



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 9, September 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 7.569



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# To Study the Hardness Behaviour of 316L Stainless Steel Built by Wire arc Additive Manufacturing

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**ABSTRACT:** WAAM (wire arc additive manufacturing) is a wire-feed additive manufacturing technology that creates components by deposition of materials layer by layer. Because of its environmental friendliness, high deposition rate, and cost competitiveness. WAAM has been a potential alternative to traditional machining. WAAM technologies to manufacture complex designed components. In this study built 316L stainless steel plate with help of ER 316 L consumable wires using welding robot machine. The variable parameters are current, welding speed, shielding gas and Gas flow rate were used. The substrate and side edges of the plates were removed using Micro wire cut electric discharge machining and the surface was finished on a vertical milling machine. To check the different types of Hardness test like Vickers, Brinell and Rockwell tests were performed. It is concluded that Additive manufacturing of 316L stainless steel process is feasible.

**KEYWORDS:** Hardness, 316L stainless steel, Wire and arc additive manufacturing.

## I. INTRODUCTION

Now a day's Wire arc additive manufacturing process is very important because materials only has been added so automatically minimize the materials wastages. Additive processing promises to save component costs by minimizing material waste and time to market [1]. WAAM (wire arc additive manufacturing) is an arc-based additive manufacturing technology because of its high deposition rate, the utilization of either Gas Tungsten Arc Welding (GTAW) or Gas Metal Arc Welding (GMAW) has piqued the scientific community's interest in recent years [2]. The WAAM method is a direct feed method that uses metallic wire as the feed material and an arc as the heat source. Compared to the low energy efficiency of laser and electron beam wire feed AM, WAAM has a high energy efficiency of up to 90% [3]. Bharathkumar et.al found that for all the input parameters for weld bead distance, voltage flow rate, and weld velocity, the wire feed velocity is the most important. 0.55 m/min weld velocity, 4 m/min wire feed speed, and 18 voltage produce the smallest bead width of 3.07 mm length, while 0.25 m/min weld velocity, 8 m/min wire feed speed, and 28V voltage produce the largest bead width of 15.83 mm length [4]. K.S.Derekar et.al found that the mechanical properties of the WAAM product are the main factors that set it apart from previously academically-only approaches like super plastic production. The respective wrought goods, cost savings, no dimensional limits on product shape, the need for substantially simpler and less expensive instruments, and ease of operation [5]. Johnnie et.al WAAM typically uses three heat sources: PAW, MIG and TIG. MIG is faster and factual than TIG and PAW since the welding torch uses a continuous wire spool. As an AM alternative, WAAM is increasingly being used. According to numerous studies, WAAM may drastically cut costs and improve product quality in industrial domains, primarily in the aerospace and automotive industries [6]. Jin et.al WAAM samples are extremely anisotropic in terms of microstructure and tensile strength because to the layer-wise deposition method's directionality. Learning new methods, like as in situ rolling + WAAM, can help overcome anisotropy issues caused by coarse columnar crystals in the deposition direction. The residual stress in WAAM components can also be decreased by in situ rolling's + WAAM [7]. Ashley M. Roach et.al reported as determined by micro hardness, the micro structure and intrinsic material strength of the 316L alloy used in this study did not improve significantly as a function of sample size for the 316L alloy used in this investigation [8]. A systematic analysis of recent technical advances in the WAAM process, focusing on mechanical behaviours, microstructure, process faults and post-process treatment has been presented. Integrating material qualities with the



performance features of various WAAM processes provides a quality-based approach for generating high-quality and deficiency components [9]. 316L SS is well-known for its applications as a biomaterial for manufacturing many medical devices. One of the problems of 316L SS SLM processing is minimizing (if not completely avoiding) residual porosity and low surface consistency. These parameters are important, particularly for biomedical applications requiring high static and dynamic properties, high corrosion resistance and ductility. The primary purpose of this study is to find out how different SLM processing parameters affect mechanical characteristics, microstructure, and fracture [10].

