Journal of Manufacturing Engineering, September 2022, Vol. 17, Issue. 3, pp 098-103

TENSILE, HARDNESS, XRD AND SURFACE VONMISES STRESS OF 316 L STAINLESS STEEL BUILT BY WIRE ARC ADDITIVE MANUFACTURING (WAAM)

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ABSTRACT

Wire arc additive manufacturing (WAAM) is a popular wire feed additive manufacturing technology that creates components through the deposition of material layer-by-layer. WAAM has become a promising alternative to conventional machining due to its high deposition rate, environmental friendliness, and cost-competitiveness. It is used to Fabricate complex shaped parts. The variable parameters are current, welding speed, shielding gas, and gas flow rate. This research fabricates 316 L stainless steel (WAAM plate) using a wire arc welding robot machine. Substrate and Side edges are removed using Microwire cut EDM, and the vertical milling machine finishes the surface. The tensile, hardness and X-ray Diffraction are compared with the standard 316 L stainless steel. The modelling and analysis of 316L stainless steel are carried out using COMSOL Multiphysics 5.3 software. It is concluded that the additive manufacturing of 316L stainless steel by wire and arc process is feasible.

Keywords: *Wire and arc additive manufacturing, 316L Stainless Steel and Comsol software*

1. Introduction

The issue Additive manufacturing is a technology that promises to reduce part cost by reducing material wastage and time to market [1]. Frazier et al. ASTM has defined additive manufacturing as a process of joining materials to make objects from 3D model data, usually layer upon, as opposed to subtractive manufacturing methodologies [2]. Ding 3,4] concerned that Wire and arc additive manufacturing (WAAM) is, by definition, an arc-based process that uses either Gas Tungsten arc welding(GTAW)or the Gas Metal arc Welding (GMAW) process has drawn the interest of the research community in recent years due to its high deposition rate. Vinoth et al. investigated the 316 L SS WAMM processed plate using ER 316L SS Wire pool. Voltage, current, Gas flow rate, welding speed, and wire feed rate [6] were used as the experimental process parameters [5]. Some applications using WAAM-produced parts are already in the market, and it is expected that the industry will play a critical role in expanding the applications of WAAM parts. Combined with the development of certification procedures and effective non-destructive inline methods, it can be expected that WAAM will become one of the most used additive manufacturing technologies in the near future [7]. Zhang estimated that a major benefit of the WAAM process relates to the low capital investment, as the components of a WAAM machine may be derived from open-source equipment sourced from an array of suppliers in the mature welding industry. WAAM is a direct feed process that uses arc as the heat source and metallic wire as the feed material. Compared with the poor energy efficiency of wire feed AM using laser and electron beam, the energy efficiency of WAAM can be as high as 90% [8]. The Surface roughness in WAAM is quantitatively determined through optical measurement, a non-invasive method that can provide sufficient information [9]. Fang investigated the bead geometry varies in the first few layers due to the decreasing cooling rate and gradually becomes steady when the heat input and dissipate ion reach a balance. Bead geometry is a critical parameter for WAAM that affects geometric accuracy, material utilization, and productivity [10]. 316L and 409L SS is well-known for their applications as a biomaterial for manufacturing many medical devices. One of the challenges with SLM processing of 316L SS is to minimize (if not avoid altogether) residual porosity and poor surface quality. These requirements are critical, especially for

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biomedical applications requiring high static and dynamic properties, ductility, and high corrosion resistance. Because of this, the primary focus of research is to evaluate the effect of SLM processing parameters on mechanical properties, microstructure, and fracture [11, 12]. This experimental work focuses on fabricating the WAAM processed laminate, subsequent taking the Tensile, hardness, X-Ray diffraction, modeling and analysis of 316L stainless steel using COMSOL Multiphysics 5.3 software.

2. Materials and Methods

2.1 316L Stainless Steel

Grade 316L, the low-carbon version of 316, is highly resistant to sensitization (grain boundary carbide precipitation) and is extensively used in heavy gauge welded components (about 5mm and over). Grade 316H, with its higher carbon content, has some application at elevated temperatures, as does stabilized grade 316Ti. Nitrogen-strengthened versions also exist as 316N and 316LN. Only 316 and 316L are readily available in Australian stock. The alloy (316L) is quite ductile and forms easily. Cold-working operations will increase the strength and hardness of the alloy and might leave it slightly magnetic. Most standard processes can readily weld it. Post-weld heat treatment is not necessary and then to work hardening during deformation and is subject to chip breaking.

