Experimental Analysis on Wire Arc Additive Manufacturing

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Abstract - *In the present study, wire arc additive manufacturing on mild steel using conventional metal ion gas deposition is performed. After deposition, microscopic analysis is performed to check the welding defect like hot cracking and gas porosity for further process optimization. The hardness of the final product in three different stages are analyses which lie between 18 to 47 kg/mm^2. After hardness analysis, mechanical testing of the specimen is analyzed in which maximum tensile and yield strength are 25.05 and 560.69MPa, respectively in the through deposition direction. It was found that layer deposition occurred in both parallel (X) and perpendicular (Y) orientations.*

Key Words: *Additive manufacturing, 3D printing, EDM, Microscopic, Equiaxed, Columnar, Fabrication.*

1. INTRODUCTION

The term Additive manufacturing (AM) refers to a class of technologies used to create layered physical objects directly from computer-aided design (CAD) data [1]. These techniques allow designers to quickly prototype their designs. Such a three-dimensional and smaller model of a part or assembly, compared to a simple two-dimensional drawing, gives design engineers a better idea of its dimensions and functionality. In addition to prototyping, AM techniques are used to make molds or mold inserts (high-speed tooling) and even to make fully functional end-use parts (called rapid manufacturing). AM or 3D-printing has revolutionized the manufacturing industry in everything from conceptual modeling to functional parts manufacturing, and now it's engineering design [2, 3]. And advancing the next generation of innovation. By reducing the design and manufacturing costs of various complex components and enabling game-changing designs, AM has significantly impacted many industries. . Due to its continuous development, there is a need to acquire new manufacturing applications and increase the reliability [4, 5].

One of the less well-known metal AM techniques is wire arc additive manufacturing (WAAM), although it has a lot of potential for 3D printing on a big scale in a variety of industries. Some of the limitations of the powder bed fusion procedure can be eliminated by using WAAM. It provides a higher deposition rate and greater build volume in contrast to SLS. This technology allows for the quick printing of fully dense metal parts with little porosity. It is the best choice for repair work because it is more affordable than other metal printing technologies. WAAM is a Direct Energy Deposition (DED) technology variant that 3D prints metal components using an arc welding technique. In contrast to other metal AM methods, WAAM uses an electric arc as the heat source to melt a metallic wire. The part is printed on a substrate material (a base plate) that is later removed during the finishing operation. The process is managed digitally. When the wire is melted, it is extruded onto the substrate as beads. The beads combine to form a coating of metal as they adhere to one another. Once the metal component is reached, the procedure is repeated layer by layer.

2. RESEARCH METHODOLOGY AND EXPERIMENTAL PLAN

WAAM is a variation of a Direct Energy deposition technology and uses an arc Welding process to 3D print metal parts. The standard MIG welding setup shown in Figure 2 is used to carry out the experiment, and the metal deposition process is shown in Figure 1.

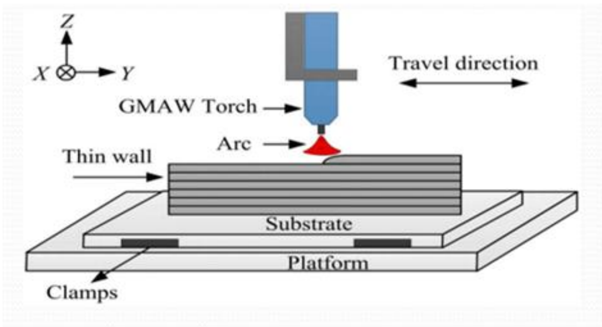

Figure 1: Schematic diagram showing the methodology of printing using the WAAM process [6].

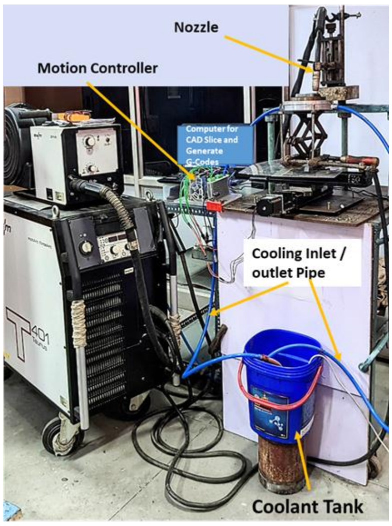

Figure 2: Working experiment setup for MWFAM Printing process.

