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Research Paper

Fabrication and study of Aluminium product by Wire Arc Additive Manufacturing Technology

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ABSTRACT: *This paper presents an overview of Wire Arc Additive manufacturing technologies for production of metal parts. It is mostly preferable to complex design. Requires minimum time for manufacturing. Aluminium alloy AL1060 selected for fabricating the part, because the Aluminium has good conductor of heat and thermal conductivity, also it is much denser than other material. Wire and arc additive manufacturing (WAAM) has proven that it can produce medium to large components because of its high-rate deposition and potentially unlimited build size. Like all additive manufacturing (AM) technologies, however, an optimized process planning that provides uniform, defect-free deposition is key for the production of parts. Moreover, AM, particularly WAAM, is no longer just a prototyping technology, and most of today's attention is on its transformation to a viable and cost-effective production. With this transformation, a number of issues need to be addressed, including the accuracy and effectiveness of the manufactured components. Therefore, the emphasis should be on dimensional precision and surface finish in WAAM. This paper covers heat input and management concept, related to the resulting shrinkage, deformation, and residual stresses, which is particularly critical. In addition, we focus on process planning including build orientation, slicing, and path planning, as well as the definition of process parameter selection from a single track to multi-track and multilayer, and finally geometric features froma thin-wall to lattice structures with several case studies*

KEYWORDS: 3D Metal Printer, Additive Manufacturing , Al Alloy, High Denser, WAAM

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I. INTRODUCTION

Additive manufacturing (AM) is an innovative net shaped or near-net-shaped manufacturing technology used for producing final solid objects by depositing successive layers of material in powder or wire form via melting them using a focused heat source directed from an electron beam, laser beam, or plasma or electric arc. In 1990, this technology emerged in Europe and now it is pioneeed in the same continent.

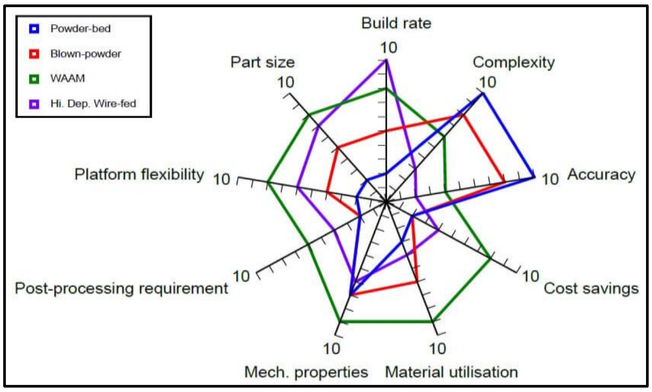

Figure 1.1 Quality and Production Parameter involved in AM process [3]

Several new AM technologies were established and more new commercial systems introduced to the market after 1991.

Additive Manufacturing can help to significantly reduce high buy-to-fly (BTF) ratios of cast, forged, and machined parts in the aerospace industry. BTF ratio reflects material efficiency of manufactured components, and it is often referred by the aerospace community to establish an amount of material needed to purchase rather AM technology basically offers significant reduction in lead time, cost, and waste material in the form of machining chips and less toxic waste from cutting fluid. than manufacture final 'flying' part. BTF ratio is the weight ratio between the raw material used for a component and the weight of the component itself

