Effects of Aluminum Alloy ER 4047 Bead Characteristics Deposited by Wire Arc Additive Manufacturing

M.Mohamed Jameel[1], Dr. B. Anandavel[2], Prof.N.Thennammai[3]
[1]*PG Student, Department of Metallurgical Engineering, Government College of Engineering, Salem, Tamilnadu, India*
[2]*Assistant Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem, Tamilnadu, India*
[3]*Associate Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem, Tamilnadu, India*

Abstract - Wire arc additive manufacturing (WAAM) is a fusion manufacturing process in which the heat energy of an electric arc is employed for melting the electrodes and depositing material layers for wall formation or for simultaneously cladding two materials in order to form a composite structure. Wire and arc additive manufacturing (WAAM) process is a group of additive manufacturing (AM) techniques that use an electric arc as a heat source and a metal wire as a feedstock for the fabrication of 3D metallic components in a layer-based manufacturing process. This directed energy deposition-arc method is advantageous and efficient as it produces large parts with structural integrity due to the high deposition rates, reduced wastage of raw material. These features have resulted in a constant and continuous increase in interest in this modern manufacturing technique which demands further studies to promote new industrial applications. The high demand for WAAM in aerospace, automobile, nuclear, and dies industries demonstrates compatibility and reflects comprehensiveness.

Keywords: AM, Wire and arc additive manufacturing (WAAM), Cold Metal Transfer, Microstructure, SEM, EDS, OES.

1.INTRODUCTION

In recent decades, additive manufacturing techniques (AM), also referred to as 3D printing or rapid prototyping, have attracted the attention of various industries such as aerospace, automotive, and construction. AM is the process of manufacturing 3D printing by adding layer-upon-layer of material. The various advantages of AM compared to conventional manufacturing (CM) processes can be discussed in three aspects. First, AM makes it possible to build complex components that are difficult to manufacture by the CM processes. Second, the AM processes improve the buy-to-fly ratio by reducing the amount of waste material, which reduces the final price of the parts. Third, the AM process can have a significant impact on reducing energy consumption and protecting the environment by reducing both the production time and the weight of parts produced due to new designs or material modifications. Wire and Arc Additive Manufacturing (WAAM) refers to a specific group of AM techniques that use an electric arc as the heat source and a metal wire as the feedstock. The WAAM technique uses arc welding processes and more specifically automated arc welding. The three welding methods commonly used in the WAAM technique are Gas Tungsten Arc Welding (GTAW), Plasma Arc Welding (PAW), and Gas Metal Arc Welding (GMAW). Therefore, WAAM technique is divided into three groups, namely GTAW-based WAAM, PAW-based WAAM, and GMAW-based WAAM. The main advantage of WAAM over other AM techniques is that its deposition rate is higher, hence WAAM is used to produce large near-net-shape components. Another advantage of WAAM is its lower capital costs compared to other methods.

Despite the increasing consumption of aluminium and its alloys in various industries due to its unique properties, such as high strength-to-weight ratio, high ductility, and high durability, most of the research and productions in the WAAM field have focused on the stainless steels, nickel and titanium alloys. The main reason is the gas pores and the coarse dendritic structure formation during the WAAM process, which leads to a severe loss of the mechanical properties of the aluminium alloy components.

CMT-WAAM is considered to be more suitable than traditional WAAM processes because of its regulated heat input and optimize the weld lines. When fabricating multilayers of metal, irregularities such as overlap between passes, lack of fusion between layers, gas porosity, and surface-connect porosity are all possibilities. Thus, the manufacturing of multilayered products remains a challengeable problem. This study attempts to optimize the weld bead characteristics and to fabricate a multilayer wall and study of micro structural properties and Micro hardness valve for the ER4047 aluminum alloy.

1.1 Additive Manufacturing

Additive manufacturing (AM) is also known as 3D printing. It is a transformational approach to industrial production that uses a computer-controlled process to generate three-dimensional objects through the process of adding materials layer-by-layer. Additive manufacturing (sometimes referred to as rapid prototyping or 3D printing) is a method of manufacture where layers of a material are built up to create a solid object. While there are many different 3D printing technologies this article will focus on the general process from design to the final part. Whether the final part is a quick prototype or a final functional part, the general process does not change.

Additive manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three- dimensional object, with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer.3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models created with CAD result in relatively fewer errors than other methods. Errors in 3D printable models can be identified and corrected before printing. The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

CAD models can be saved in the stereo lithography file format (STL), a manufacturing that stores data based on triangulations of the surface of CAD models. STL is not tailored for additive manufacturing because it generates large file sizes of topology optimized parts and lattice structures due to the large number of surfaces involved. A newer CAD file format, the Additive Manufacturing File format (AMF) was introduced in 2011 to solve this problem. It stores information using curved triangulations.

