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# Optimization Of Process Parameters For ER-4043 Aluminum Deposited By Wire Arc Additive Manufacturing

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***Abstract: Manufacturing of a part is done by addition of material which is an Additive Manufacturing (AM), now a days gaining its own importance in Manufacturing scenario because of its wide benefits. Wire-Arc Additive Manufacturing (WAAM) process is one of the assured options in manufacturing to traditional reductive manufacturing for fabricating large size metal components with complex geometry, which includes wastage of material, time and cost. This processes generally involve high residual stresses and distortions due to the excessive heat input and high deposition rate. The improvements of surface quality and mechanical properties are critical factors in Wire-Arc Additive Manufacturing. In the present work, the effect of process conditions, on various parameters for Wire-Arc Additive manufactured aluminum alloy components based on Taguchi design of experiments were studied.***

***Key words: WAAM, ER-4043 MIG wire, Al-6061 substrate plate, L9 Orthogonal Array.***

## 1. INTRODUCTION

*1.1 Wire-Arc Additive Manufacturing:*

Additive Manufacturing (AM), a modern and advanced fabrication process where the parts are fabricated in a layer-by-layer process by input provided in the form of Computer Aided Design (CAD) model, which is deposited on the substrate plate. This has becoming a popular method of manufacturing of parts with complex geometries which are difficult to fabricate by conventional methods of manufacturing. Part production through AM begins with the creation of a CAD model of the desired part that will subsequently be converted into a Stereolithographic (STL) file, the standard interface for AM systems. AM technologies differ in their production methods based on the material processing, the manner in which individual layers are created, and the methods by which layers are fused together where different materials like metals, polymers, ceramics and biomaterials are involved. Many commercial AM technologies are available, and commonly used additive manufacturing technologies for metal parts viz. Binder Jetting, Direct Energy Deposition (DED), and Powder Bed Fusion. Wire-Arc Additive Manufacturing (WAAM), comes under DED technique which has unique efficiency and cost advantages, and attracting the present researchers in many fields. Here, WAAM process is employed to fabricate a specimen, where ER-4043 Aluminium wire is deposited on Al-6061 substrate plate, and the apparatus of WAAM process is shown in Fig-1.


Figure1: Wire Arc Additive Manufacturing Apparatus

Donghong Ding et al. [1] reviewed about various wire feed Additive manufacturing techniques, available methodologies followed, parameters involved in the process. The accuracy of specimens fabricated by this process is considered and discussed about the presence of high residual stresses and distortions caused by high energy input. Fu Youheng et al. [2] implemented optimization technique of Response Surface Methodology (RSM) to identify the count of experiments to evaluate the welding design matrix of Bainite steel. Based on input parameters, the test is split as 3 parts and total forty-six trials have been done. The results express that, no defects are observed and optimized samples have good surface quality and appearance. Satyanarayana G et al. [3,8] presaged about geometry generated and temperature enhancement around the weld pool during the CFD simulation process used to weld an end plate to a fuel rod which is used in nuclear system, and executed a three-dimensional non-linear thermo fluid analysis integrating the buoyancy and related stresses and confirmed the results with experimental data results. Later the results are compared by optimization technique using Taguchi method. Padhi S K et al. [4] done an experiment by welding AA6061 and AA6068 Aluminium alloys by Friction Stir Welding (FSW) with selected parameters like pin speed, traverse speed, shape and size of pin and predicted about the mechanical properties of the joint. Results unveil and compared with analysis of variance optimization. G Arun Kumar et al. [5] attempted to weld a base metal joint of low carbon steel using Shielded Metal Arc Welding (SMAW) and further applied a Nano coating on welded joint and predicted the mechanical properties and observed microstructure of welded zone. Results show that welded zone exhibits good mechanical strength, thermal properties and shows better properties than conventional welded joint. S K Padhi et al. [6] studied about the performance of electroplated copper thickness of the plastic Electro Discharge Machining (EDM) electrode, and observed that the electrode performance was effective and suitable for machining work of D2 steel and later the results are compared with welded joint done with conventional solid electrode Bala subramanyama P N V et al. [7] studied about the influence of vibrations stress on different welding techniques used to join mild steel specimens. the welding process considered are MIG and SMAW to predict the vibration tests and destructive tests like Charpy, Izod was conducted and non-destructive like Brinell Hardness was tested. Results reveal that these tests are counterpointed on welding process which use pressure. Amit H Karwande and Sreeram Srinivasa Rao [9,12] used the Friction Stir Welding (FSW) process and optimised the process parameters to get an outcome of welded joint with high quality under different tool size conditions. And implanted the Taguchi optimization technique in welding Aluminium and magnesium alloy materials. A Suresh and G Diwakar [10] evaluated about the process parameters involved in plasma arc welding of Austinitic Stainless steel- 3041 plates and formulated an optimization function which have many decision variables which was netted with other parameters and solved by Kuhn-Tucker method and implemented the outcomes of process parameters in welding. Satyanarayana. G, et al. [11,14] imitated by simulation about butt joint made of Zirconium alloy material (E110) by Nd:YAG pulsed laser welding process with 3-D heat and fluid flow model. The resulted outcomes are compared with analysis done by numerical model and observed that the numerical results are best suited with simulation results. Shaik Ansar Ali Ahmad et al. [13] examined about the hit on mechanical properties of fine grained structure which is Friction Stir welded 2014 Aluminium alloy with selected welded parameters and observed the grain size was 2-4 microns when it undergoes fast cooling with blend dry ice and ethanol and also the grain size influences the mechanical properties of materials.