Fig. 1 316 L Stainless steel wire (1.2mm)

Fig. 2 316 L Stainless Steel Plate

2.2 Fabrication of material using welding Robot machine

This Machine has been working in two areas: Welding and Additive Manufacturing (3d printing). This Machine based Gas Metal Arc Welding (GMAW). Six-Axis Rotating machine. Only used in steel types of materials Wire-feed Rate in 1.2mm. WAAM is a near-net shape process requiring a finish machining pass. WAAM cells can be based on robotic systems or computer numerical controlled gantries. With the latter being typically retrofitted machine tools and robotic machining becoming more common, both systems will be able to provide integrated machining. A six-axis machine with automatic tool selection could be equipped with a welding power source and torch used to produce a fully finished part, thus avoiding issues related to part relocation and datum references and minimizing non-value-adding activities. Machining can correct errors, avoid scrapping the part, and further reduce waste [1]. Figure (3,4,5) shows images of the welding robot machine and various motions. Table 1 shows the process parameters used while fabricating the plate.

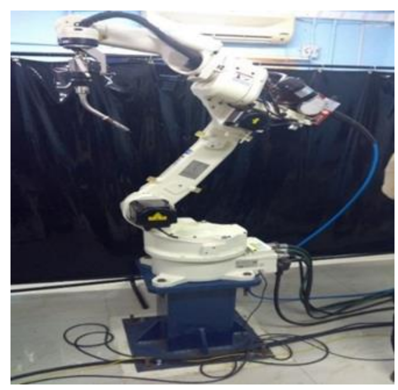

Fig. 3 Welding Robot Machine

Fig. 4 Forward Motion

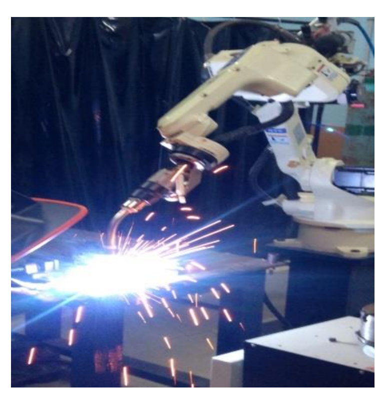

Fig. 5 Backward Motion

Fig. 6 Heat Condition

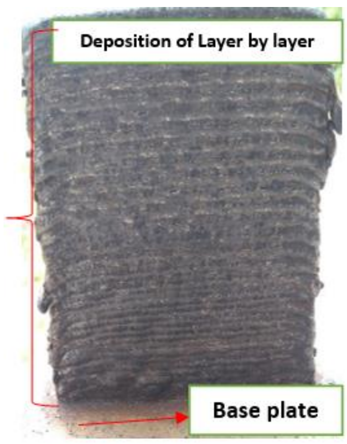

Fig. 7 Photographic image of WAAM Processed plate

Table 1 Process Parameter

Description	Values
Current(A)	120
Voltage(V)	15
Welding Speed(cm/min)	30
InterlayerWaiting time(sec)	60
Gas Flow Rate(L/min)	20
Shielding Gas	Argon+Co2

2.3 Microwire cut EDM (Electric Discharge Machining)

MWEDM can cut small or odd-shaped angles, intricate contours, or cavities in pre-hardened steel. The EDM cutting tool was guided along the desired path. Consecutive sparks Produce a series of micro-craters on the Workpiece and Remove material along the cutting way by Melting and Vaporization. After the Side edges were removed with the help of MWEDM, the surface finished using the milling machine (Fig 8). Fig 9 shows that surface finishing using a vertical milling machine.

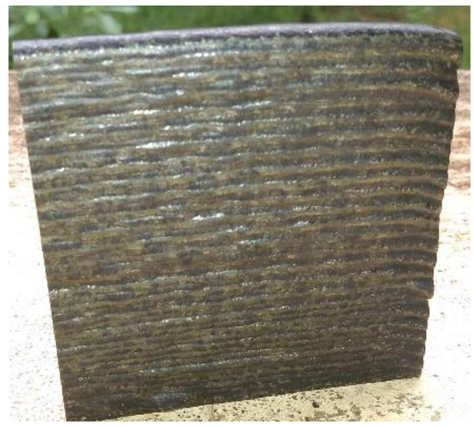

Fig. 8 Front view of the WAAM Plate

Fig. 9 Surface Finishing by the milling machine

3. Result and Discussion

Mechanical tests (Ultimate tensile strength, Brinell hardness, XRD, Modelling and analyzing) have been performed, and their corresponding testing samples manufactured by WAAM

3.1 Tensile test in wrought material

The Tensile test is one of the most widely used of Mechanical tests. Tensile strength is defined as the ability of a material to support the axial load without rupture and is determined through the tensile test. When equal and opposite forces are applied simultaneously at both ends that pull the material, it tries to elongate it, and the diameter reduces. Tensile test has been done. In Fig.18, The maximum value obtained, 559Mpa is in accordance with the values expected for this material. Obtained Ultimate tensile strength value increased compared to conventional 316L SS.