In this research work WAAM Processed plate taking various hardness test like Vicker, Brinell and Rockwell and compared to the conventional 316 L SS Plate.

## II. MATERIALS & METHODS

### 2.1 316L Stainless Steel

The low carbon form of 316 stainless steel, which is exceptionally sensitization resistant (precipitation of grain boundary carbide) and is extensively utilized in heavy gauge welded components. At high temperatures grade 316H is useful, as is stabilized grade 316Ti, which has higher carbon content. The strength and hardness of the alloy would be improved by cold working operations and could leave it mildly magnetic. It can readily be welded by most regular procedures. Heat treatment of the post-weld is needless and then works during deformation hardening and is subject to chip cracking.

### 2.2 WAAM Processed 316 L stainless steel plate

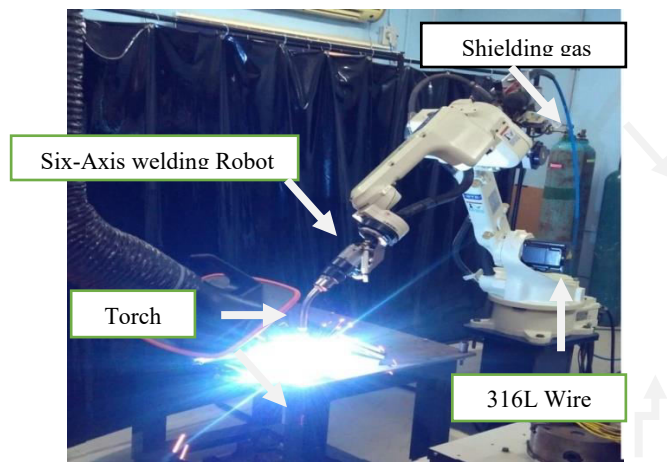
The system used to manufacture the final product has been used in two industries, such as welding and additive manufacturing (3d printing). This system is based on a heating source with helium shielding gas for Gas Metal Arc Welding (GMAW). It has a revolving six-axis. The wire-feed rate at 1.2 mm is only found in steel material forms. WAAM is a close net form method that involves a finishing machining pass. Either computer numerical controlled or robotic systems portals may be based on WAAM cells. Fig.1 Shows that Image of the welding robot machine which fabricated by WAAM Plate. Fig. 2 shows that Heat condition which is occurred by current passing one layer to another layer between waiting time is 40 sec. Fig. 3 & 4 shows that the view of the WAAM plate shows additively manufactured Plate with using layer by layer method 50 layers one by one added on that particular plate. Fig .5 shows that Shows cutting the base plate and side edges were removed using Micro Wire cut Electric discharge machining. Fig.6 shows that surface finish on that material using the vertical milling machine.

The following process parameters used fabricated in WAAM plate

**Table 1. Process Parameter**

Current(A)	Voltage(V)	Welding Speed(cm/min)	Interlayer Waiting time(sec)	Gas Flow Rate(L/min)	Shielding Gas
120	15.6	40	40	15	Argon+co2





**Fig 1: Image of the Welding robot machine**



**Fig 2: Heat Condition of the WAAM Specimen**



**Fig 3: Front view of the WAAM Specimen**



**Fig4: Side view of the WAAM Specimen**



Fig 5: WAAM Processed Plate



Fig 6: Surface image of the WAAM Specimen

### III. RESULTS AND DISCUSSION

#### 3.1 Vickers Hardness Test

The process commonly used to measure hardness is the Vickers hardness test. A square-based pyramid diamond indenter is pushed into the surface of the specimen with a predetermined force. After the indenter is removed, the diagonals of the resulting impression are measured, and the hardness number, noted as HV for Vickers testing, is calculated by the following equation

