commercially available nickel-based superalloys, Inconel 718 is widely recognized for its excellent combination of mechanical strength, corrosion resistance, oxidation resistance, and high-temperature stability. These characteristics have resulted in its extensive use for manufacturing turbine components, aerospace structures, power-generation equipment, and other engineering systems

operating under severe thermal and mechanical conditions. However, the alloy is difficult to machine using conventional methods because of its high strength, rapid work hardening behaviour, and relatively low thermal conductivity, making additive manufacturing an attractive alternative for component fabrication.

Although numerous investigations have reported the processing of Inconel 718 using different WAAM techniques, comparatively fewer studies have focused on the mechanical characterization of manually fabricated GTAW-based WAAM components. Experimental information on tensile behaviour, hardness, and impact resistance produced under practical laboratory conditions remains limited. Generating reliable mechanical-property data is therefore important for assessing the applicability of manual GTAW-based WAAM in engineering practice.

In the present study, an Inconel 718 plate was fabricated using a manually operated GTAW-based WAAM process under controlled deposition conditions. The fabricated material was evaluated through tensile, Rockwell hardness, Charpy impact, and Izod impact testing in accordance with ASTM standards. The experimental results are intended to provide reliable mechanical-property data and contribute to the understanding of manually fabricated WAAM Inconel 718 for future industrial and research applications.

II. MATERIALS AND EXPERIMENTAL METHODOLOGY

A. Materials and GTAW-Based WAAM Fabrication

Commercially available Inconel 718 filler wire (3 mm diameter) was selected as the feedstock material, while a mild steel plate was used as the deposition substrate. Before fabrication, the substrate surface was properly cleaned to eliminate contaminants and to promote sound metallurgical bonding during deposition.

The Inconel 718 plate was manufactured using a manual Gas Tungsten Arc Welding (GTAW)-based Wire Arc Additive Manufacturing (WAAM) process under an argon shielding atmosphere. Deposition was performed with a welding current of 115–130 A, an arc voltage of 10–13 V, an argon flow rate of 12–15 L/min, and a travel speed ranging from 90 to 150 mm/min. To improve layer uniformity and thermal distribution, successive layers were deposited using an alternating 0°/90° strategy, resulting in a fabricated plate of approximately 140 × 140 × 13 mm. A schematic illustration of the fabrication setup is presented in Figure 1.

Table 1: Material Details and WAAM Fabrication Parameters

Parameter	Value
Material	Inconel 718
Feedstock	3 mm Inconel 718 Rod
Process	Manual GTAW-based WAAM
Substrate	Mild Steel
Shielding Gas	Argon
Welding Current	115–130 A
Arc Voltage	10–13 V
Argon Flow Rate	12–15 L/min
Travel Speed	90–150 mm/min
Deposition Strategy	Alternating 0°/90°
Plate Size	140 × 140 × 13 mm

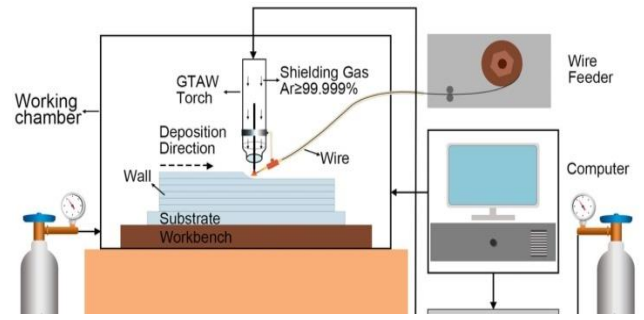


Figure 1: Schematic representation of the GTAW-based WAAM setup used for fabrication of the Inconel 718 plate

B. Specimen Preparation and Mechanical Testing

Test specimens were machined from the fabricated WAAM plate for mechanical evaluation. Tensile specimens were prepared in accordance with ASTM E8/E8M, whereas Charpy and Izod impact specimens were fabricated following ASTM E23 requirements. The experimental programme included tensile testing, Rockwell hardness measurement, and both Charpy and Izod impact testing to evaluate the mechanical performance of the deposited material.

All experiments were conducted under standard laboratory conditions using calibrated testing equipment. To improve the reliability of the measurements, three independent observations were recorded for hardness and impact tests, and their average values were used for analysis. The adopted testing procedure ensured good repeatability while minimizing experimental uncertainty.