### *1.2 Filler material and substrate plate*

The general referred name of ER-4043 is AlSi-5, which has 5% silicon aluminium and mainly used to weld Aluminium alloys. In the present work, ER-4043 Aluminium MIG wire of 1.2 mm diameter has been used as filler material was selected for experimentation, and Al- 6061 material plate is taken as a substrate. It is an important filler wire widely used to connect two separate plates of aluminium, and it offers good fluidity and less crack sensitivity than other filler wires for aluminium. This welding wire is mostly suitable with pure Argon gas in controlled atmosphere to avoid the direct contact with surrounding atmosphere, and offers good seam welding, less spatter, and excellent welding properties. The chemical composition of filler material and supporting plate are mentioned in Table-1, and various mechanical properties of ER-4043 and Al-6061 are mentioned in Table-2.

Table-1: Chemical Composition of Materials

| **ELEMENT** | **CHEMICAL COMPOSITION (Weight %)** | |
|---|---|---|
| | **ER-4043** | **Al-6061** |
| Silicon, Si | 4.5 - 6.0 | 0.4 to 0.8 |
| Copper, Cu | Max. 0.3 | 0.15 to 0.4 |
| Iron, Fe | Max. 0.6 | 0.7 |
| Manganese, Mn | Max. 0.5 | 0.15 |
| Magnesium, Mg | Max. 0.5 | 0.8 -1.2 |
| Zinc, Zn | Max. 0.1 | 0.25 |
| Titanium, Ti | Max. 0.2 | 0.15 |
| Chromium, Cr | ---- | 0.04 -0.35 |
| Beryllium, Be | 0.0008 max | ----- |
| Others | 0.05 to 0.2 | 0.5 to 0.2 |
| Aluminum, Al | Balance | Balance |

Table-2: Mechanical Properties

| **PROPERTY** | **Properties of Materials** | |
|---|---|---|
| | **ER-4043** | **Al-6061** |
| Shear strength | 170MPa | 83 MPa |
| Tensile strength, Ultimate | 285MPa | 115MPa |

| | | |
|---|---|---|
| Tensile strength, Yield | 270 MPa | 48 MPa |
| Poisson's Ratio | 0.34 | 0.33 |
| Modulus of Elasticity | | 1- 80MPa |

### *1.3 Orthogonal Arrays*

In Taguchi method,certain set of arrays called orthogonal arrays (OA) are adopted. These standard arrays provide the way to manage minimum number of experiments, that give the full knowledge about all factors which influence the performance parameters leads to shorten the time, cost and also avoids the wastage of material.

## 2. EXPERIMENTAION

### *2.1 Orthogonal Array*

In this work,a Cold Metal Transfer (CMT) welding machine with a linear manipulator for WAAM, is used to fabricate specimens according to Taguchi L9 orthogonal array (OA which are listed in Table-3.

Table-3: L9-Orthogonal Array

| **Experiment** | **A** | **B** | **C** |
|---|---|---|---|
| **1** | 1 | 1 | 1 |
| **2** | 1 | 2 | 2 |
| **3** | 1 | 3 | 3 |
| **4** | 2 | 1 | 2 |
| **5** | 2 | 2 | 3 |
| **6** | 2 | 3 | 1 |
| **7** | 3 | 1 | 3 |
| **8** | 3 | 2 | 1 |
| **9** | 3 | 3 | 2 |

### *2.2 Specimen Preparation:*

By following the L9 Orthogonal Array, 9 samples are fabricated by using WAAM process with 3 input data parameters at 3 levels each. Table-4 lists the process parameters considered. These parameters were chosen on basic trials and on various references. Pure Argon gas is used as shielding purpose. The metal deposition rate was kept steady at 0.75 kg/hr.

