International Journal of Modern Agriculture, Volume 10, No.2, 2021
ISSN: 2305-7246

Design And Manufacturing Al-Si (Er4043) Aluminum Aircraft Landing Gear Base Plate Using Wire Arc Additive Manufacturing Process (Waam)

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Abstract

The Wire Arc Additive Manufacturing or WAAM is strategy of completing the 3D manufacturing by means of arch through feedstock deposits layer and then repetitive layer line approaching to most precisive manner. WAAM can be better option to manufacture than the traditional method. The WAAM came into action more due to popular versatile design which can be easy to attain after some modification in the science. Though this method is not much feasible for manufacturing the components. All the same time many designers are lighting up on the manufacturing of shapes through it. Further, this can be the better crucial science after some crucial modifications. The main found of mechanism on aluminum 4043 is less material wastage, high buy-to-fly (BTF) ratio and anti-corrosive property. The aluminum consists of traces of hydrogen in the molten pool and released on solid to become hole indicates main reason of porosity. Hence aluminum is also not viable for commercials due to weld defect and turbulent melt pool which is caused due material deposition and reproducibility. This research paper conclude test on aluminum 4043 in the line of microstructure, chemical composition and Brinell hardness. The approach in the paper conclude for uses of aluminum 4043 to its best peak application.

Key words: WAAM, Additive Manufacturing, Welding, Microstructure, Chemical Composition, Brinell Hardness Test

Introduction

Wire Arc Additive Manufacturing abbreviated as WAAM is the modern technique to design 3D printing through layer-by-layer deposition. The WAAM is the technology which teaches about the production of versatile drawings with about 30 times less raw material usage than in traditional process [1] WAAM design the component through the electric arc as source and feedstock wire for melting. It is further proceeds by robotic manipulators which generates desirable layers as per requirement [2 – 4]. The WAAM implementation is also dealing with buy- to- fly ratio. The buy to fly ratio of 33:1 for titanium and 20:1 for titanium duct is reported [5,6]. This ratio should be low and can be achieved to industry for inflexible machining materials. [7]

The leading work of model printing is done by 6-axis robot which provides flexibility to work [8]. The requirement is done by designing CAD geometry, slabbed into layers and further proceed by dropping material into consecutive beats. This generates required dimensions build. However, the working to get optimal path and stable build is still in studies [9,10]. The geometrical distinction, printing direction, layer-height, cooling timing for consecutive layer are some particular reasons for the above-mentioned problem. But this process can affect the material mechanical properties like thermal, volumetric fraction, ultimate tensile strength, yield strength to major and minor. [11]

Aluminum has high specific strength and good corrosive resistance. So, the demands of aerospace and aviation majorly fulfilled by aluminum alloy. Also, the ability of good formation and light-weighting makes this element in abundancy for aerospace, aviation and airframe components [12,13]. However, it is found that aluminum layer is limited by cracks and porosity. The temperature should be specified under the threshold level [14]. the functional problem found in aluminum alloy is porosity. This is mainly due to traces of hydrogen initiated in the figure. This bubble should be resolved to get rid of porosity [15,16]. This abundancy of porosity affects

properties such as poor in ductility, fatigue and strength. These problems can also cause due to stress concentration because of geometrical discontinuities.[17]

The aim behind studying of aluminum 4043 in this paper is to find best testing results under microstructure, chemical composition and Brinell hardness test. Albeit, some issues arise due to cooling time, deposition and solidification [18,19]. Therefore, all the above relative inhibitory is needed to be worked and should be updated. Indeed, the WAAM can be good solution for time saving, resources saving and effort puts in building projects in prior period. This also pertinent to be advantageous in work quality, the safety of workers, productivity increment.