Table 2: Dimensions of Fabricated Plate and Mechanical Test Specimens

Test	Standard	Dimensions/Specification
Fabricated Plate	—	140 × 140 × 13 mm
Tensile	ASTM E8/E8M	Gauge length: 25.06 mm Gauge width: 10.12 mm Gauge thickness: 6.10 mm Cross sectional area: 61.73 mm ²
Charpy Impact	ASTM E23	55 × 10 × 10 mm V-notch: 45° Notch depth: 2 mm Notch root radius: 0.25 mm
Izod Impact	ASTM E23	55 × 10 × 10 mm V-notch: 45° Notch depth: 2 mm Notch root radius: 0.25 mm

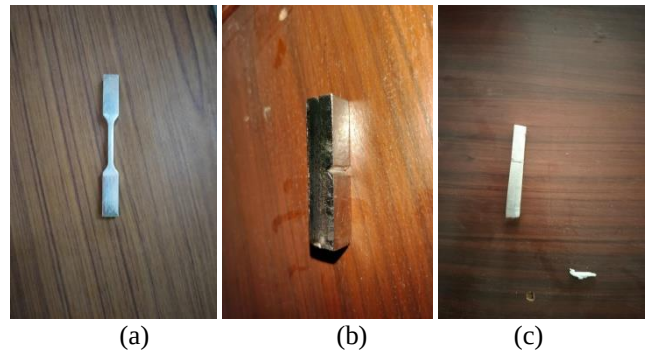


Figure 2: Mechanical test specimens prepared from the fabricated Inconel 718 plate: (a) tensile specimen, (b) Charpy impact specimen, and (c) Izod impact specimen

III. RESULTS AND DISCUSSION

A. Mechanical Testing

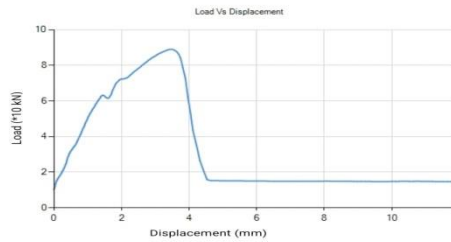
The mechanical performance of the fabricated Inconel 718 plate was evaluated through tensile, Rockwell hardness, Charpy impact, and Izod impact testing. Tensile testing, performed in accordance with ASTM E8/E8M, demonstrated that the fabricated material possessed high strength together with measurable plastic deformation before failure. The specimen achieved a yield strength of 1020.54 MPa, an ultimate tensile strength of 1441.72 MPa, a maximum load of 89.0 kN, and an elongation of 3.63%. The corresponding experimental arrangement and the load–displacement curve are presented in Figure 3.

Table 3: Tensile Test Results

Property	Value
Yield Strength	1020.54 MPa
Ultimate Tensile Strength	1441.72 MPa
Maximum Load	89.0 kN
Elongation	3.63 %

1) Mechanical Properties

The tensile test results indicate that the deposited material exhibited effective interlayer bonding and maintained adequate structural integrity throughout the loading process. The combination of high yield strength and ultimate tensile strength suggests that the selected deposition conditions produced a mechanically stable WAAM component. Although the measured elongation was relatively limited, the specimen sustained plastic deformation before fracture, indicating satisfactory ductility for structural applications.



(a)



(b)

Figure 3: Tensile testing: (a) Load–Displacement curve obtained during tensile testing of the WAAM-fabricated Inconel 718 specimen and (b) Universal Testing Machine (UTM) setup

B. Hardness and Impact Properties

Rockwell hardness and impact testing were performed to assess the resistance of the fabricated material to localized deformation and sudden loading. The average hardness was measured as 44.2 HRC, while the average absorbed energies obtained from the Charpy and Izod impact tests were 148.67 J and 136.67 J, respectively. These values demonstrate that the fabricated Inconel 718 possesses an appropriate balance between hardness and toughness. The corresponding testing arrangements are illustrated in Figures 4, 5, and 6.

Table 4: Hardness and Impact Test Results

Property	Value
Average Rockwell Hardness	44.2 HRC
Average Charpy Impact Energy	148.67 J
Average Izod Impact Energy	136.67 J

1) Hardness and Impact Properties

The hardness results indicate that the deposited material offers good resistance to permanent surface deformation. Likewise, the measured impact energies confirm that the fabricated component is capable of absorbing a considerable amount of energy before fracture under impact loading. The combined observations suggest that the adopted GTAW-based WAAM process produced a material with satisfactory mechanical reliability suitable for engineering applications where both strength and toughness are required.