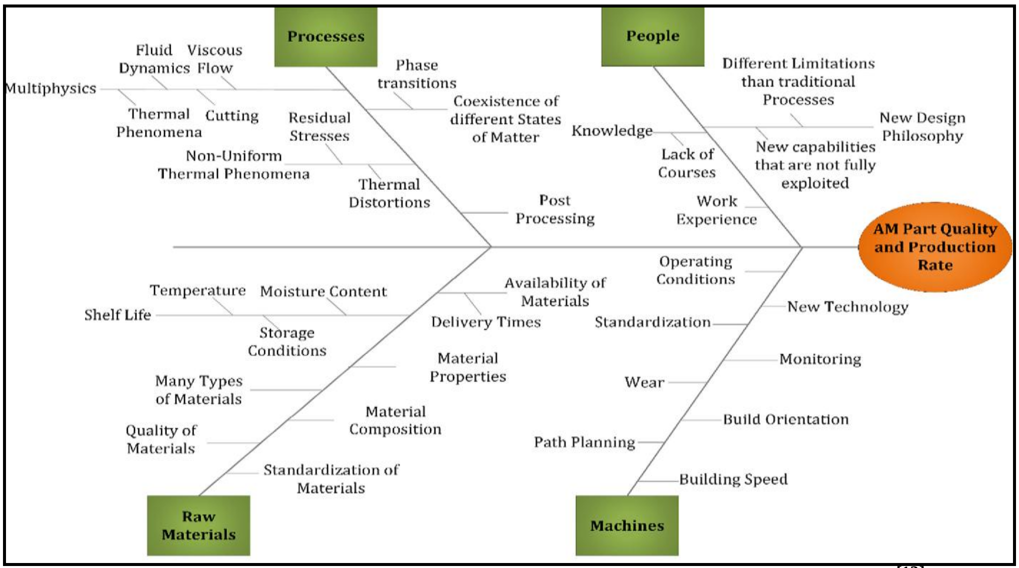

Figure 1.2 Quality and Production Parameter involved in AM process [13]

Traditional machining methods typically produce components with BTF ratios of 5:1, but sometimes greater than 20:1 due to large amount of waste and difficult-torecycle material.. The finished part has a weight of 250 lb and to machine from a forged billet would require a starting billet weight of 5000 lb which gives a BTF ratio of over 20. This method is extremely wasteful in terms of material. In contrast, using some processes in AM technology, the substrate has a weight of 200 lb as a rolled sheet and 75 lb of wire which is added with 25 lb machined away to get the final profile. This gives BTF ratio near to 2 and saving materials of 4825 lb.

In summary, WAAM is still considered new technology for manufacturing of consistent production of parts according to necessary quality standards. WAAM research has been centered on physics, metallurgy, and applications rather than studying the relationship between processing parameters and geometric characteristics and challenges, including underlying physics, part quality, and accuracy, part distortion, and deformation. Few studies have been carried out on the accuracy of WAAM production and there exists a gap in the available knowledge. In order to achieve the appropriate component dimension and surface finish, the process parameters relating to geometry must be controlled. In this regard, careful attention should be paid to the consistency of the materials, i.e., surface finish and geometric precision. Whilst this review focuses on process-specific parameters for the part quality and accuracy of WAAM parts, it is important to clearly state the boundaries of which specific subjects are covered

This thesis is focused on analysis of the process of building parts on stainless-steel by Wire Arc Additive Manufacturing (WAAM). These types of technologies and variants are increasing weight in our society. Sometimes due to the need for repair of damaged components, in other situations to produce geometrically complex components and on the other hand to reduce the environmental impact on the production and repair of these components. With the rising of the environmental concerns, and the need for a better resources' management associated to the production, the use of the additive manufacturing might be the solution required. The simplicity and adaptability of the WAAM process made it the optimal choice for this development.

II. LITERATURE REVIEW

2.1 Wanwan Jin[1] - WAAM has been proved to be a low-cost, high efficiency AM process (compared with PBF AM processes) for producing large-scale stainless steel parts. Recent studies on WAAM of various stainless steels have been reviewed from the aspects of macroscopic characteristics, microstructure evolution, post heat treatments, residual stress and distortion, defects, and mechanical properties.

(1) Macroscopic characteristics of WAAM stainless steel parts are closely related to wire feeding speed and scanning speed, welding current mode, cooling time, and interlay temperature.

Further studies on optimizing the above-mentioned process parameters are needed for achieving better dimensional accuracy and surface quality of WAAM parts.