Fig. 10 UTM machine (Tinius Olsen 50KL)

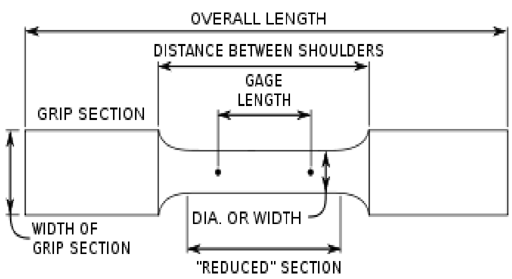

Fig. 11 Tensile Test Specimen Nomenclature

Table 2 obtained Tensile Test Results

Test	Conventional 316L Stainless Steel	WAAM prepared 316L Stainless steel
Tensile Test (Ultimate Tensile Strength)	485 MPa	559 MPa

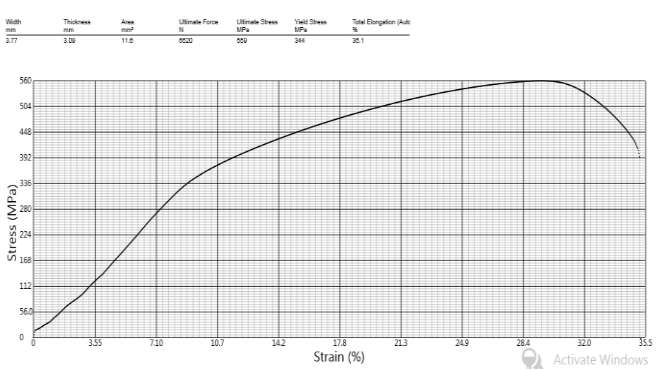

Fig. 12 Stress strain curve for WAAM Plate

3.2 Brinell Hardness strength

The hardness tested conducted using a Brinell hardness testing machine [Make: SAROJ and 3000 KG]. Fig.14 shows the image of the Brinell Ball indenter. Brinell hardness test found that the hardness of the WAAM specimen (Fig.13) values varied from 160 to 166. These values are taken by the specimen distance range (Left to right) is 5, 10, 15 and 20 mm (Fig 15).

Fig. 13 Hardness Specimen

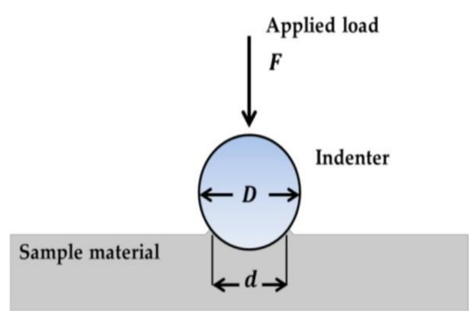

Fig. 14 Brinell Ball indenter

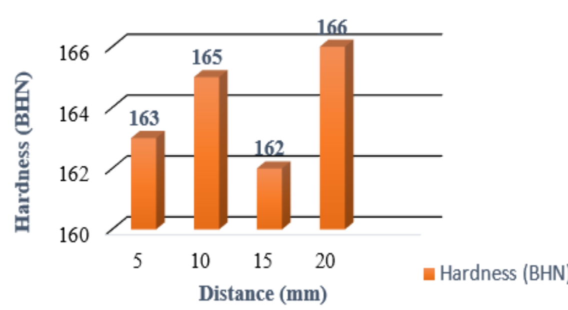

Fig. 15 Hardness Measurements

3.3 X-Ray Diffraction

X-ray Diffraction techniques are used for the identification of crystalline phases of various materials and the quantitative phase analysis after the identification. A Scattering of X-Rays by the atoms of a crystal produces an interference effect so that the diffraction pattern gives information on the structure of the crystal or the identity of a crystalline substance. The X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. Fig 16 Shows that the X-Ray Diffraction image and Table 3 denoted the Peak values of X-Ray diffraction.