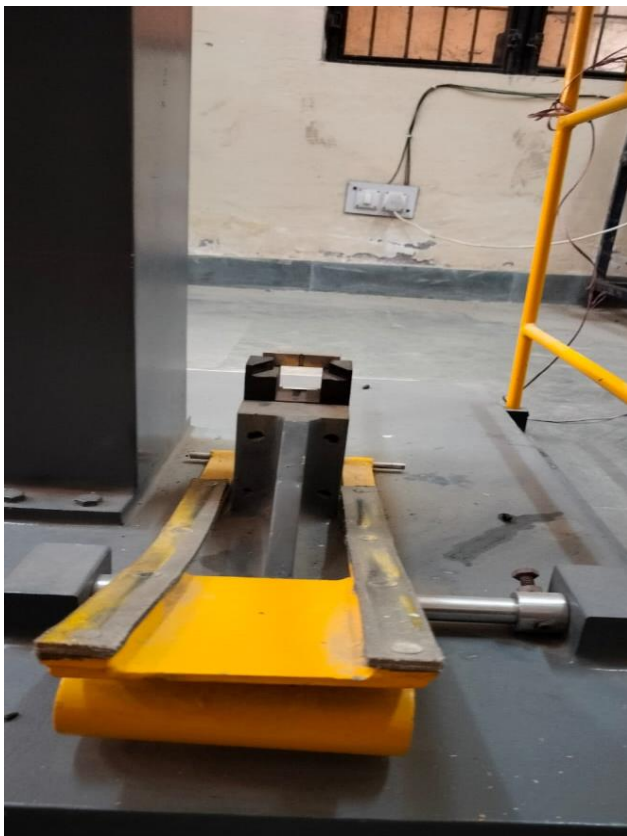


(a)

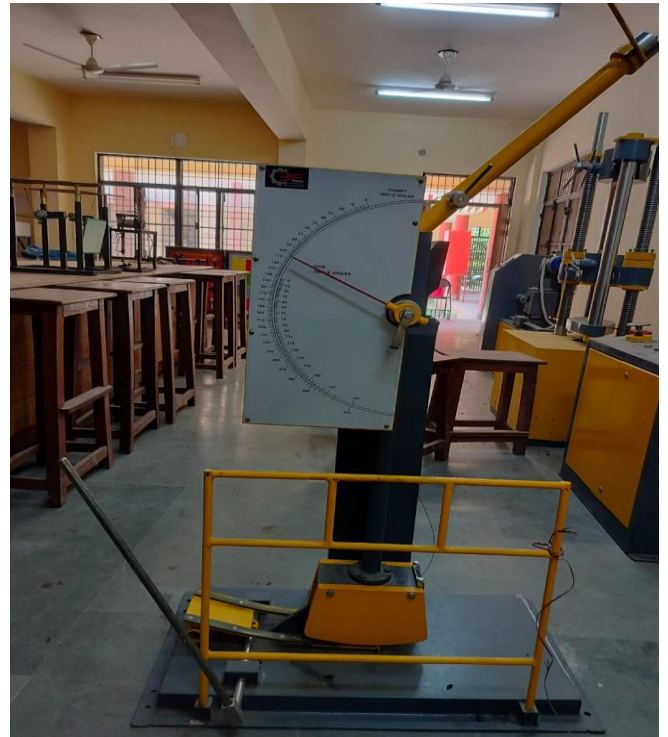


(b)

Figure 4: Rockwell hardness evaluation: (a) Rockwell hardness testing machine and (b) specimen during testing



(a)



(b)

Figure 5: Charpy impact testing: (a) Charpy specimen before testing and (b) Charpy impact testing machine



(a)



(b)

Figure 6: Izod impact testing: (a) Izod specimen before testing and (b) Izod impact testing machine

2) Overall Mechanical Performance

The experimental investigation demonstrates that the manually fabricated GTAW-based WAAM Inconel 718 plate achieved a balanced combination of tensile strength, hardness, and impact resistance. The mechanical properties obtained in this study indicate that the selected fabrication parameters were effective in producing a sound deposited structure with good metallurgical integrity.

The observed performance is comparable to the mechanical behaviour commonly reported for WAAM-fabricated Inconel 718 in the available literature. Overall, the experimental findings suggest that the adopted manufacturing approach is capable of producing mechanically reliable components that are suitable for applications involving elevated temperatures and structural loading. These results also provide useful experimental data for future investigations focused on process optimization and performance improvement.