Mild steel wire with a copper coating and an MS base plate were employed in the experimentation for the current study's usage of traditional MIG welding techniques. For the goals of metal wire fusion additive manufacturing, three input parameters (applied power, wire feed rate, and table speed) are chosen with three different values and an oscillation speed that is constant at 5.18 mm/sec. Figure 4 shows the results of the analysis of three layers of the metal deposition specimen after it was successfully completed. Following the completion of the deposition procedure, the specimen is taken from the base plate using wire EDM to remove any uneven surfaces, and grinding is then carried out. Using alumina powder and DI water, the grinding process is polished after. After the deposition procedure is finished, the specimen is taken from the base plate using wire EDM to remove any uneven surfaces, and then the grinding process is carried out. Following the grinding process, Figure 4's polishing with alumina powder and DI water is carried out. Finally, a chemical etching procedure using 97% ethyl alcohol and 3% HNO3 is carried out. Figure 5 illustrates the analysis of the specimen grain structures after depositing, cutting, grinding, polishing, and etching.

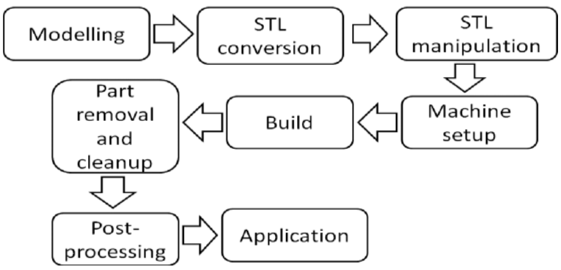

Figure 3: Experimental procedure for wire arc additive manufacturing.

Table - 1: Values of deposition parameters for wire arc additive manufacturing.

S. No.	GAP (mm)	Power (kW)	Wire feed rate (m/min)	Table Speed (mm/sec)	Oscillation speed (mm/sec)
1	8	2.48	4.8	1.63	5.18
2	8	2.74	5.5	1.44	5.18
3	8	2.98	5.9	1.14	5.18

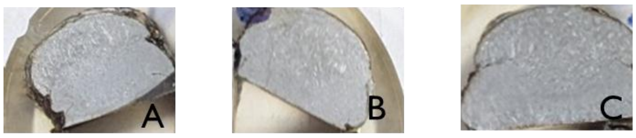

Figure 4: Specimen for viewing of microscopic and atomic microscopic structures.

Table -2: Microscopic view data of 3D printed specimen three layers.

S. No.	Gap (mm)	Current (Amp)	Voltage (V)	Table Speed (mm/sec)	Remarks
1.	8	110	22.6	1.24	B
2.	8	121	22.6	1.24	A
3.	8	132	22.6	1.24	C

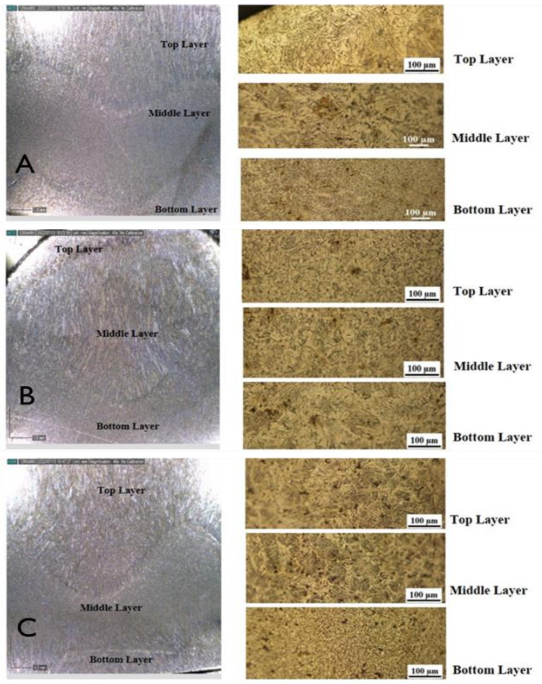

Figure 5: (A, B & C) Microscopic view of 3d printed specimen three layers segments.