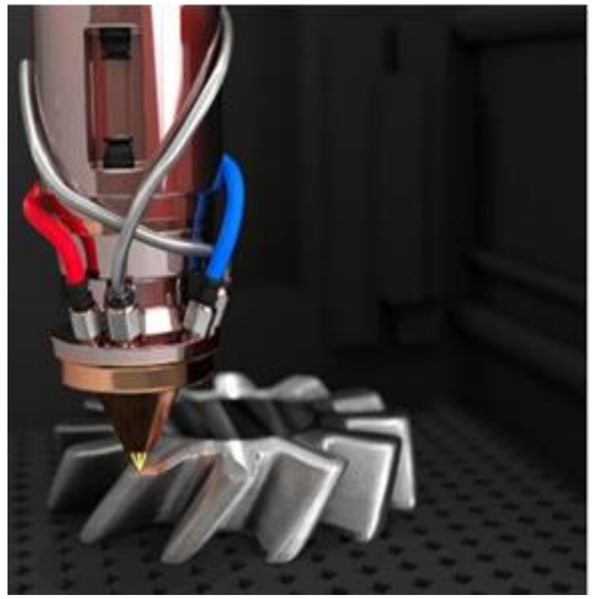


Figure 1.1 Additive Manufacturing

1.2 Wire Arc + Additive Manufacturing

This additive manufacturing process uses an arc welding process to 3D print objects. This process is controlled by a robotic arm that follows a predetermined path. The object is built upon a base plate and the object can be cut when finished. This process can work with a wide range of metals such as stainless steel, nickel-based alloys, titanium alloys, and aluminium alloys as long as they are in wire form.

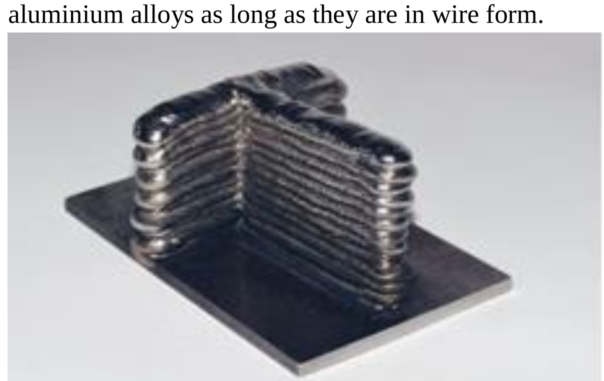


Figure 1.2 Wire Arc Additive Manufacturing

WAAM hardware currently uses Welding power source, Welding torches and wire or rod feeding system. The designing can be monitored by computer aided design and product can be developed by using computer numerical controlled gantries.

1.3 Cold Metal Transfer

Additive manufactured aluminum is influenced by porosity. Fronius cold metal Transfer (CMT) is a modified MIG variation, which depends on controlled dip transfer mode system; this should convey dots with phenomenal quality, lower heat input and almost without scatter. It has been shown that, utilizing a blend of good quality welding wires and certain synergic working modes, porosity can be reduced [ii], disposition is done by layer by layer on 3-dimension printing as shown in figure

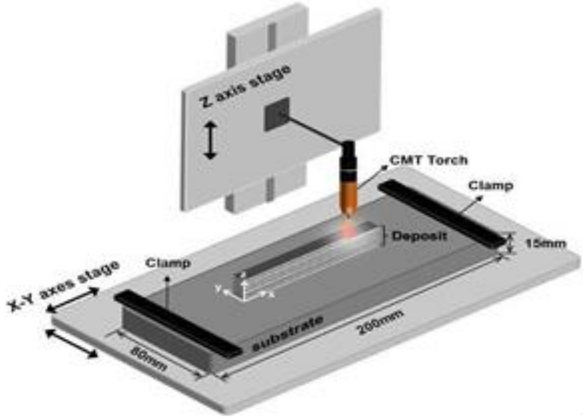


Figure 1.3 Multilayer Deposition using CMT

1.4 Selection of Materials

ER4047 is an Aluminum alloy welding wire which is widely used as all position MIG welding wire, it consists of 5% silicon, it improves the fluidity and it heals the cracks so it is widely used in ships, locomotive, chemical engineering, food, sports equipment, mould, furniture, vessel, container as welding application.

Table 1.1 Chemical composition ER4047

Elements	Si	Fe	Cu	Mn	Mg	Zn	Be	Al
Wt%	11-13	0.80	0.10	0.15	0.10	0.20	0.0003	Bal

Typical Mechanical Properties:
Melting Range - 1070°F-1080°F (577°C-582°C)
Ultimate Tensile Strength (MPa) -144-227Mpa
Yield Strength (MPa) – 69-190 MPa
Percent Elongation in 2” - 5-12%
Density - 0.097 lbs/in3
Post Anodize - Color Gray

2.RESULTS AND DISCUSSION

2.1 Multilayered wall formation

As mentioned above bead on plate was done on the Al6063 base plate. The Multilayer wall was deposited under selected parameter, the evaluation of bead mechanical properties and Material characterization are revealed in the following stages.

Table 2.1 Value for developing wall

No. of Layers	Mean value Time taken for deposition	Ampere	Voltage	Interval time for each layer	Torch speed (mm/min)	Wire feed(mm/min)
19	42 sec	80A	10.2V	60 sec	300	400

2.1.1 Tensile test

Tensile test results of ER4047 Multilayer beads in transverse direction under ASTM E8 Round Type specimen using universal testing machine (UTM) are shown below.