IV. CONCLUSION

This study investigated the feasibility of fabricating Inconel 718 using a manually operated Gas Tungsten Arc Welding (GTAW)-based Wire Arc Additive Manufacturing (WAAM) process. The fabricated plate was successfully produced under the selected deposition conditions and subsequently evaluated through tensile, Rockwell hardness, Charpy impact, and Izod impact testing in accordance with relevant ASTM standards.

The experimental results demonstrated an ultimate tensile strength of 1441.72 MPa, a yield strength of 1020.54 MPa, an average Rockwell hardness of 44.2 HRC, a Charpy impact energy of 148.67 J, and an Izod impact energy of 136.67 J. These findings indicate that the adopted fabrication approach is capable of producing Inconel 718 with a satisfactory balance of strength, hardness, and impact toughness.

Overall, the investigation confirms that manual GTAW-based WAAM is a practical manufacturing route for producing mechanically reliable Inconel 718 components. The experimental data generated in this work provide a useful reference for future studies involving process optimization, microstructural characterization, post-deposition heat treatment, and the broader application of WAAM in advanced engineering industries.

References

- [1] ASTM E8/E8M-24, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International, 2024.
- [2] ASTM E18-24, Standard Test Methods for Rockwell Hardness of Metallic Materials, ASTM International, 2024.
- [3] ASTM E23-24, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, ASTM International, 2024.
- [4] T. A. Rodrigues et al., "Current Status and Perspectives on Wire and Arc Additive Manufacturing (WAAM)," *Materials*, 2019.
- [5] J. Jang et al., "Phase formation kinetics during heat treatments of Inconel 718 deposits based on CMT-WAAM," *Materials Characterization*, 2022.
- [6] B. Tomar et al., "A review on wire arc additive manufacturing," *Materials Today Communications*, 2022.
- [7] Y. Li et al., "Comprehensive review of wire arc additive manufacturing," *Results in Engineering*, 2022.
- [8] E. Hosseini and V. A. Popovich, "A review of mechanical properties of additively manufactured Inconel 718," *Additive Manufacturing*, 2019.
- [9] C. E. Seow et al., "WAAM Inconel 718: Effect of post-deposition heat treatment," *Materials & Design*, 2019.
- [10] M. Shahwaz, P. Nath, and I. Sen, "Recent advances in additive manufacturing technologies for Ni-based Inconel superalloys," *Journal of Alloys and Compounds*, 2025.
- [11] H. Abusalma et al., "Residual stress formation in Wire and Arc Additive Manufacturing," *Journal of Manufacturing Processes*, 2022.
- [12] A. Mostafaei et al., "Additive manufacturing of nickel-based superalloys: A state-of-the-art review," *Progress in Materials Science*, 2023. 108157, 2019, doi:10.1016/j.matdes.2019.108157.
- [13] N. Xi et al., "Wire arc additive manufacturing of Inconel 718: Constitutive modelling and its microstructure basis," *J. Manuf. Process.*, vol. 75, pp. 1134–1143, 2022, doi:10.1016/j.jmapro.2022.01.067.
- [14] X. Xu et al., "Enhancing mechanical properties of wire + arc additively manufactured INCONEL 718 superalloy through in-process thermomechanical processing," *Mater. Des.*, vol. 160, pp. 1042–1051, 2018, doi:10.1016/j.matdes.2018.10.038.
- [15] M. Rashid et al., "Advances in wire-arc additive manufacturing of nickel-based superalloys," *Int. J. Lightweight Mater. Manuf.*, vol. 7, no. 6, pp. 882–913, 2024, doi:10.1016/j.ijlmm.2024.05.009.
- [16] R. M. Kindermann et al., "Wire-arc directed energy deposition of Inconel 718: Effects of heat input and build interruptions on mechanical performance," *Addit. Manuf.*, vol. 76, Art. no. 103765, 2023, doi:10.1016/j.addma.2023.103765.

- [17] A. Mostafaei et al., “Additive manufacturing of nickel-based superalloys: A state-of-the-art review on process-structure-defect-property relationship,” *Prog. Mater. Sci.*, vol. 136, Art. no. 101108, 2023, doi:10.1016/j.pmatsci.2023.101108.
- [18] P.-C. Huan et al., “Comparative study on the microstructure, mechanical properties and fracture mechanism of wire arc additive manufactured

Inconel 718 alloy under the assistance of alternating magnetic field,” *Mater. Sci. Eng. A*, vol. 854, Art. no. 143845, 2022, doi:10.1016/j.msea.2022.143845.