$$HV = 2P \frac{\sin\{\alpha/2\}}{d^2} = P 1.8544 P/d^2$$

Where

P is the Force in Kilogram. d - Diagonal of the impression in mm.  $\alpha$  - Face angle of the pyramid diamond indenter. Vickers hardness testing was performed incrementally over the entire weld and Heat affected zone (HAZ) region, with a minimum test point separation distance of three times the diagonal measurement of the indent, and the results are typically plotted graphically. Fig 7 (a,b,c&d) shown that Images of the Vickers hardness test specimens. Vickers Hardness test found that the hardness of the Top of the WAAM plate (Fig.8) values varied from 180 to 190 HV. The hardness of the Middle of the WAAM Plate (Fig.9) Values varied from 160 to 170 HV. The Hardness of the Bottom of the WAAM Plate (Fig.10) values varied from 170 to 175 HV. In this values are taken by the specimen distance range (Left to right) is 4,8,16 mm. The average hardness of Top was measured to be always higher than the hardness of both Middle and bottom. This difference can be possibly addressed to the considerable effect of thermal straining, which in turns induced strain hardening on the lower part of the deposit.

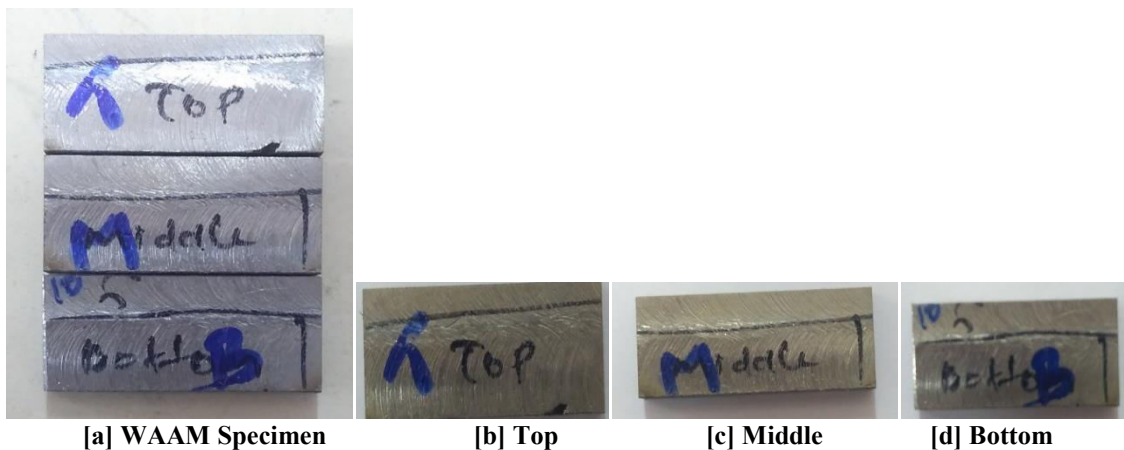
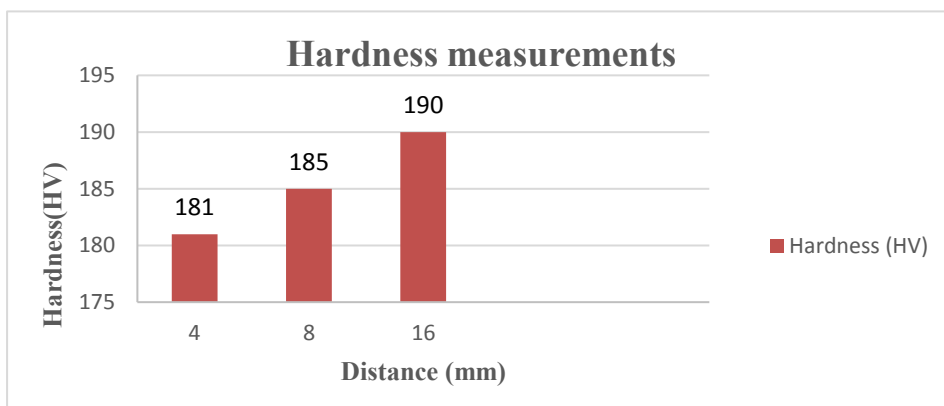
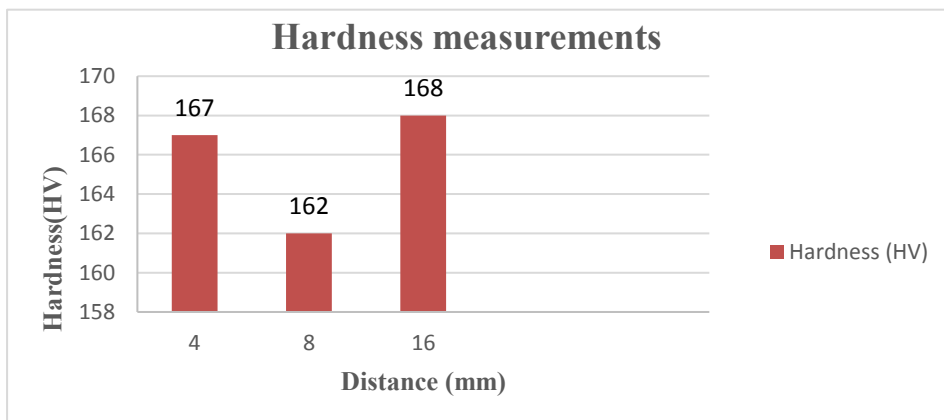