Table 2.2 Values of tensile testing in transverse direction of bead

Test Parameters	Observation
Yield strength (N/mm^2 or MPa)	68
Tensile Strength (N/mm^2 or MPa)	115
Elongation (%)	8.5
Reduction (%)	18.5

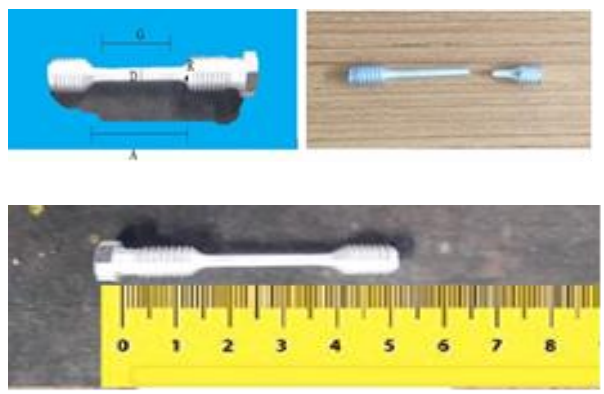


Figure 2.1 Tensile specimen

Dimension of Tensile Specimen
G – Gauge length = 20
D – Gauge diameter = 2.5
A – Length of reduced parallel section = 30
R – Fillet radius = 2
(All Dimensions are in mm)

2.1.2 Micro hardness test

Hardness value of ER4043 Multilayer deposited bead tested on Micro Vickers hardness tester under ASTM E384-2016 are shown below

Table 2.3 Hardness values of ER4047 bead

Test Parameters	Observation
Load (in grams)	300
Observed Values (HV)	53,51,52

2.1.3 SEM with EDS

The 3D image of ER4047 multi- layer deposit bead was observed using Scanning Electron Microscope.

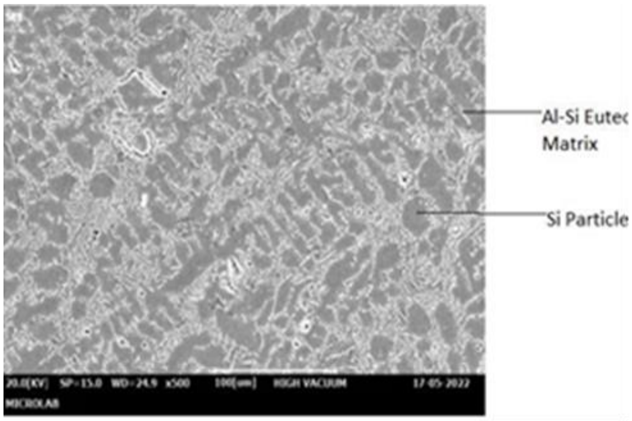
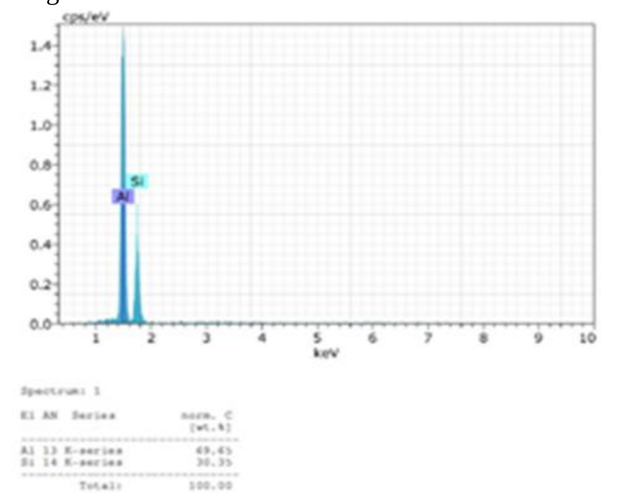


Figure 2.2 SEM Images of ER4047 Multilayer deposition

The composition of Eutectic Al-Si compound was analyzed using EDS.



Graph 2.1 EDS Analysis

CONCLUSION

From the present study the following Conclusion where made

[1] The optimization of ER4043 using CMT was done

[2] Bead characteristics like width, height and wetting are measured on varying current and travel speed.

[3] The results show that the increase in Current Ampere and travel speed reduces the width and wetting angle of the Monolayer beads

[4] The hardness value rises on each Monolayer bead with increasing in Travel speed due to the fast solidification.

[5] Microstructure reveals the silicon which is segregated in low current due to rapid solidification makes silicon segregates before evenly distributed and in high current the times takes for solidification is more so the silicon is distributed evenly.

[6] Multilayer wall was deposited at 80 V with 300mm/min travel speed using Er4047

[7] Microstructure of multilayer revealed the Al-Fe-Si eutectic particles in a matrix of aluminium solid solution.

[8] Micro hardness was studied

[9] Chemical composition test was conducted on the multilayer deposit by Optical Emission Spectroscopy shows all element of ER4047 present after the deposition.

[10] Orientation of multilayer wall is an unavoidable task in WAAM.