(2) Thermal history in WAAM processes plays an important role in controlling the microstructure, such as the ratio of austenite and ferrite phases. Thus, it is feasible to control the microstructure by controlling the process parameters.

2.2 K.E.K. Vimal[2] -WAAM is an automatic manufacturing process which is controlled by computer control system. It is most suitable for producing components with complex and irregular shapes. Already existed welding techniques can be used to deposit metal. Metal deposition rate depends up on type of welding technique adopted and heat input. WAAM can affectively apply where less utilisation of material and less total cost of component is required. WAAM components mostly suffered with residual stresses, porosity and delamination. Most of the researchers have focused on porosity phenomenon. Further research on residual stresses and delamination defects will improve its capability.

2.3 Baker [3] -filed a patent naming ‘Method of making decorative articles’ which was assigned to the Washington Electric company demonstrated the technique of constructing receptables and decorative articles using non-adherent substrate. He called it as superposed deposit of metal using manipulated helical path of a fusible electrode. The electrode was controlled manually. This formation of receptacles is considered as the foundation stone in the development of WAAM technique.

2.4 Wang et al. [4]from Southern Methodist University proposed a WAAM system based on a VP-GTAW heating source for directly building cylindrical parts made of aluminum alloys, such as Al-5356 and Al-4043. The authors emphasized the need for on-line monitoring and control systems of process parameters such as pre-heating, arc-length, heat input, and bead geometry knowledge base for achieving good quality parts.

2.5 K.P. Karunakaran, S. Suryakumar [5] have developed hybrid layered manufacturing system using the integration of additive and subtractive manufacturing methods. They have combined the best features of both additive and subtractive approach. Setup that was made named as ArcHLM setup which is integration of weld deposition unit and CNC machine. The interesting inferences were made from this case study: ArcHLM route for this case took 42% less time than that of the CNC route. ArcHLM route for this case cost 28% less than that of the CNC route. Cost of the raw material was lower in ArcHLM for this case study.

2.6 Suryakumar [6] studied mechanical properties of objects made through weld deposition for metallic objects made through HLM (hybrid layer manufacturing) to analyze the hardness and tensile strength of WAAM manufactured metallic components. He also tried to conceptualize the effect of thermal cycle on tensile strength and hardness made through hybrid layer manufacturing. Due to thermal variation across layers on increasing z height difference in maximum hardness he observed on the top layer while it was less in layers below top layers. While for tensile stress it was same for horizontal while in vertical direction it was observed to be lower in vertical direction but it was possible to rectify it by increasing amperage.

2.7 Xiong [7] studied the reason behind the poor surface quality in GMAW based AM manufacturing and he tried to study the crucial parameters which affect the surface quality and found interlayer temperature, wire speed and travel speed were important. He found that increasing the interlayer temperature was attributed to increased surface roughness not only that but this even contributed to decreased layer height due to decreased heat conduction rate with increased layer height. He also found that when travel speed (TS) was low that resulted in more height hence caused more stair stepping effect but increasing travel speed was limited to 420 mm/min as increasing travel speed beyond it caused poor surface quality due to spatter due to arc instability. While WFS (wire feed speed) when increased caused more surface roughness due to mixing of layers and thus resulted unstable molten pool.

2.8 Tabernero et al., [8] compared the high deposition rate welding process like PAW, CMT and Top TIG and study their mechanical properties anisotropy and classified and concluded selection of which method according to the nature of filler wire, that can improve the quality of materials fabricated in WAAM.

2. 9Williams et al., .[9] Concluded the optimum parameter for depositing aluminum wire in TIG at electrode positive and studied optimum percentage for formation of multilayer in TIG for WAAM and investigated the microstructure at different EP% and concluded the time cycle for TIG

2.10. Bai et al., .[10] investigated the deposition 2219 al wire in TIG and studied the microstructure and mechanical properties like fracture properties in tensile as well as hardness test and concluded the mechanical properties of the 2219 aluminum wire in TIG for wire arc additive manufacturing

2.11. Geng et al., .[11] by using mathematical model to calculate the fly angle of TIG tip on the weld pool and also optimized the angle of torch and distance of the TIG tip from the substrate for producing a smooth layer for the WAAM

2.12. Zhang et al., [12] investigated the Er2594 microstructure, crystal characterization and mechanical testing for the TIG based WAAM and concluded the their effect on their characterization and noted the conclusion for the various purposes on their anisotropy analysis.