Material Used and Methodology

MACHINE AND EQUIPMENTS:

In the lines of experiment on building the aluminum wall, the aluminum 4043 is used as the spool wire or melting material. This Al 4043 spool wire with diameter 1.2mm material will be deposited in the base metal by the welding torch to get two rectangular dimensional body. Both of 125mm x 105mm x 6mm as length x breath x width respectively of specimen manufactured. The base metal plates for the purpose are aluminum with series 6061 with dimension 8mm and 12mm as thickness. The build is taking care by the 6-axis robotic machine (fig 2.1) (Kemppi India *Pvt. Ltd.,* Lakshmi Towers, 2/270, 1st street, Kazura Gardens, Neelangarai, Chennai). the main systems in the process were YASKAWA YRC 1000 AR1440 coding controller (fig 2.2) (Kemppi India *Pvt. Ltd.,* Lakshmi Towers, 2/270, 1st street, Kazura Gardens, Neelangarai, Chennai). The main part of assembly consisting of cable assembly, shield gas(argon), wire feeder, feeding torch and welding power source with fixed plate for the design of subtract. Input units are given through KEMPPI A7 MIG (fig 2.3) (Kemppi India *Pvt. Ltd.,* Lakshmi Towers, 2/270, 1st street, Kazura Gardens, Neelangarai, Chennai).

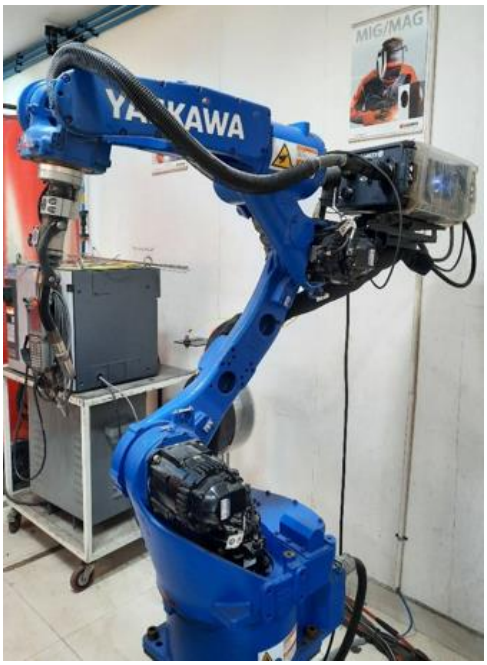


Fig 2.1 6-axis robot

Fig 2.2 YASKAWA YRC 1000 AR1440 Coding controller

Fig 2.3 KEMPPI A7 MIG Power source

ANALYSIS IN ANSYS SOFTWARE:

The manufacturing is first analyzed on software ANSYS for scalable solution of software. The dimensions to be manufactured is given as 125mm of length x 105mm breath x 6mm width (Fig. 2.4 and Fig. 2.5) .The block analysis represents the finite element analysis for calculating stationary and non-stationary mechanical problems. It tells heat exchange, heat transfer, deformable solids, acoustics, problem of liquid and gas. It delivers efficiency reduction in physical constraints with high quality and minimize risk. This facilitate end-to-end solution of manufacturing which is helpful while fabricating and testing.

