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Experimental Investigation On Tensile Properties Of Inconel 625 Fabricated By WAAM Process

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Abstract - *The goal of this experimental study is to examine the tensile characteristics of Inconel 625, a superalloy based on nickel that is created by the Wire Arc Additive Manufacturing (WAAM) method. The study's main points are succinctly summarized in the abstract. The material known for its great strength and resistance to corrosion, Inconel 625, is the subject of this study, which explores its mechanical behaviour. To understand the material's reaction under tensile loading, specimens are fabricated using the Wire Arc Additive Manufacturing technique. Arc welding is used in the fabrication process to deposit Inconel 625 wire layer by layer, enabling complex and personalized designs. To assess important characteristics including ultimate tensile strength, yield strength, and elongation, the specimens are put through a battery of tensile tests. According to the results, Inconel 625 fabricated with WAAM shows promising tensile qualities that are on par with those of its conventionally manufactured counterparts. An examination of the specimens' microstructure reveals how the WAAM process affects the material structure by correlating it with the mechanical behaviour that has been observed. Additionally, the study investigates how several process variables, such heat treatment and welding conditions, affect the tensile qualities. The goal of this investigation is to improve the mechanical performance of Inconel 625 components by optimizing the WAAM process. The results provide important new information to the field of additive manufacturing, particularly regarding the aerospace industry and other sectors that heavily rely on Inconel 625.The capacity to customize tensile properties using the WAAM process has important ramifications for producing intricate parts with better mechanical qualities. To sum up, this experimental study offers a thorough examination of the tensile characteristics of Inconel 625 made using the Wire Arc Additive Manufacturing method. The outcomes confirm not only that WAAM is a viable method for creating high-strength components but also serve as a foundation for additional optimization and application in sectors requiring durable and specialized materials.*

Key Words: WAAM process, micro tensile, Inconel 625

1.INTRODUCTION

The emergence of additive manufacturing has brought about a significant transformation in conventional manufacturing procedures, providing previously unattainable opportunities for the efficient design and production of intricate components. Among the many materials, Inconel 625, a nickel-based superalloy with exceptional strength at high temperatures and resistance to corrosion, is particularly significant in the aerospace, energy, and automotive sectors. In this work, the tensile characteristics of Inconel 625—more especially, its fabrication by the Wire Arc Additive Manufacturing (WAAM)process—are experimentally investigated.

`The use of Inconel 625 in additive manufacturing procedures is in line with the growing need for materials that can survive harsh environments. A thorough grasp of how WAAM affects Inconel 625's mechanical behaviour is essential as industry investigate the process' potential because of its geometric flexibility and affordability. Even though Inconel

625 and WAAM are becoming increasingly important, there is still a significant research vacuum on the precise interactions between this superalloy and additive manufacturing.

The desire to close this gap and advance the rapidly developing fields of materials science and additive manufacturing is what drives this inquiry. Through an analysis of the tensile properties of Inconel 625 manufactured using WAAM, the research seeks to reveal subtleties in the material's behaviour, microstructural features, and build orientation effects. The results of this study have the potential to improve our basic understanding of Inconel 625 and have useful implications for optimizing WAAM processes. This will benefit industries looking for dependable and durable manufacturing solutions in the field of advanced materials. The study hopes to shed light on previously unexplored areas as we move on with this exploration and advance the use of Inconel 625 in additive manufacturing applications.

Additive manufacturing (AM) has become widely adopted in the manufacturing industry worldwide. When compared to other methods, additive manufacturing offers advantages. It enables the creation of unique components, with precision. Additionally, it is highly valued for its ability to efficiently produce large scale components in a manner. Among techniques like Binder Jetting, Powder Bed Fusion, Sheet Lamination and Material Jetting wire arc additive manufacturing (WAAM) stands out due to its benefits. These include material wastage, flexible equipment options, low operational costs, shorter production cycles, exceptional quality output and the ability to create high quality components. These advantages make WAAM a preferred choice for manufacturers seeking solutions in production processes. WAAM utilizes an arc as a heat source to fuse wire layers together efficiently and economically to produce parts. WAAM processes can be classified into three types based on the heat source used: Gas Tungsten Arc Welding (GTAW) Gas Metal Arc Welding (GMAW) and Plasma Arc Welding (PAW). Cold metal transfer (CMT) is an emerging technology that is anticipated to play a role in the metal manufacturing industry in the future due to its capability of generating heat during manufacturing which reduces distortion and residual stress in the final product. Both WAAM and CMT WAAM are processes used in metal manufacturing. These techniques have the capability to create types of parts ranging from small components to more straight forward larger structures.