2.13 Z.pan et al., [13] reviewed the process planning for the WAAM and pattern and different ideology should be studied for working in the WAAM layer deposits and essential mechanical properties should be understand and welder quality should be included on the selection of which process and nature of filler wires.

2.14 Singh et al., .[14] reviewed the CAD modeling and various development in WAAM and their challenges and optimizing their parameter for the formation of multilayer and wire feed rate, torch travel speed, and the shielding gas supply and the setup of the WAAM power source and the CAD modeling aspect should be mainly focused in their important criteria are discussed

2.15 Yang et al., [15] investigated the by deposited bulky sample of TiB2/Al-Si composites in TIG based WAAM and studied the microstructure, mechanical properties of the sample by after heat treatment T6 and observed the variation occurred like defect such as pore in the surface and other defect that are present in the sample.

2.16 Zuo et al., .[16] Investigated the hybrid arc by the combination of MIG and TIG, arc is produced by TIG torch and the wire feed is feeded by the MIG torch this torch combination produces the hybrid heat source for WAAM al 5356 was deposited and its microstructure, mechanical properties, SEM and hardness valves are analysis

2.17 Cheepu et al.,[17] studied about the super TIG for WAAM and conclude the more effective than normal conventional TIG and also investigated about the waiving effects and its heat circulation and microstructure formations

2.18 Zhang et al., .[18] used the TOP-TIG method to fabricate super duplex stainless steel, and fined the perfect combination of corrosion resistance and mechanical properties was obtained in WAAM

2.19 Cai et al., [19] Studied deposition of two titanium wires in both TOP TIG and normal conventional TIG and experimented their parameters in weld molten and also tested the microstructure and mechanical properties in TOP TIG and normal TIG.

2.20 Cheepu et al.[20], studied about the super TIG for WAAM and conclude the more effective than normal conventional TIG and also investigated about the waiving effects and its heat circulation and microstructure formations.

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2.22 Cai et al., [22] Studied deposition of two titanium wires in both TOP TIG and normal conventional TIG and experimented their parameters in weld molten and also tested the microstructure and mechanical properties in TOP TIG and normal TIG.

2.23 Zhang et al., [23] analyzed the microstructure, mechanical properties, and crystallization of low alloys steel by deposit in Top TIG for WAAM

2.24 BintaoWua , ZengxiPana

A detailed review of recent technological developments in WAAM process has been presented, with a focus on microstructure, mechanical properties, process defects and post-process treatment. Through matching a knowledge of material characteristics with the performance features of particular WAAM techniques, a quality-based framework is proposed, for producing high-quality and defect-free components. In WAAM of metallic materials, the fundamental interrelationships between material composition and microstructure govern the material properties and fabrication quality. Since the WAAM process is an inherently non-equilibrium thermal process, it is challenging to predicate and control the microstructural evolution, which is responsible for the variation of mechanical properties in the deposited part. Further research attention should be paid on the study of underlying physical and chemical metallurgical mechanisms in WAAM process to provide a guidance for the process optimization, improvement and control. The defects generated in WAAM-produced part are closely related to the target material characteristics and process parameters. The development of strategies or ancillary process to overcome defects generation are of prime importance. With the requirement of high quality WAAM part, the proposed quality-based framework will see a wide application in the future years.

