A REVIEW ON WAAM BY USING MIG WELDING

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ABSTRACT - Wire and arc additive manufacturing (WAAM) has proven that it can produce medium to large size components because of its high rate of deposition and potentially unlimited build size. Moreover, AM, particularly WAAM, is no longer just not only a prototyping technology but also a great benefit on its transformation to a viable and cost-effective production. So, we are planning to create the 3D object using WAAM technology so that we can check the properties of the 3D object that is created by using WAAM technology. Many of the projects are based on additive manufacturing and we intend use the same concept but most of the additive manufacturing technologies are limited to low-melting point-based materials, thus we planned to use the WAAM as the additive manufacturing method to create the 3D object.

Keywords: WAAM, CAD, Deposition, material

1. INTRODUCTION

WAAM is similar to Fused Deposition Modeling (FDM). The materials used in general are plastic, polymer, and ceramic, metal. WAAM has a huge scope in large-scale production in various industries. WAAM uses standard welding equipment, welding power source, and torches. WAAM is a modification of the Direct Energy Deposition technology and it uses an Arc welding process to print metal objects. WAAM involves melting the metal wire using an electric arc as the heat source. This molten metal is extruded in the form of beads on the substrate. As the beads stick together, they create a metal layer and this process is repeated by depositing the molten metal layer over layer until the object is completely formed. Unlike the other additive manufacturing processes which use either laser or an electron beam as the source of energy to melt the metal powder or wire, the WAAM technology melts the metal wire using an electric arc. Instead of removing material, WAAM technology is used to print the 3D models directly from the CAD design. Hence, it is considered as an alternative method to subtractive manufacturing.

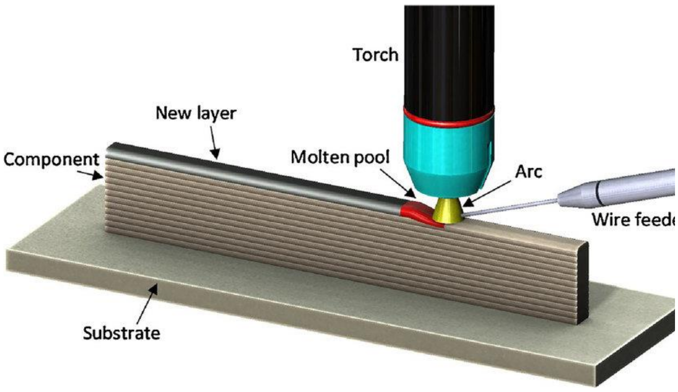

Figure 1: WAAM [1]

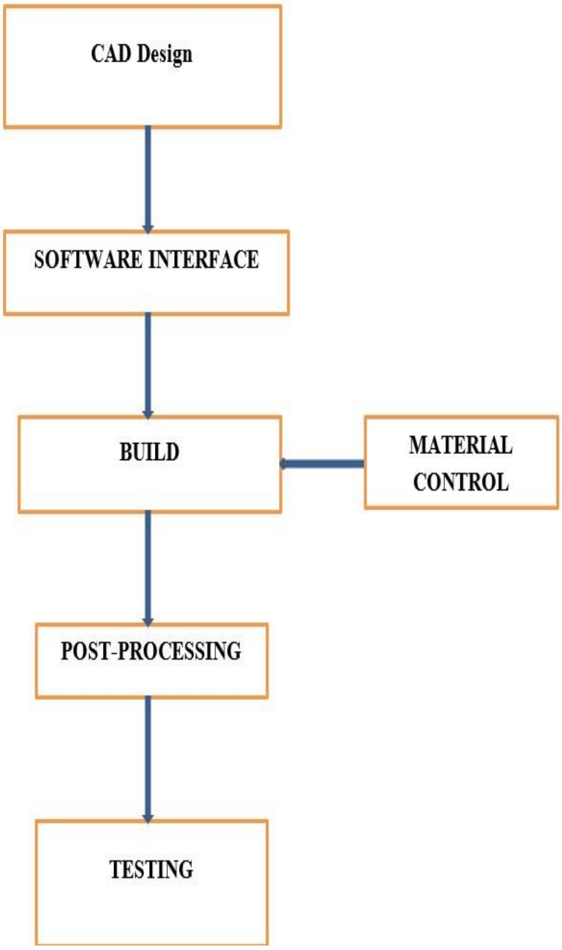

Figure 2: Flow chart of WAAM Process

2. LITERATURE REVIEW

2.1. Paper 1:

In this proposed paper by **Laurentiu Dan Ghenghea** some experiments with the shielded metal arc welding process are presented. Which have been done to investigate what was the internal structure of welded products made when bead over bead has been deposed, also some hardness tests of manufactured structure and machining tests for milling process has been presented.