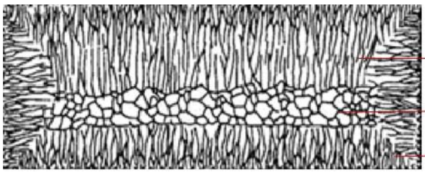

Figure 6: Solidification structure of 3D printed part of mild steel material [7].

3. MATERIALS AND EXPERIMENTAL PROCEDURE

3.1. Materials

The materials selected for this work included a support plate in EN-8, supplied in the T6 condition. The dimensions were 20 mm in thickness and 154 mm in diameter. The wire was a 1.2 mm diameter solid wire of copper coated solid wire conforming AWS class of SFA 5.18 ER70S-6 and is frequently used in the welding of EN-8 for structural applications. Its nominal chemical composition in weight percentage is outlined in Table 3.

Table - 3: Nominal chemical composition of the selected SFA 5.18 ER70S-6 wire.

C	Mn	Si	S	P	Cu
0.06-0.14	1.40-1.60	0.80-1.0	0.025 max	0.025 max	0.50 max

3.2. Layer Deposition

An experimental setup for wire arc additive manufacturing is demonstrated in Figure 2. For experimental purposes, a EWM Phoenix 401 MIG welding power source. Zero grade CO2 gas used for shielding.

The basic welding parameters for metal fusion wire additive manufacturing that are used are tabulated in the table. The parameters are chosen in such a way that stable deposition at lower heat is performed for edge layers.
The flange is made up of 3 beads in total, all of which were deposited in the same direction and spaced 5 mm apart. Due to an unexpected welding pause, Figure 5 shows an uneven surface halfway through one of the passes. With the same conditions, the remaining portion of the pass was instantly deposited.

3.3 Testing and characterization

In order to perform Rockwell hardness measurements and inspect for potential weld defects, the additive manufacturing component was put through tensile testing with samples oriented in three different directions, including parallel to the deposition/welding direction (X), perpendicular to the direction of the weld (Y), and through the thickness (Z). These were sliced to look at the cross sections in both the horizontal and vertical directions. Three different types of treatments were performed for specimens. To create contrast between the weld metal, the heat-affected zone (HAZ), and the support plate, the pieces were first ground and polished before being etched in ethanol and nitric acid solution. In the wake of this preparation, the hardness was assessed.

4. RESULT AND DISCUSSION

4.1. Microscopic inspection

After three layer of metal deposition, a microscopic visual inspection is perform to analyses the grain structure of solidified surface are shown in the Figure 5. During the grain analysis different type of grain structures are found.

After fabrication, a microscopic visual inspection is performed to check the different welding defects, like welding creak and porosity on the surface. Due to following the grain boundary, the welding crack present on the surface is an intergranular type. Most of the welding cracks are available in the high-temperature zone where equiaxed grain boundaries are present. These all cracks are hot cracks and developed at the grain boundary due to the low melting phase. During the thermal weld cycle of cooling less grain boundary cannot handle the tensile stresses, and these hot cracks are generated [8].

Porosity in the manufactured component is the main concern in the additive manufacturing process, affecting weldments' fatigue life [9]. Published results reveal that porosity may have a significant effect on the fatigue life of weldments. The main cause of porosity is moisture present in the wire or shielding gas. Both oxygen and nitrogen should be avoided as components of the shielding gas in WAAM because similar to hydrogen; they may be detrimental to the characteristics of aluminum welds.

4.2. Tensile properties

A tensile testing specimen of length is 32 mm prepared as shown in Figure 7. The sample A has a mean yield and tensile strength of 25.05 and 387.40 MPa, sample B has 21.23 and 513.32 and sample C have 19.67 and 560.28 MPa respectively. The graphical representation of tensile testing for all three sample are represented in Figure 8. When the specimen was oriented parallel or perpendicular to the direction of layer deposition, the ductility was high. The area reduction has decreased to

30% for samples taken in the through-thickness direction. It was determined that the Young's modulus ranged between 18.52 and 20.25 GPa. The strength levels produced in this work are greater than those in prior published works for Al-6.4% Mg, which has a slightly higher Mg content than commercial 5183 wire [10, 11].