2.25 C. R. Cunningham,

In this paper, a WAAM cost model has been designed and realised to quantify the cost effectiveness of WAAM production. The cost model, for the first time, includes the full process chain for the WAAM process and includes tool path based deposition time to improve the accuracy of the deposition time estimation and account for the Sensitivity Ranking Case Study 1 - Propeller Case Study 2 X-Part Variable (%) Variable (%) 1 Daily uptime 71.2 Daily uptime 88.6 2 Shield gas flow rate 43.5 Depreciation years 72.0 3 Shield gas cost 42.5 WAAM machine cost 44.0 4 WAAM machine cost 39.3 Heat treatment time 39.0 5 Depreciation years 31.9 Parts per build 28.0 various tool path strategies that may be adopted in the manufacture of a part. The results show significant costs savings can be made for two case study Ti6Al4V parts. A cost reduction of 20-45% is found compared to electron beam additive manufacturing and 69-79% reduction for direct metal laser sintering. Compared to conventional CNC machining a breakeven point is found at a BTF ratio of 5. However, an average cost reduction of 53% can be achieved by a BTF ratio of 10. Using this model, a sensitivity analysis identified the key cost drivers in the WAAM process and has shown that indirect costs have a substantial impact for both large and small components.

2.26 Ma, J., Kang,

Investigated **TiB2** reinforced Al-7Si-Cu-Mg composites made by arc addition and casting. The mechanical properties of aluminium-based composites are improved by TiB2 particles, which are nano- or sub-micron in size and have normal and circular morphology. In terms of microstructure and properties of aluminium matrix composites, two related processes are compared. The distribution of alloying elements in the TiB2-reinforced Al-Si-based composite material of (WAAM) is found to be more distributed by comparing SEM and EDS study. TiB2 particles have a smaller size and a more uniform distribution.

III. DETAIL DESCRIPTION

Wire Arc Additive Manufacturing (WAAM) is one of the lesser-known metal 3D printing technologies, but one that holds huge potential for large-scale 3D printing applications across multiple industries.WAAM3D was founded in 2018 to commercialise Cranfield University's intellectual property in the field of WAAM. According to the company, the lack of supply chain – namely software tools, WAAM-designed hardware, raw materials, training and services – has hindered the deserved industrial adoption of WAAM processes, despite its proven business benefits.

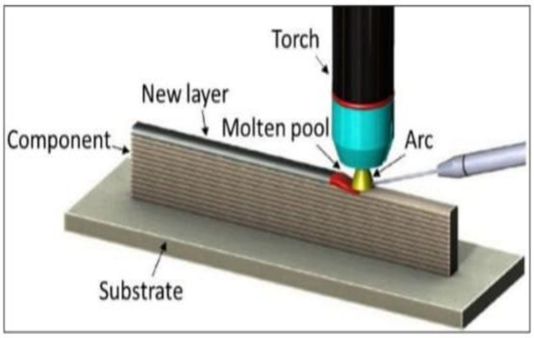

Figure 2.1 Schematic Diagram of WAAM process [1]

Essentially, 3-D printing involves the progressive deposition of material under computer control to generate a three-dimensional structure. Because the material source is very small and control is extremely accurate the process offers the potential to produce near-finished complex shapes that are difficult if not impossible to create by any other technique.

2.1 WORKING PRINCIPLE

WAAM is a variation of a **Direct Energy Deposition** technology and uses an arc welding process to 3D print metal parts. Unlike the more common metal powder AM processes, WAAM works by melting metal wire using an electric arc as the heat source.The process is controlled by a robotic arm and the shape is built upon a substrate material (a base plate) that the part can be cut from once finished. The wire, when melted, is extruded in the form of beads on the substrate. As the beads stick together, they create a layer of metal material. The process is then repeated, layer by layer until the metal part is completed.

2.2 POST PROCESSING

Most WAAM processes need some form of post processing. This is a necessary step to address the side-effects of WAAM: Residual stresses and the surface roughness. To reduce the residual stresses in the part, a stress relief treatment is applied after printing. This treatment is done at an elevated temperature to reduce the risk of premature failure and increase the performance and life-span of the part. In some cases a specific heat treatments is applied to adjust the material properties.