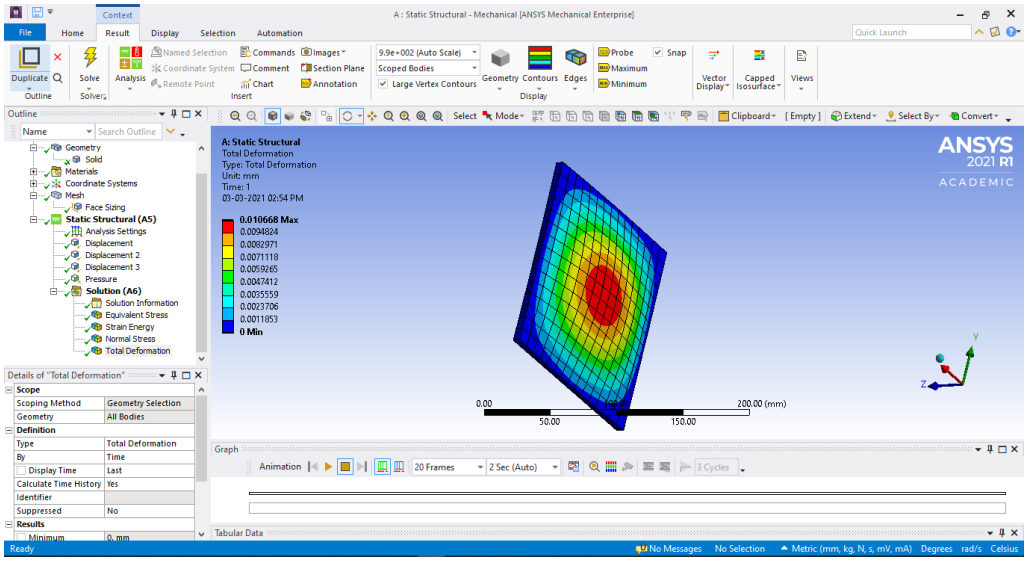


Fig. 2.4: Total Deformation Analysis

DIMENSIONS ARE IN MM

125X105X6

VERTICAL POSITION (AL 4043)

Base temp (room temp) = 25*c

Top layer (melting point) = 632*c

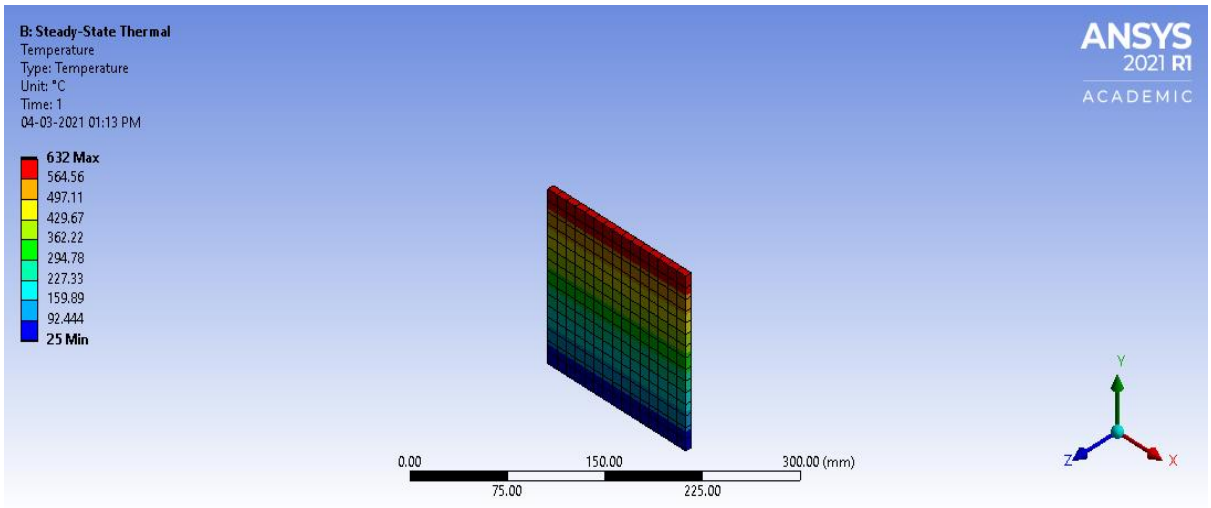


Fig. 2.5: Total Temperature Analysis

MATERIAL USED:

The parent material that is aluminum 4043 (35-113, Kalli Kuppam Rd, Old Ambattur, Sai Nagar, Ambattur, Chennai,) had the way easy to flow in molten state. Since it is corrosive resistance material, it adds on the point to choose for the purpose. There is the physical composition of this material consisting great amount of silicon. It not only has good fluidity behavior compare to other series of aluminum like 5000s and 6000s but also falls in first for crack sensitivity matter [19]. Although the name of experiments based on Al 4043, but the role important is also paid by the base metal aluminum 6061. The fame and trend of aluminum 6061 gives its role to

be the base metal for the component. Containing silicon and magnesium as its most traced element makes up the alloy precipitation-hardened. [12]