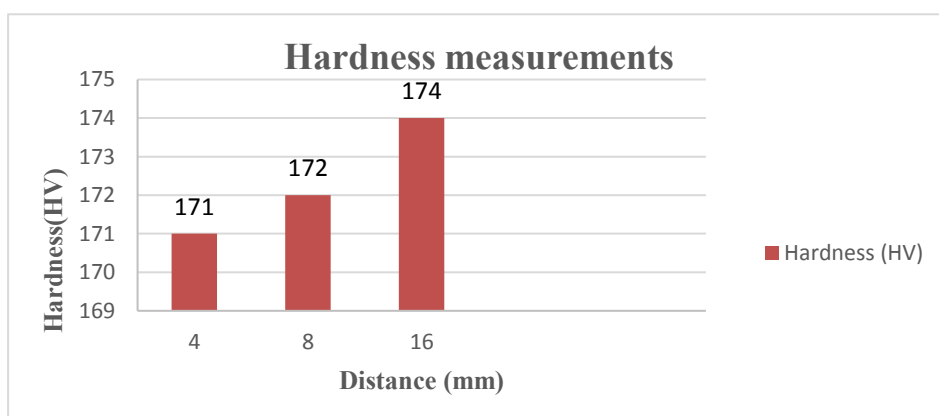
Fig 7 a,b,c &amp; d : Vicker Hardness Test Specimens



**Fig 8: Hardness at TOP of the Specimen**



**Fig 9: Hardness at Middle of the Specimen**



**Fig 10: Hardness at Bottom of the specimen**

### 3.2 Brinell Hardness Test

In this Test taken by Brinell Hardness testing machine. Make: SAROJ , SR No: OIAL/ME/09. [3000 KG] shown by Fig.11. Fig.12 shown by Image of the Brinell Ball indenter. Fig.13 shown by Image of the Brinell specimen. Hardness in HRBW [  $\phi 5$  /75 Kgf]. Brinell hardness test found that the hardness of the WAAM specimen (Fig.14) values varied from 160 to 166. In this values are taken by the specimen distance range (Left to right) is 5, 10, 15 and 20 mm.