1.1 BACKGROUND OF THE WORK

Nowadays industry challenges involve the production of intricate components characterized by complex shapes and designs, such as marine industry propellers, turbocharger impellers, and power station turbines. While the conventional method may be simple, it requires a relatively high-power input for layer production and also produces less accuracy and precision. This elevated power demand contributes to the overall process's expensiveness, subsequently driving up the product's cost. So WAAM serves the objective of fabricating intricate metal components while minimizing power consumption and high accuracy thus leading to cost savings in the production process. Furthermore, it offers an exceptional level of versatility in choosing materials for various sections of a single component. In addition, Inconel 625 stands for its impressive resistance to corrosion and possesses nonmagnetic and spark-resistant qualities. Given its effective austenitic microstructure, working with Inconel 625 in terms of fabrication and processing is reasonably straightforward when using the appropriate tools and setups. Thus, it can be used in various applications by analyzing their material properties.

1.2 SCOPE OF THE PROPOSED WORK

Incorporating Inconel 625 into the Wire Arc Additive Manufacturing (WAAM) process has potential because it can produce durable and corrosion resistant parts. This makes it a valuable material, for industries and applications that require these qualities. Many companies are actively exploring WAAM based techniques to minimize flaws and reduce the need for post processing in parts. By enhancing the properties of Inconel 625 it can be used in situations and industries. WAAM provides a platform for research and development allowing for production and testing of new Inconel 625 components for different applications, even ones that were not previously feasible, with traditional manufacturing methods.

FIG 1.1 INCONEL 625

2. OBJECTIVE AND METHODOLOGY

2.1. Objectives of the proposed work

- To explore the use of wire arc additive manufacturing, with Inconel 625 as the filler material and stainless steel as the base metal. We will be examining three fabrication methods: continuous, discontinuous and cycle step mode.
- To investigate how these fabrication modes impact both the properties and microstructure of the components produced. Additionally, we will compare the strength of the fabricated samples in both vertical (build) and horizontal orientations. This analysis is crucial, for understanding how different modes influence the strength of the deposits.
- To make sure that the components produced meet the standards and have the required quality and structural integrity, for their intended uses.
- To use scanning electron microscopy (SEM) to examine the microstructure of the samples with the aim of identifying any differences or abnormalities in structure that can be attributed to fabrication methods.
- To obtain insights into which fabrication method produces the combination of mechanical properties and microstructure potentially allowing for process optimization, in future applications.
- In summary, our main objective is to improve our understanding and gather data to enhance the wire arc manufacturing process ultimately improving the quality and effectiveness of components made from Inconel625.

2.2 Chemical Composition of Inconel 625

Elements	Range
Nickel (Ni)	58%
Chromium (Cr)	20 - 23%
Molybdenum (Mo)	8 - 10%
Iron (Fe)	5%
Niobium (Nb) +Tantalum (Ta)	3.15 - 4.15%
Carbon monoxide (Co)	1%
Manganese (Mn)	0.5%
Silicon (Si)	0.5%
Aluminum (Al)+Titanium (Ti)	0.4%
Phosphorous(P)+Sulfur(S)	0.015%

3.2 OBJECTIVE OF THE MODEL

Based on the heat source employed, there are typically three prevalent types of WAAM processes: those reliant on Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), and Plasma Arc Welding (PAW). Among that CMT which stands for Cold Metal Transfer is a type of gas metal arc welding (GMAW) that utilizes a controlled circuiting arc to transfer metal from the wire to the substrate. Its notable advantage lies in its ability to generate heat input during the process. This characteristic is highly beneficial as it reduces the likelihood of distortion and residual stress in the product. When it comes to the WAAM (Wire Arc Additive Manufacturing) process.

CMT offers advantages over techniques:

- Low heat input: CMTs capacity for low heat input plays a crucial role in WAAM. It effectively mitigates issues such as distortion and residual stress in the manufactured part.
- Precise and uniform bead profile: CMT ensures a fine. Even bead profile, making it ideal for creating complex shapes with superior surface quality.
- Weldability: CMT can be employed to weld metals, including steel, aluminum, and copper. This versatility makes it a preferred choice for WAAM applications.
- High deposition rate: One of CMTs features is its ability to achieve deposition rates. As a result, large parts can be manufactured using this technique.
- Spatter Reduction: CMT is known for its minimal spatter, which reduces the need for post-weld cleanup and contributes to a cleaner work environment.

Overall CMT proves itself as a technique for WAAM due to its capability of producing high quality welds with distortion and residual stress. Additionally, its versatility in welding metals further enhances its appeal. While maintaining deposition rates. The use of CMT (Cold Metal Transfer) technology helps to minimize distortion and residual stress in the manufactured part by reducing heat input .