SET UP OF MACHINE:

The dimensions of requirement are drawn in the base metal. The area to be welded is taken care of proper clamping of material without any obstacle. It is maintained in pure plane surface and cleaned before clamping. The pure movement of six-axis robot is regulated by coding as input. with the help of input language, the robot provides repeatable and accurate movement accordingly. Al 6061 as base is clamped to the best of accurate as possible. One end of the raw wire of aluminum 4043 from the wheel is fitted in the component of robot and get out through feeding torch. The gas gets regulated through the gas chamber called shielding gas. The shielding gas fired for aluminum is argon. The component is approximately having 99.99% of argon. This cycle institute with flow rate of 15 LPM (liter per minute).

FABRICATION:

The current, voltage and holding time can be set and do so through MIG A7. The holding time refers to time given to robot for staying in the rest position between two consecutive layers. This is to ensure the temperature fallen and cleaning purpose of each layer. There is the difference in units input between first two layers and the rest in other to get stable and adequate base layer. The first two layer have high voltage, ampere and wire feed speed (fig 2.6). The feeding torch is set in the proper way to get perfect figure. The torch is then provided by input of movement, units and argon gas. This torch starts to run through the way while molten metal is coming out as shown in fig (fig 2.8). it moves straight to the end and stops to give material and stay there up to holding time (fig 2.7). It is important to clean the layer after row formation. After the holding time the feeder again start to process and continue till two layers. The units for next layers are same. It again starts the cycle from where it stops. And this processes until requirement. It is essential to measure the dimensions in between for precautions.

Fig 2.6 First Layer

Fig 2.7 Holding Time

Fig 2.8. Running Time

Test on Sample:

For the experimentation stage the buildup component should be separated through the base metal plate and smoothen to its best.

MICROSTRUCTURE TEST:

According to barker, for getting the sample microstructure an electrolytic polish of etch and etching were processed and examine in polarized wave. The microstructure test is processed with the OLYMPUS MX40F optical microscope (OM) [20]. The plate is aligning to the XZ-plane (fig 2.9). The examination of chemical composition is done through optical emission spectroscope. It starts with electric spark occurred due to electrode and sample piece followed by the vaporizing atom under high energy state known as “discharge plasma". The spectral light is split through diffraction grating to get targeted elements.