At last, some experimental researches have been done for additive manufacturing using a self-made device for fused object manufacturing of pieces for the car presented in formula Students, also the same colleague used a Z Corp 3D printing device to manufacture a small model of the car in powder and a liquid binder. In this research, the main objective was to investigate if it is possible to weld layer upon layer of welded bead to form a vertical wall with good mechanical characteristics for a further mechanical operation like milling. [14]

The phases of welding deposition layers were seen in the initial catching of metallic support in specific welding devices, the first layer deposition and attentive cleaning of the surface and the color of the other welding deposition layer because of the heat developed by electric arc used like heating source to melt the electrode. After test piece manufacturing using WAAM, the cutting of cross-sections have been done for grinding surfaces to do micro-hardness tests, this operation gave the first information that had resulted in pieces did not have fragile internal structures. [14]

The measurements of micro-hardness in cross-sections of deposited material from the wire core of the shielded electrode did not change the values showing the internal structure is not composed by fragile part, in this experiment, a high cooling welded material has been used wishing to avoid repeated thermal cycles, using milling technology on test piece the process had been smooth, with small cutting forces and the resulted cheeps was metallic color with no burned zone showing that it is possible to use welded test pieces to manufacture precise mechanical elements. [14]

2.2. Paper 2:

In this proposed paper by **Nikola Knezović,** it is stated that WAAM is an interdisciplinary technology with plenty of space and different areas for improving and introducing new ideas. Some investigations suggest interpass rolling as a solution for issues with anisotropic properties other researchers proposed including non-destructive testing in process, which found porosities early, while some papers have presented the use of new materials. Some investigations should include work on these ideas, with the improvement of parameters optimization, monitoring, process control, part design, and heat treatment, which together lead to better understanding and implementation of the WAAM technology. With improvements in these areas, WAAM can become a replacement for conventional production methods, like casting and forging, in particular applications. Present issues still limit the industrial use and market's approval of WAAM, but different researches are already suggested reducing and removing them, so WAAM can become equal to traditional methods. [15]

2.3. Paper 3:

In this proposed paper by **Sudhanshu Ranjan Singh**, has reviewed there is a concern over the commercial and efficient aspects of extensive application of WAAM. The equipment cost of WAAM is comparatively low than any other AM process involving metal deposition but still, the procurement of structurally sound and defect-free parts has many large numbers of variables in-between. Various research work has been evolved in order to improve the properties of the material and its strength by removing defects such as deformation, cracking, porosity, and spatter. [16]

It was found that appropriate post-process execution could eliminate major challenges such as the deposit quality material and its mechanical properties, surface roughness, residual stress, distortion, and porosity. To improve the WAAM technique for various industrial applications, there is a need for further research and development in some areas and some challenges which are to be conquered in a positive aspect. WAAM shows up to be the suitable candidate out of all metal deposition AM techniques to replace the existing methods of manufacturing parts from forgings or billets, especially for the aerospace industry. As WAAM technique is a process and material-specific, therefore, they should be well improved for a particular area application, rather than focusing on a lone system to address all the possible problems and challenges of the industrial community. In this paper, Efforts have been made to continue to improve the unfold high-quality WAAM processes having a better quality-based framework with integrated CAD and process planning software capable of automatically producing parts, leading to more application in the future. [16]

2.4. Paper 4:

In this proposed paper by **K. S. Derekara,** the growing market demands of aluminum products, mainly high-strength alloys in automobile and aerospace, could be fulfilled using WAAM as an economical alternative option. GMAW based CMT variants have been widely applied and studied as a technique for WAAM of aluminum. The elimination of porosity in aluminum welding was appreciably tackled by the application of interlayer rolling and the

CMT-PADV technique. The study of weld pool behavior and weld metal solidification characteristics of heat-treatable and non-heat-treatable aluminum alloys for thin and thick structures through a metallurgical viewpoint can prove to be an important constructive field of study. [17]

2.5. Materials used in printing:

In WAAM technology the material out of which the object or the component has to be made should be in the form of wire. WAAM technology is used in creating 3D objects by depositing materials such as carbon and low alloy steels, stainless steel, nickel-based alloys, titanium alloys, and aluminum alloys. In general, the properties after deposition are similar for many materials but not exactly the same compared to those obtained in the case of conventional weld metal in a joint.

Figure 5: Low carbon steel made from WAAM [2]

Figure 6: Aluminium Alloy made from WAAM [4]

Figure 7: Titanium alloy made from WAAM [3]

TYPE	MELTING POINT	DUCTILITY	TENSILE STRENGTH
Low Carbon Steel	1410°C	High ductile	370 MPa
Mild Carbon Steel	1425-1540°C	Medium ductile	370 MPa
Stainless Steel	1510°C	Less ductile	505MPa
Mild Steel	1350°C-1530°C	High ductile	440 MPa
Nickel alloy	1453°C	High ductile	1,240 MPa
Titanium alloy	1,668°C	Less ductile	240 MPa-1400 MPa
Aluminum alloy	463 – 671°C	Less ductile	690 MPa

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2.6. Equipment in WAAM

In general, the WAAM involves the usage of Basic components such as Wire material, Substrate, Welding Torch, Shielding Gas, Power Supply, Feed Mechanism.