Surface finishing is the second most important post processing step in WAAM. Every WAAM part is built in layers, which is visible on the surface. In order to optimize the fatigue life, the tensile behavior and the corrosion resistance, it is important to adopt a finishing process like milling or grinding.

2.3 REPAIR OPERATION

- WAAM is also a good option for repair and maintenance operations for specific components like turbine blades, as well as also moulds and dies.
- Worn-out features or damaged parts can be repaired with WAAM by depositing new material on its surface. This can result in significant cost savings as it eliminates the need to produce a new part from scratch.

Figure 2.2 WAAM forming large mechanic arm a. Printed arm b. Installed arm [4]

Figure 2.3 Load testingof MX3D bridge b. The MX3D bridge at Dutch Design Week [4]

2.4 Costing as compare to other process

- WAAM hardware usually includes off-the-shelf welding equipment, which is less expensive than many metal 3D printers available on the market

- In terms of material costs, the welding wire used in the WAAM printing process is significantly less expensive than the metal powder used in metal PBF.

III. MATERIAL SELECTION

3.1 Material wire used in WAAM

- WAAM can work with a wide range of metals, provided they are in wire form. This list Fig 3.1 includes **stainless steel, nickel-based alloys, titanium alloys** and **Aluminium alloys**.
- Any metal that can be welded can also be used with WAAM.This is because WAAM technology is based on welding, a well-established manufacturing technology in and of itself..Additionally, wire is typically easier to handle than powder, which requires specialised protective equipment to use.