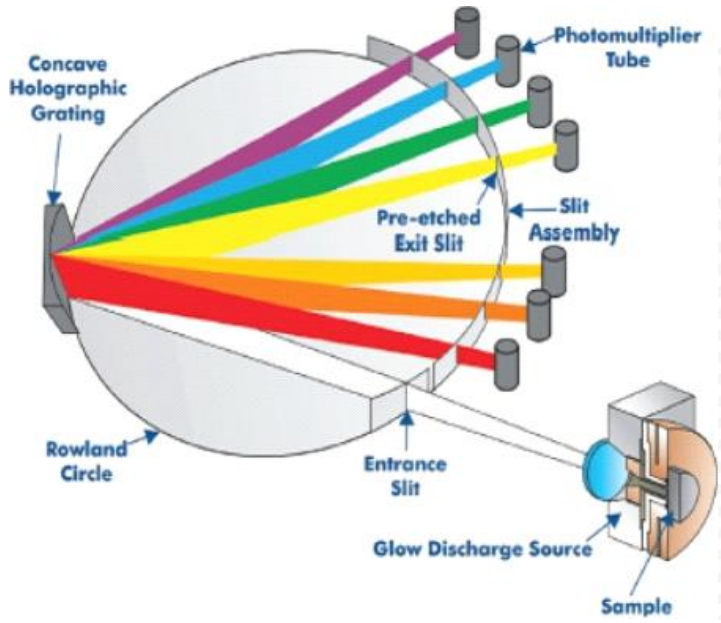


Fig 2.9 OLYMPUS MX40F optical microscope (OM) **Fig 2.10 Spectroscopy**

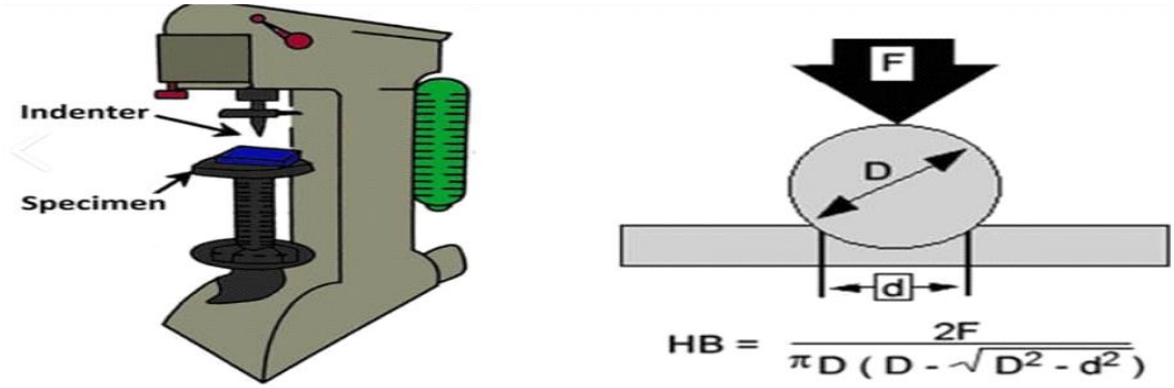


Fig 2.11 Brinell hardness test

CHEMICAL COMPOSITION TEST:

The quantitative and qualitative intensity of spectrum for each element analysis is detect through photomultiplier tube (so called as detectors). The spark released in an argon atmosphere is extracted by steady action of emitted spectra through spark pulse. This is also known as Spark Atomic Emission Spectrometry (fig 2.10). This offers elemental analysis of sample which become inevitable for aluminum metallurgy processes.[21]

BRINELL HARDNESS TEST:

The Brinell hardness test is carried out through a carbide ball indenter. This ball is pressed by testing forces and stays till dwell time (generally 10-15 seconds) specified. The indenter (typically 10 mm) stamp a round in the sample after removal. The size is measured by load (generally from 3000kg-f to 500 kg-f) for application device. The indentation is assumed to be spherical with radius exact to half of diameter of ball (fig 2.11). The Brinell hardness number abbreviates as BHN or HBW is determined by force test upon indent curved surface area [22].

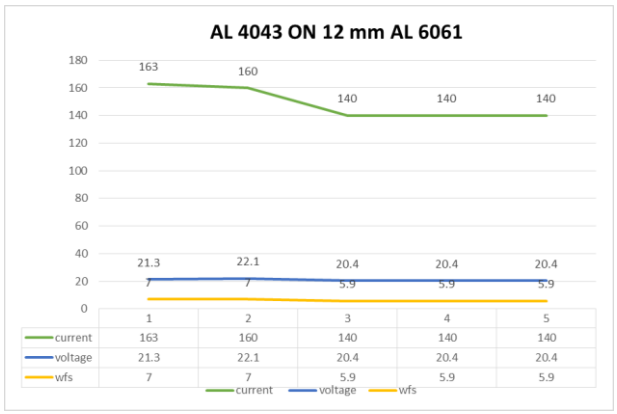
The Brinell Hardness Number (BHN or HBW) is calculated using the following Brinell hardness test formula:

$$\text{BHN} = \frac{L}{A_c} = \frac{2L}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

Result and Discussion:

Final product by WAAM:

The initial investigation is pertinent to the influence of deposition of raw aluminum with diameter 1.2mm with respect to input provided from MiG A7. The built is directly influenced through input voltage, current provided and wire feed rate with holding time. The importance of cleaning each layer is observed. Initial 2 layers of the components are little higher inputs which differing from next and remaining same till the end. The first component of dimension 125mm x 105mm x 6mm on 8 mm plate, suffers from the units, as the current provided initial at 131 A to 108 A with constant after fourth layer at 114 amperes. The voltage starts with 18.9 V with constant after 18.2 V after fourth layer. The wire feed rate is almost constant through the process. The secondary component with dimension 25mm x 105mm x 6mm on 12 mm plate in the metal base of and feeding metal had differ from the first. Starting from 163 A to 140 A after three layers and then constant for entire. The voltage given is 21.3 V to 20.4 V at constant afterwards. The table no 01 shows for al 4043 on 8mm with graph (3.1) and final product (fig 3.1) and table no. 02 shows al 4043 on 12 mm with graph (3.2) and final product (fig 3.2). Wire speed rate is 7 for first two and 6 for the rest.



Graph no: 3.1 plot with current, voltage and Wire feed rate;

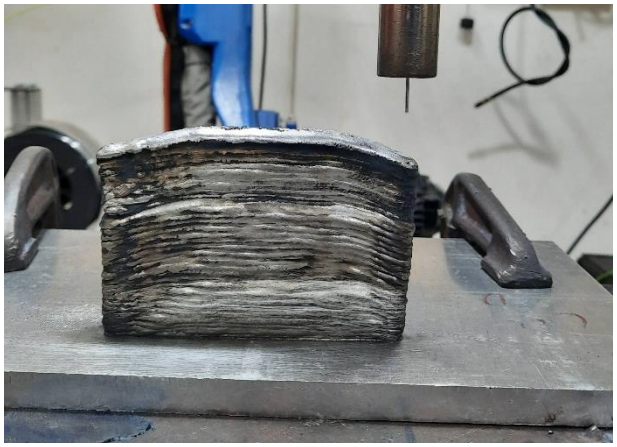
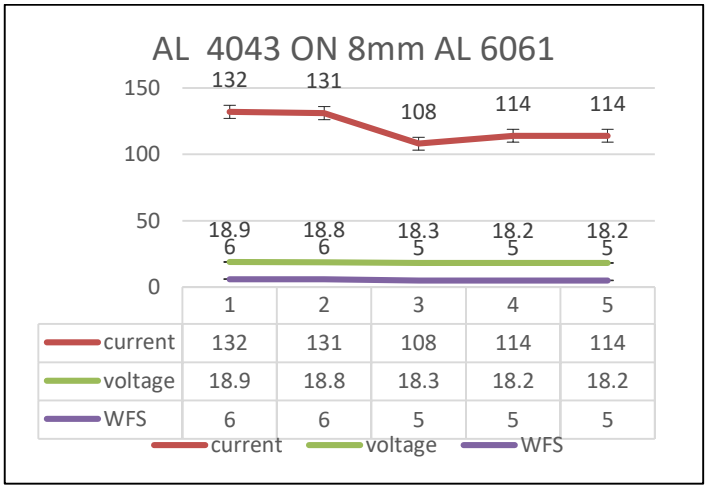


Fig 3.1: sample wall on 8mm plate



Graph no: 3.2 plot with current, voltage and wire feed rate;

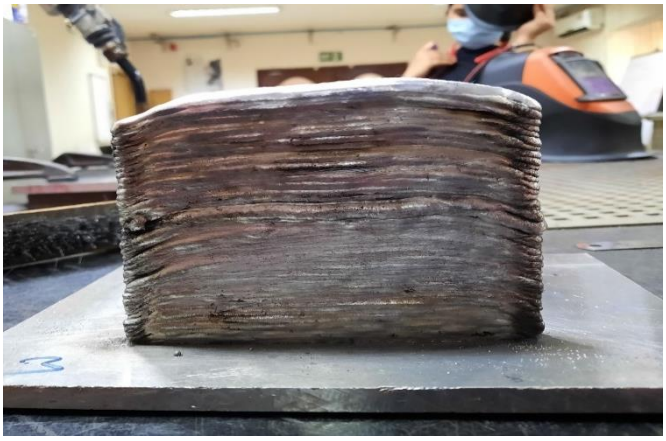


Fig 3.2: sample wall on 12mm plate

Microstructure:

The microstructure of the build tested samples shown in fig 3.3 and fig.3.4 with the resolution of 100x/100µm and 500x/25µm. Meaning 100x for every 100µm and 500x for every 25µm it shows the inter-dendritic network for both. It means having the branched types of resembling tree in between. The eutectic silicon (that is silicon having precipitation in eutectic near eutectic aluminum-silicon alloy) appears in lamellar form of metallographic specimen. Thus, the distribution of eutectic silicon in the matrix of aluminum solid is observed in the structure.

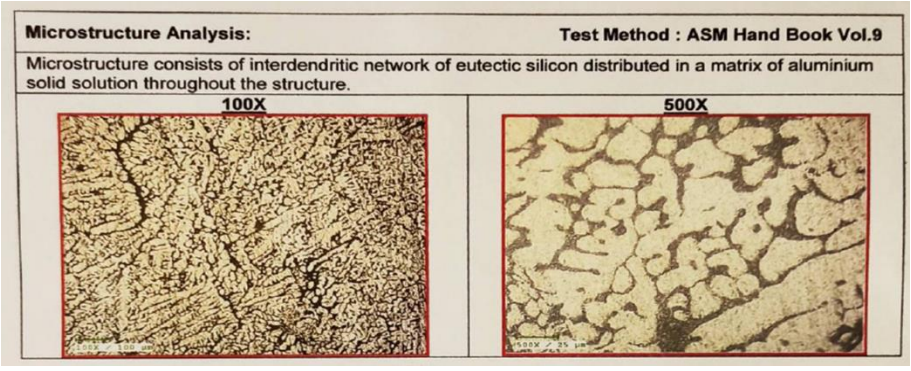


Fig. 3.3 : Microstructure on Al 4043 on 8mm Al 6061

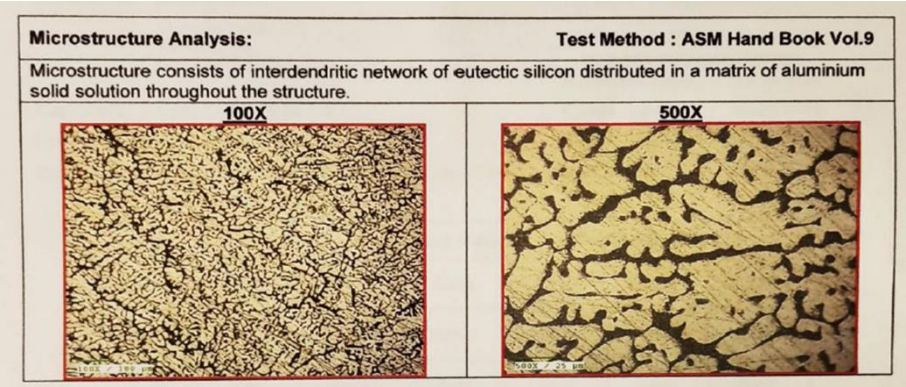


Fig. 3.4 : Microstructure on Al 4043 on 12mm Al 6061

Chemical analysis:

The chemical analysis of al 4043-filler wire is carried out in 8mm plate. This test report shown the composition chemically on aluminums 4043 on 8mm in table 3.1. Composition for 12 mm plate is shown in table no 3.2 By the grader of Chennai Mettex lab private limited. The table illustrate the composition having is as the majorly silicon with around 4.5% followed by iron and it and so on. It shows that the properties of build sample are slightly differ with the property of aluminum filler wire grate 4043.The silicon concentration in the 12mm plate is slightly differ with the 8mm plate. 12 mm consist of 4.589% where 8mm has 4.552 %.