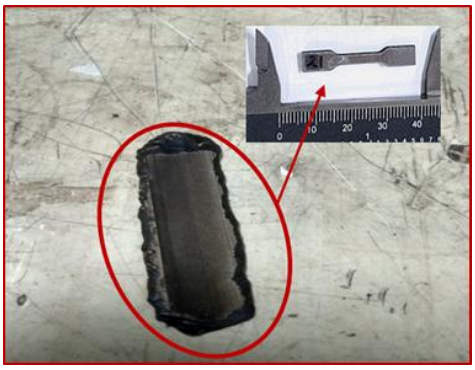

Figure 7: Cut specimen by Wire EDM process for extract Tensile Specimen.

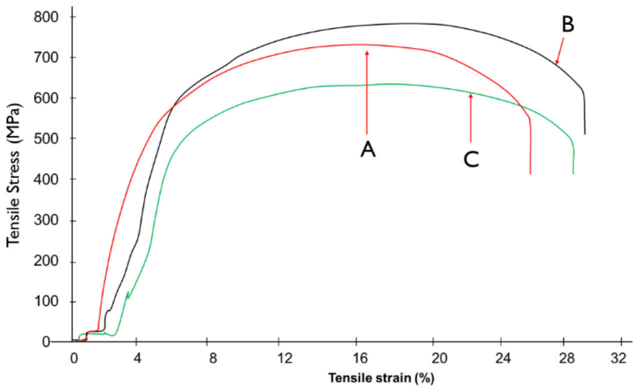

Figure 8: Tensile stress (MPa) vs tensile strain (%) for all three sample.

4.3. Hardness

The hardness of different samples is measured at different locations from the bottom to the top of the sample, as shown in Figure 9 and tabulated in Table 4. The hardness value for sample A varies from 21 to 32 kg/mm2; for sample B, it is 27 to 47 kg/mm2, while for sample C, hardness values vary from 18 to 30 kg/mm2. These hardness value levels are lower than those found by Ericsson et al. [12] in the heat-affected zone, which varies between 60 and 70 kg/mm2 [13, 14].

Table - 4: Hardness testing results for different sample.

Points (Top to Bottom)	A (HRD)			B (HRD)			C (HRD)		
Top	25	32	30	27	30	44	23	28	29
Middle	29	30	29	31	32	47	25	30	28
Bottom	21	28	27	28	30	29	18	29	27

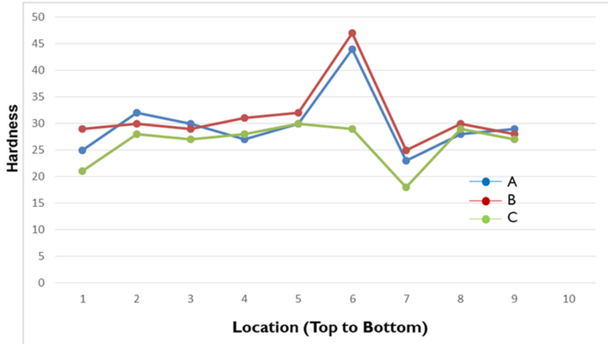

Figure 9: Variation in the hardness at different location of speciman.

5. CONCLUSION

In the present study Copper coated solid wire conforming AWS class of SFA 5.18 ER70S-6 is used on mild steel support plate is used to performed WAAM process. The following work is concluded as follows:

- Along with the usual porosity, multilayer deposition caused some cracking in warmed weld metals from later passes.
- In the tensile testing of specimen, the yield and tensile strength of 320 and 155MPa is obtained respectively.
- Hardness of three different specimen are measured after MWFAM process which is for sample A is varies from 21 to 32 kg/mm^2, for sample B it is 27 to 47 kg/mm^2 while for sample C hardness values is varies from 18 to 30 kg/mm^2.

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