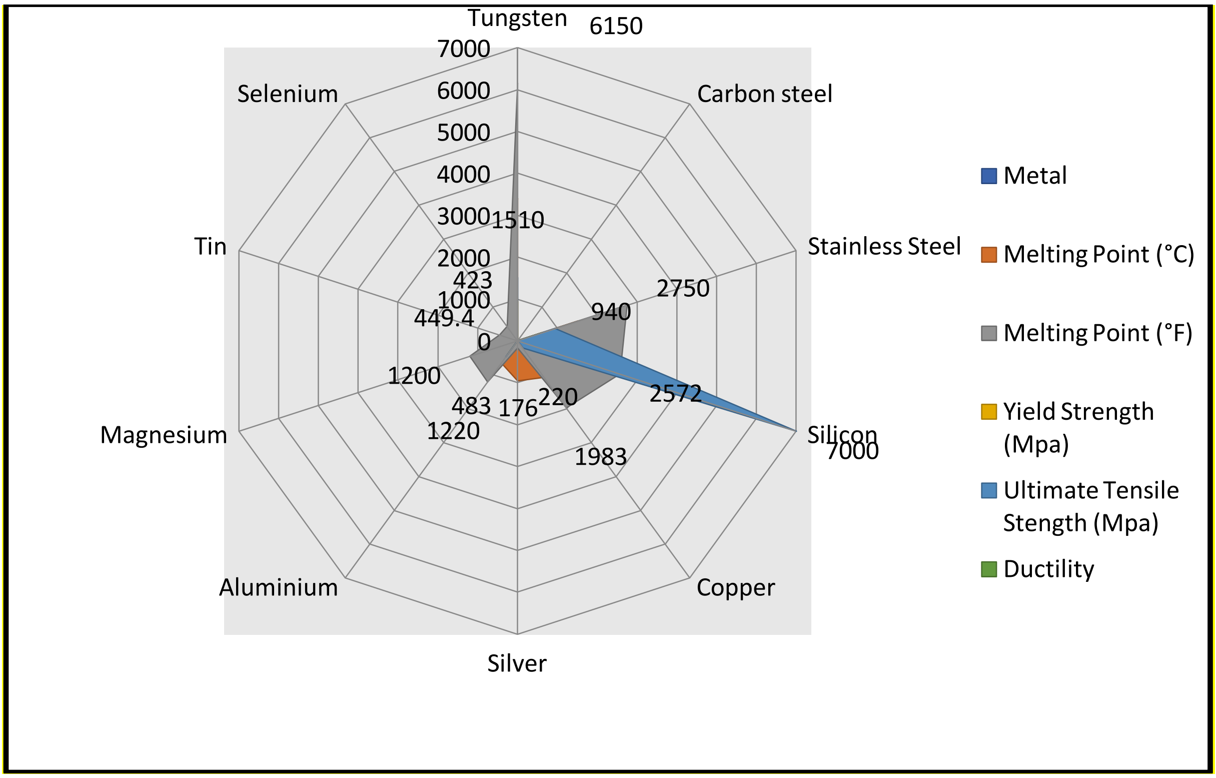

Fig. 3.1 Material Selection

- Parts produced with WAAM are particularly notable for their high density and strong mechanical properties, which are comparable to parts manufactured with traditional manufacturing methods.
- As the wire feedstock is a 100 per cent dense input material, there is negligible porosity induced in the fabrication process, leading to a very dense final part.

IV. EXPERIMENTAL SETUP

IV- DESIGN CONCEPT OF WAAM SETUP

4.1. Coordinate Controller arm

Controller is the main structural component of whole setup. The most important aspect of any machine is its structural components strength which directly affects the integrity of setup and reliability of machine. In WAAM setup we only require linear motion in three axes i.e. X-axis, Y-axis & Z-axis . First step in designing any robot is fixing the Degree of Freedom (DOF) of robot. so, according to the requirement of motion stated before the degree of freedom for electronic arm is 3.

4.2. Weld deposition unit

Penetration, productivity and process stability are the important criteria while selecting the welding method and its parameter. The depth to which welding takes place is penetration, for better quality of joint depth must be higher. Productivity is depending on the rate off melt of filler. But when welding is used for continuous weld deposition like in WAAM, higher resolution spatter free operation less heat input becomes the prime criteria. Based on the above inference and considering the availability, pulsed GTAW was found to meet the requirement of WAAM.

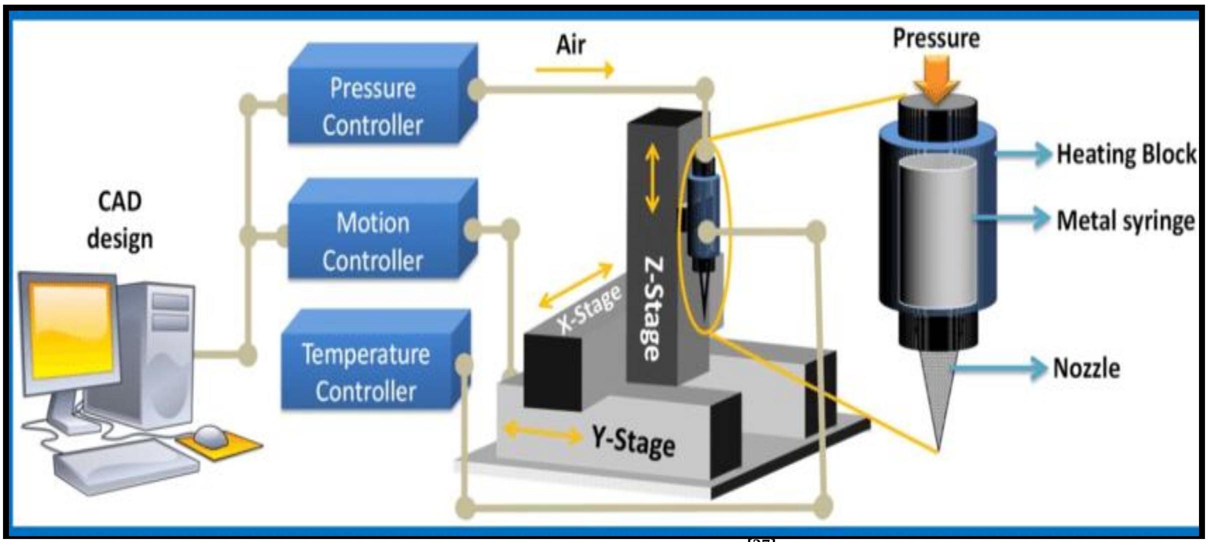

Fig. 4.1 Experimental Setup [27]