Table-4: Process Parameters and their levels

| **Symbol** | **Process Parameters** | **Level-1** | **Level -2** | **Level -3** |
|---|---|---|---|---|
| **A** | **Gas Pressure (bar)** | 10 | 12 | 14 |
| **B** | **Current (Ampere)** | 55 | 60 | 65 |
| **C** | **Nozzle distance (mm)** | 6 | 8 | 10 |

## 3. PERFORMANCE CHARACTERISTICS

### *3.1 Tensile Test*

According to American Society of Testing of Materials (ASTM) standards, the specimens are shaped and made to size with the help of wire EDM process. A total of nine tensile test


(a): Specimen Preparation on Substrate Plate

(b): Total of Nine Specimens prepared using WAAM

Figure2: Fabricated samples

specimens and nine hardness test specimens are prepared for testing.

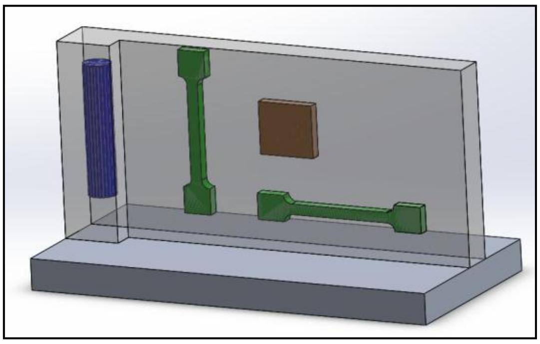

Figure3: CAD designs of specimens

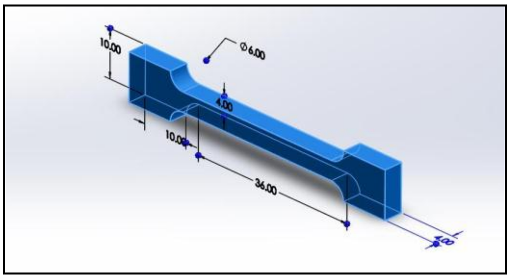


Figure4: Tensile test specimen as per ASTM standards

### *3.2 Hardness Test:*

Micro-Vickers Hardness testing machine and specimens are shown in Fig-6(a) and Fig-6(b) (Make: METCO, Chennai, Model: ECONOMET MH VHX1) where hardness equipment has a range to test the Vickers hardness value by the applied load from 10gms to 1kg. Here, each specimen of size 20mm×20mm×4mm, (total 9 specimens) are prepared by using Wire EDM

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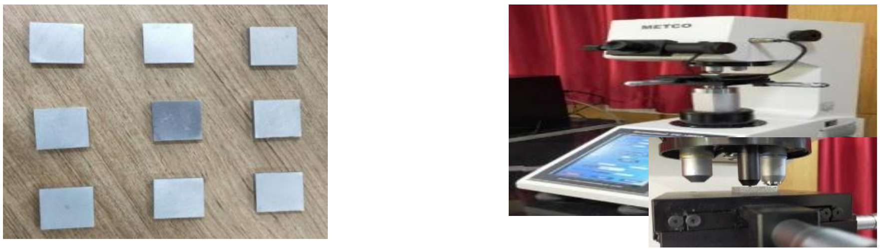
are tested at 200gms of load with a time duration of 10seconds. which are taken from the middle section of the deposited wall along the longitudinal direction.

(a): Test specimen (b): Micro tensile testing machine

Figure5: Specimen and Equipment for Tensile Test



(a): Specimens by Orthogonal Array (b): Micro-Vickers hardness tester (with Macro view of diamond indenter and specimen)

Figure6: Microhardness test specimens and Equipment

*3.3 Signal to Noise Ratio:*

When strong noise is present in trials, it is recommended to run number of repetitions of tests which depends on cost factors also. If trial cost is low, it is desirable to test number of trials as possible. This repetition of test determines the variation index called as Signal- to-Noise ratio (S/N Ratio). This S/N ration concept is used in many fields like acoustics, mechanical vibrations, etc., To analyze this variable data, consideration of average value for trials exhibits the optimal solution. The standard deviation (σ) is a common indicator for variability. For the given data if both standard deviation and
average values are taken then, it is easy to calculate the Mean Square Deviation (MSD). The relation between S/N ratio and MSD is given by Equation-1.

$$S/N \text{ ratio} = -10 \log_{10} (MSD) \qquad (1)$$

Where MSD = $(1/(y_i)^2)$, $y$ the target value that is to be achieved for the samples. The S/N ratio values obtained for the trials for various properties of samples are listed in following Table-5 to Table-8.