Fig 11: Image of the Brinell Hardness Machine

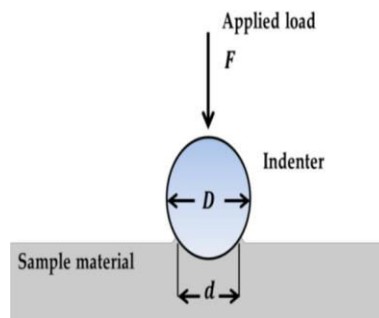


Fig 12: Brinell Ball Indenter



Fig 13: Image of the Brinell specimen

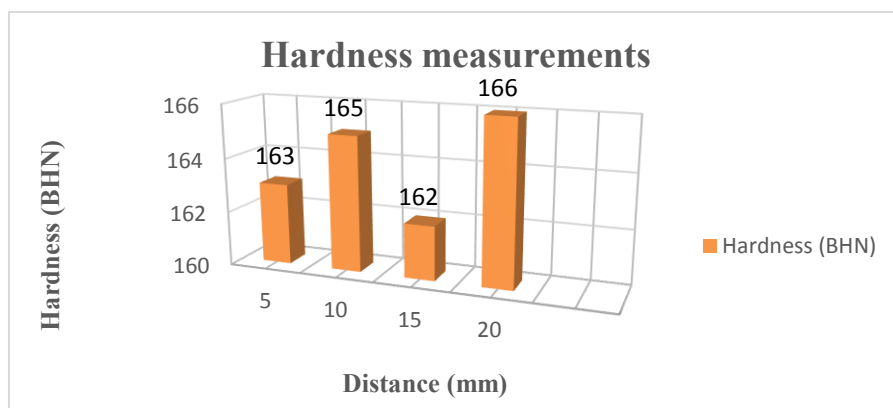


Fig 14: Brinell Test Measurement Values

### 3.3 Rockwell Hardness Test:

In this test taken by Rockwell Hardness testing machine shown by (Fig.15). Make : FIE, Model: RASN-T FIE 250. Fig.16 shown by Image of the Rockwell Hardness test specimen. Rockwell hardness test found that the hardness of the WAAM specimen (Fig.17) values varied from 84 to 86. In this values are taken by the specimen distance range (Left to right) is 5, 10, 15 and 20 mm.



Fig 15: Image of the Rockwell Hardness Machine



Fig 16: Image of the Rockwell Hardness Specimen

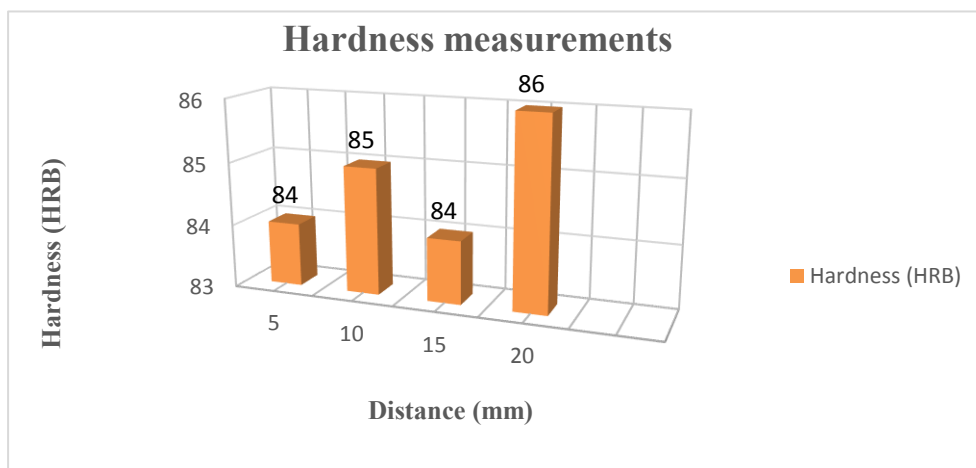


Fig 17: Rockwell Test Measurement Values





#### IV. CONCLUSION

In this Research work 3mm thickness plate was built by through feeding ER 316L stainless steel wire using welding robot machine and modifying the WAAM Parameters such as Current, Voltage, gas flow rate and welding speed. Substrate and Side edges are removed by Micro wire cut EDM and Surface finishing by with help of vertical milling machine. Investigated by the Various Hardness tests taken such as Vickers Micro hardness, Brinell and Rockwell. The Vickers micro hardness test Top of the plate was measured to be always higher than the Middle and Bottom. The Brinell hardness test found that the values varied from 160 to 166 BHN. The Rockwell hardness test result values varied from 84 to 86 HRB.

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