4.3. CAD & CAM Software

The most important part in WAAM setup is accurate 3D modelling of part which has to be manufactured by means of layer by layer deposition. Modelling is first step of 3D printing. For 3D modelling a Solid edge software is selected. The 3D modelling software will give the end file format as part file(.prt) containing part structure specifics and 3D model attributes. But this file cannot be directly feed to the WAAM microcontroller. It needs some pre-processing. First this file must be converted into 3D printable file format i.e. Stereolithography (.stl) or 3D manufacturing Format (.3mf). Once the object part file is converted into 3D printable format, then the slicing of model structure has to be done according to the material properties, printer capabilities, etc. WAAM uses a basic principle of additive manufacturing method to manufacture a product layer by layer, for this purpose the slicing is important. A Slicer is a program that converts digital 3D models into printing instructions for a given 3D printer to build an object. The working of slicing software is, they take 3D model, make horizontal slices from it, and send the appropriate G-codes to the 3D printer to execute. Ultimaker's Cura is most widely used slicing software which is open source.

4.4. Electronic Unit

The microcontroller board is brain of any automated system. For the application of WAAM, there is a need of microcontroller board with precise control as the operating procedure and control has high constraints. The Printboard AT90USB1286 has been selected for WAAM setup. The major function of microcontroller board is to run the program or G-code event by event, monitors the position of guide blocks of robot as well as position of welding torch and drive the stepper motor through the step sticks. AT90USB1286 has 4 integrated Allegro stepper drive and on board 4 channel DAC which is main reason to select this microcontroller as we need to control four different motors i.e. X, Y & Z axis motor and one wire feeder motor. A microcontroller is typically programmed with a narrow range of function i.e. to collect the input and produce output. Here microcontroller takes input in form of G-code file produced by slicing software and gives the output is the form motion of cartesian robot carriage and welding torch deposition.
The process flow of WAAM setup is as follows -
In this way by combining all these i.e. Cartesian Robot, Weld deposition unit, CAD&CAM software and Electronics unit a WAAM system has been developed.

4.5. Welding Parameter selection

By using available resources, the WAAM test setup has been made. It consists of Cartesian gantry robot, Sigma Weld Alex 400PT TIG welding source, Auto TIG torch, semi-automatic controller, work table. The actual setup is shown in figure (4.1)[4]

Table 1.Welding Parameter [27]

Parameter	Level 1	Level 2	Level 3
Current (Amp)	215	225	230
Travel speed (mm/min)	130	140	150
Wire feed speed (mm/min)	1500	1800	2000

During this experimentation the other parameters

IV. Setting are,
V. Welding electrode – tungsten (Φ3.2 mm);
VI. Shielding gas – 100% Argon;
VII. Shielding gas flow – 17-18 LPM;
VIII. Welding voltage – 15-18 Volt;
IX. Welding position is 1G down-hand.

V. CONCLUSION

This article reviewed the manufacture of aluminium metal matrix composites through additive manufacturing (WAAM). Taking into account the key aspects of metal matrix material processing, the WAAM process, the advantages and challenges of this method, it was found that the additive manufacturing method is considered to be a better alternative method for processing metal matrix composite materials. The mixing methods of MMCs and their critical issues, classification of AM processes, WAAM process with Literature and challenges also were reviewed.

The review was also included the discussion of WAAM of some AMs with different reinforcement materials (TiC, TiB2) and different power sources. The results showed that the solidified deposited material with reinforcing particle prepared by wire arc welding had an identical structure in both parallel and perpendicular to the weld direction.. The deposited material had a large number of pores, which may be attributed to contamination of the reinforcing particles exposed to the air.

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