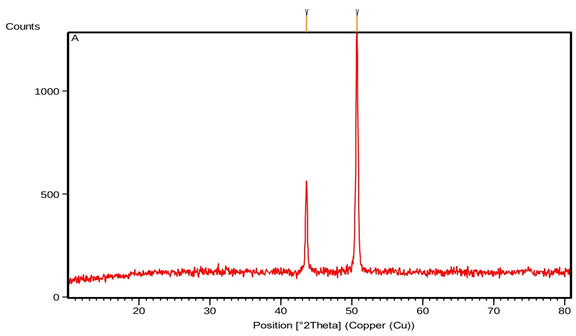

Fig. 16 X-Ray Diffraction Image (Positionº2 Theta)

Table 3 Peak Values of X-Ray Diffraction

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]
43.6106	429.92	0.2460	2.07546	37.01
50.6981	1161.76	0.2952	1.80070	100.00

3.4 Modelling of Structural Analysis In 316 L Stainless Steel Plate

The analytical method proposed the determination of Von-misses stress that approached the stress-strain Relationship obtained from the Tensile Strength using COMSOL Software**.**

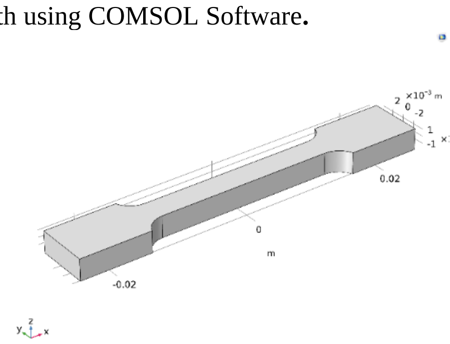

Fig. 17 Geometry of 316 L Stainless Steel

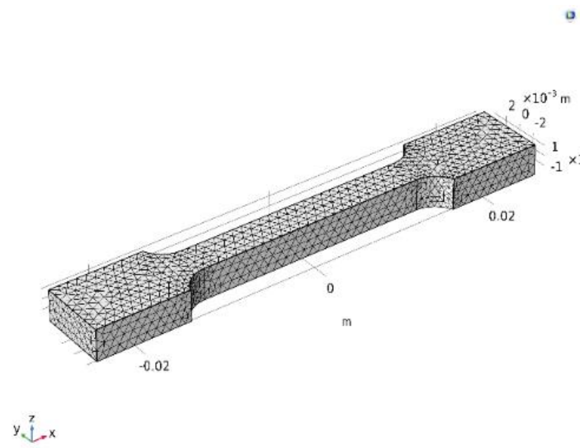

Fig. 18 Finite Element Model Discretization

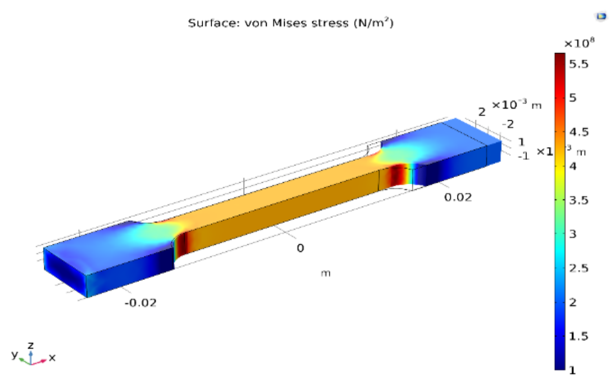

Fig. 19 Surface Von Mises Stress

This model is used for the mechanical properties of a material, and the plastic strain modifying this property can be evaluated using the analytical model. Tensile strength was of great importance to have practical knowledge of engineering data used in Mechanical Design and knowing the importance of each one of them and how important it is to have an idea of the behaviour of material for the use of Analytical method in a safe and reliable way

4. Conclusion

This Research article deals with the fabrication of 316 L stainless steel plate using the WAAM technique in the welding Robot machine. Unwanted side edges and the substrate is removed from the actual specimen. The surface finishing was carried out using the vertical drilling machine. The Universal testing machine was utilized to carry out the tensile evaluation of the 316 L stainless steel plate. The higher tensile strength was achieved at the cross-section of 90°. The specimen cut in 90° orientation proved to have better tensile strength than the standard 316L stainless steel plate. The Brinell hardness test shows that the hardness of the specimen was also significantly improved. The crystalline structure was found using the X-diffraction technique, and the results are disclosed. The structural analysis is carried out using the COMSOL Multiphysics software package, and the analyzed reports are studied and described in this research article.

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