Table-5: S/N Ratio for Tensile Strength

| FACTOR | LEVEL-1 | LEVEL-2 | LEVEL-3 |
|---|---|---|---|
| Gas pressure(bar) | 196.53 | 150.986 | 197.51 |
| Current (Ampere) | 180.87 | 171.05 | 193.106 |
| Nozzle distance(mm) | 130.7 | 186.76 | 166.33 |

Table-6: S/N Ratio for Tensile Strength with averages

| FACTOR | LEVEL-1 | LEVEL-2 | LEVEL-3 |
|---|---|---|---|
| Gas pressure(bar) | 65.51 | 50.32 | 65.83 |
| Current (Ampere) | 60.29 | 57.01 | 64.36 |
| Nozzle distance (mm | 43.56 | 62.25 | 55.44 |

Table-7: S/N Ratio for Hardness

| FACTOR | LEVEL-1 | LEVEL-2 | LEVEL-3 |
|---|---|---|---|
| Gas pressure(bar) | 110.68 | 112.34 | 116.28 |
| Current (Ampere) | 111.67 | 112.05 | 115.58 |
| Nozzle distance(mm) | 110.51 | 112.04 | 116.75 |

Table-8: S/N Ratio for Hardness averages

| FACTOR | LEVEL-1 | LEVEL-2 | LEVEL-3 |
|---|---|---|---|
| Gas pressure (bar) | 36.89 | 37.45 | 38.76 |
| Current (Ampere) | 37.22 | 37.35 | 38.6 |
| Nozzle distance(mm) | 36.83 | 37.34 | 38.91 |

*3.4 Analysis of Variance (ANOVA):*

ANOVA is a statistical technique widely used to estimate the confidence level, but it does not estimate the directly but provides the variation in the data. This analysis involves the calculation of many quantities like degrees of freedom, mean square, sum of squares etc., It provides an key factor of rating, based on these ratings, the outcome of test is identified and related control measures were acquired.

From ANOVA test , the results are shown in Table-9 and Table-10.

Table-9: ANOVA for Tensile strength

| FACTOR | S.O.S | DoF | Variance | % Contribution | F-test |
|---|---|---|---|---|---|
| Gas pressure(bar) | 2.86x106 | 2 | 1.43 | 79 | 238.3 |
| Current (Ampere) | 0.628x106 | 2 | 0.314 | 17.3 | 52.3 |
| Nozzle distance(mm) | 0.12x106 | 2 | 0.06 | 3.31 | 10 |
| Error | 0.012x106 | 2 | 0.006 | 0.33 | |
| SoS-Total | 3.62x106 | 8 | | | |

Table-10: ANOVA for Hardness

| FACTOR | S.O.S | DoF | Variance | % Contribution | F test |
|---|---|---|---|---|---|
| Gas pressure(bar) | 399.39 | 2 | 199.6 | 29 | 2.45 |
| Current (Ampere) | 217.22 | 2 | 108.61 | 16 | 1.33 |
| Nozzle distance(mm) | 571.024 | 2 | 285.51 | 42 | 3.5 |
| Error | 162.68 | 2 | 81.34 | 12 | |
| SoS-Total | 1350.3 | 8 | | | |

## 4. RESULTS AND CONCLUSION

- The experimental design is orthogonal, it is then possible to separate out the effect of each parameter on the Grey Relational grade at different levels.
- From the S/N ratio, it was revealed that maximum levels of gas pressure, current and intermediate level of nozzle to tip distance gives better tensile strength and maximum levels of all the three factors gives better hardness of the specimen.
- It was concluded from S/N ratio that A3, B3 & C2 specimen has maximum tensile strength
- Similarly, A3,B3 & C3 specimen has maximum Hardness.
- From ANOVA analysis, Gas pressure has maximum contribution on Tensile strength and Nozzle tip distance has maximum contribution on the hardness of the specimen.

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