CHEMICAL ANALYSIS:			TEST METHOD: OES-ASTM E-1251-17a			
Fe%	Si%	Mn%	Cu%	Ni%	Cr%	Ti%
0.157	4.552	<0.010	0.016	0.003	<0.005	0.018
Sn%	V%	Co%	Zn%	Pb%	Mg%	AL%
<0.006	0.006	<0.002	<0.020	0.005	<0.010	95.217

Table 3.1: For chemical analysis on AL 4043 filler wire on 8 mm plate

CHEMICAL ANALYSIS:			TEST METHOD: OES-ASTM E-1251-17a			
Fe%	Si%	Mn%	Cu%	Ni%	Cr%	Ti%
0.157	4.589	<0.010	0.015	0.004	<0.005	0.018
Sn%	V%	Co%	Zn%	Pb%	Mg%	AL%
<0.006	0.006	<0.002	<0.020	0.006	<0.010	99.18

Table 3.2: For chemical analysis on AL 4043 filler wire on 12 mm plate

Brinell hardness:

The Brinell hardness number here uses ASTM E10 as the standard in Mettex Lab private limited Chennai. The HBW stands for Hardness Brinell Wolfram carbide. Wolf carbide (or tungsten carbide) highlights the working of tungsten carbide ball. It opposed to prior (HBS) working of (softer) steel balls. Here the Brinell hardness number and specification is written in "HBW/10mm Dia Ball/500kgf Load". This states that the "HBW" refers for tungsten carbide ball as indenter. "10" is the diameter of ball in millimeter. "500 kg f" is the force (in kilograms force). Both the test having different values. Since the values (table 3.3) of same materials (table 3.4)

has different structure, it shows the plain and roughness of surface manufactured by Wire arc additive manufacturing.

MECHANICAL PROPERTIES:		TEST METHOD: ASTM E10 : 2018
S. NO	Characteristics Test	Result
1	HARDNESS	38.9, 38.1, 39.4

Table 3.3: Brinell hardness of sample on 8mm aluminum 6061

MECHANICAL PROPERTIES:		TEST METHOD: ASTM E10 : 2018
S. NO	Characteristics Test	Result
1	HARDNESS	40.2, 38.5, 40.4

Table 3.4: Brinell hardness of sample on 12 mm aluminum 6061 plate

Conclusion

To sum up everything that has been started so far, using the WAAM technology the aluminum 4043 deposited in two plates of thickness 8mm and 12mm with aluminum block dimensions 125mm x105mm x6mm. The sample of these statues are carried to that lab testing for microstructure, chemical composition analysis and Brinell hardness test. For the purpose of testing different voltage, current and wire feed ratio with different holding timing and layers on subtract. Furthermore, these parameters influences were investigated.

- In wall structure (125mm x 105mm x 6mm) of couple of aluminum 6061 8mm and 12mm, there were no interfaces perceive in betwixt of two consecutives layer stating the complete fusion with almost zero oxidation.
- Undercuts and hump beats are observed after solidifying both the sample plates of dimension 125mm x 105mm x 6mm and the weld overwhelm major in the center of hump causes irregularities.
- The microstructure test in of both aluminum 4043 walls, the component consists of inter-dendritic network of eutectic silicon in a matrix of aluminum solid solution throughout the structure.
- The difference of input units and holding time can give difference in chemical composition. While the chemical composition analysis shows slightly allotropically change in the sample testing of aluminum 4043 samples on aluminum 6061 plate of 8mm and 12mm.
- The HBW (Brinell hardness number) for the two different walls are different. As the Brinell hardness define the surface structure about too coarse or too rough and also the non-homogeneous, the specimen on 12mm aluminum 6063 material had more high values after application of same parameters in both.

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