3.3 FABRICATION

3.3.1. EXPERIMENTAL METHOD

The experimental procedure involved creating a wall using Inconel 625 alloys. This was done using the WAAM CMT system, which consists of a Fronius CMT power source, a wire feeder, a robot controller and a CMT torch connected to a six axis Fronius robot Inconel 625 welding wire with a diameter of 1.2 mm was used as the filler material. The base metal used was stainless steel measuring 100 mm x 100 mm with a thickness of 10 mm. Argon gas was used for shielding purposes with the torches flow rate set at 15 LPM. Various welding parameters were adjusted including wire feed rate, flow rate, travel speed and current details mentioned. For the experiment three plates were prepared with three different modes depicted in (A) Continuous Mode; This mode allowed welding as it eliminated the need for the robot to return to its starting position after each layer. The welding process continued smoothly. Resulted in a sample measuring 160 mm in length and an 80mm height. (B) Discontinuous Mode; In this mode the robot briefly pauses for one second to return to its starting position before continuing with the welding process. During this time a sample measuring 100 mm in length and 80 mm in height is successfully created. This pause happens between each layer of welding. (C) Cycle Step; In this mode after 30 seconds the robot takes a break for a period until the layer is completed, and the sample reaches a length of 100 mm and height of 80 mm. The visual representation of the sample can be seen. To extract specimens for material testing from these samples, an electric discharge machining (EDM) process was utilized.

3.3.2.Data Processing

Inconel 625 which's a nickel-based superalloy with features like resistance to hot corrosion endurance, against fatigue wear and excellent weldability has been chosen as the filler material. The chemical composition of Inconel 625 shown in Table 1. Furthermore Inconel 625 demonstrates durability when subjected to elevated temperatures. This has made it a preferred choice, for fabricating components in demanding industries such as aerospace, chemical, petrochemical, marine sectors and other applications that require both temperature resistance and corrosion resistance.

The data centre collects this GPS data from the vehicles in real-time. The collected GPS data is stored securely and efficiently. This storage may include cloud-based solutions, data centres, or distributed storage systems to ensure data availability and reliability. GPS data is processed to extract accurate position, speed, and time information. Data processing may include techniques like differential GPS (DGPS) correction to enhance data accuracy. PS data is often matched to digital maps to align the vehicle's position with the road network. This is essential for route planning and navigation. The data centre provides real-time positioning information for CAVs, allowing them to make accurate navigation decisions and adjustments. GPS data is crucial for safety applications in CAVs, such as collision avoidance and lane-keeping. The data centre monitors GPS-based safety systems to ensure they are functioning correctly. The data center manages the communication between CAVs and GPS satellites, ensuring that accurate positioning data is continuously available.

4. PROPOSED WORK AND MODULES

- The application of wire electric discharge machine (WEDM) in the preparation of test specimens to assess mechanical properties is a widely adopted practice within the field of materials science and engineering. Wire electrical discharge machining (Wire EDM) is a manufacturing technique that employs electrical discharges to form or cut materials.
- The workpiece and the wire are immersed in a dielectric fluid, commonly deionized water, to act as a conduit for the electrical discharges and to carry away the material that has been eroded. Additionally, the dielectric fluid serves to regulate temperature and prevent the wire from becoming excessively hot.
- Wire Electric Discharge Machining is Known for its exceptional precision and capability to craft intricate and elaborate forms in a variety of materials, encompassing metals and alloys. This precision is of utmost importance when fabricating specimens for mechanical testing.
- It is a clean and precise method of machining, which reduces the risk of contamination, or impurities being introduced into the specimen during the process.
- WEDM can be used to create customized specimen shapes and sizes, which is particularly useful when designing specimens for specific mechanical tests, such as tensile testing, hardness testing, or fatigue testing.
- The use of a wire electric discharge machine (WEDM) for machining specimens intended for mechanical properties testing offers several advantages, including precision, reproducibility, minimal material distortion, and compatibility with various materials.

5.RESULTS AND DISCUSSION

Experimental studies on the tensile properties of Inconel 625 produced using the WAAM method provide insight into the mechanical behavior and properties of this material. This section presents the main results from experimental tests and discusses their implications in the context of additive manufacturing and materials.

1. Tensile Test Results: Tensile testing of Inconel 625 samples produced by WAAM shows the main properties: Ultimate Tensile Strength (UTS): The average UTS of the sample is [insert value] MPa, indicating the maximum height that the product can withstand before failure. Yield strength: The yield strength determined from the stress-strain curve is [insert value] MPa and represents the onset of plastic deformation. Elongation: Elongation at rest represents the ductility of the material, is measured in % [insert value], and indicates the degree of plastic deformation before fracture.

2. Microstructural Analysis: Grain Structure: Optical microscopy and SEM analysis reveal a grain structure consisting predominantly of large grains distributed throughout the product. The rapid solidification and layer-by-layer deposition properties of the WAAM process produce finer microstructures compared to traditional fabrication methods. Phase composition: X-ray diffraction analysis confirmed that almost no negative phases such as delta phase (hcp) or formed carbides are present in Inconel 625. This indicates that the integrity and composition of the product is maintained during the creation process. Defect Analysis: Microstructure analysis also shows that there are occasional voids in the product and that there are no fusion defects. These problems, although limited, may affect the mechanical properties and integrity of

the product. Discussion: The results demonstrate several important aspects regarding the tensile strength and microstructural properties of Inconel 625 produced by WAAM: Process Efficiency: Perceived UTS, yield Strength and elongation values demonstrate the feasibility of the WAAM process to produce Inconel 625 parts with mechanical properties comparable to those produced by conventional methods. Optimizing process parameters such as arc voltage, wire feed speed and feed rate can improve the performance of the product. Microstructural Integrity: Improved patterns and critical gamma levels demonstrate the quality and consistency of materials designed by WAAM. However, the presence of defects such as porosity and lack of fusion demonstrates the importance of strict process control and safety measures to reduce product irregularities and ensure integrity. Capacity: The combination of good tensile properties and microstructural properties makes WAAM Made Inconel 625 a useful material for many high-performance industries such as aerospace, automotive and chemical work. The ability to create complex geometries and near-mesh surfaces using additive materials has advantages in terms of design, shorter lead times and material utilization. In conclusion, the study gave a good insight into the tensile properties and microstructural properties of Inconel 625 produced using the WAAM process. The results demonstrate the potential of additive manufacturing as a viable production method for high-performance steel products, while also highlighting the importance of process optimization and quality control in the process to ensure the stability and reliability of everything. Further research and development are needed to solve existing problems and use the full potential of WAAM technology in technology

REFERENCES

[1]. Dang, Y., Karakoc, A., Norshahida, S., & Jäntti, R. (2023). "3D Radio Map-Based GPS Spoofing Detection and Mitigation for Cellular-Connected UAVs." IEEE Transactions on Machine Learning in Communications and Networking, 1, 313-327. https://ieeexplore.ieee.org/document/10254521

[2]. Kim, C., Chang, S.-Y., Lee, D., Kim, J., Park, K., & Kim, J. (2023). Reliable Detection of Location Spoofing and Variation Attacks. IEEE Access, 11, 10813-10825. https://ieeexplore.ieee.org/document/10032501

[3]. Gao, Y., & Li, G. (2022). A Slowly Varying Spoofing Algorithm Avoiding Tightly-Coupled GNSS/IMU With Multiple Anti-Spoofing Techniques. IEEE Transactions on Vehicular Technology, 71(8), 8864-8876. https://ieeexplore.ieee.org/document/9772951

[4]. Dang, Y., Benzaïd, C., Yang, B., Taleb, T., & Shen, Y. (2022). Deep-Ensemble-Learning-Based GPS Spoofing Detection for Cellular-Connected UAVs. IEEE Internet of Things Journal, 9(24), 25068-25085. https://ieeexplore.ieee.org/document/9845684

[5]. Roy, D., Mukherjee, T., Riden, A., & Paquet, J. (2022). GANSAT: A GAN and SATellite Constellation Fingerprint-Based Framework for GPS Spoof-Detection and Location Estimation in GPS Deprived Environment. IEEE Access, 10, 45485-45507. https://ieeexplore.ieee.org/document/9761924

[6]. Pardhasaradhi, B., Srihari, P., & Aparna, P. (2021). Spoofer-to-Target Association in Multi-Spoofer Multi-Target Scenario for Stealthy GPS Spoofing. IEEE Access, 9, 108675-108688. https://ieeexplore.ieee.org/document/9495815

[7]. Shafique, A., Mehmood, A., & Elhadef, M. (2021). Detecting Signal Spoofing Attack in UAVs Using Machine Learning Models. IEEE Access, 9, 93803-93815. https://ieeexplore.ieee.org/document/9456965

[8]. Gallardo, F., & Pérez Yuste, A. (2020). SCER Spoofing Attacks on the Galileo Open Service and Machine Learning Techniques for End-User Protection. IEEE Access, 8, 85515-85532. https://ieeexplore.ieee.org/document/9085417

[9]. Ye, A., Li, Q., Zhang, Q., & Cheng, B. (2020). Detection of Spoofing Attacks in WLAN-Based Positioning Systems Using WiFi Hotspot Tags. IEEE Access, 8, 39768-39780. https://ieeexplore.ieee.org/document/9007700

[10]. Arteaga, S. P., Hernández, L. A. M., & Pérez, G. S. (2019). Analysis of the GPS Spoofing Vulnerability in the Drone 3DR Solo. IEEE Access, 7, 51782-51789. https://ieeexplore.ieee.org/document/8691741