2.6.1. Wire material:

It is the material out of which the 3D object has to be made or created and it is in the form of wire. The commonly used wire materials are carbon and low alloy steels, stainless steel, nickel-based alloys, titanium alloys, and aluminum alloys.

Figure 8: Wire material [5]

2.6.2. Substrate:

It is a surface where the deposition of the molten material has to be done and it is fixed on a platform called work table.

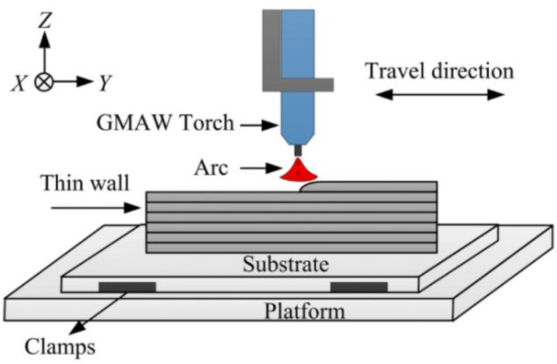

Figure 9: Substrate [6]

2.6.3. Welding torch:

It is used to produce the necessary heat energy to melt the wire material by heating to its melting point by producing an arc. It uses electrical energy as a power source to generate the arc. The wire is fed through the nozzle and in general a shielding gas is supplied in order to protect from foreign particles or impurities and after wire material is melted it is made to pass through the nozzle at a required deposition rate.

Figure 10: Welding Torch [7]

2.6.4. Shielding Gas:

It is used to protect the wire material from impurities or foreign particles in order to form a perfect layer and thereby reducing the defects after the object has been created.

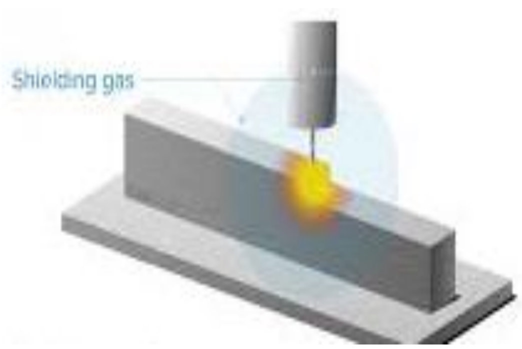

Figure 11: Shielding Gas [8]

Table 1: Materials and their properties

2.6.5. Power Supply:

It is used as a power source to supply the energy required to melt the wire material directly to the Welding torch. In general, the DC power supply is used where the positive terminal is connected to the work table and the negative terminal to the Welding torch.

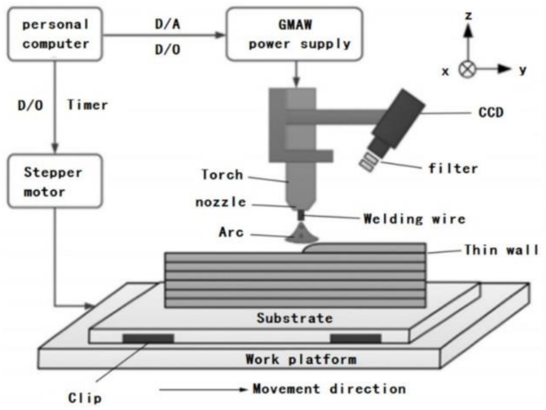

Figure 12: Power Supply [9]

2.6.6. Feed Mechanism:

It is used to supply or feed the wire material onto the substrate at a given feed rate. In general the feed mechanism involves the usage of two rollers in between which the wire material is made to pass through the Welding torch.

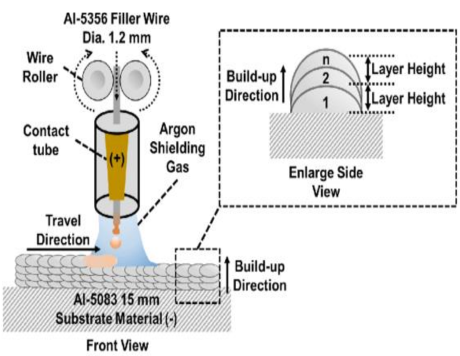

Figure 13: Feed Mechanism [10]

2.7. Advantages of WAAM:

1) It reduces manufacturing cost.
2) It increases manufacturing efficiency.
3) It reduces the number of stages of production.
4) It can use a wide range of materials.

2.8. Limitations of WAAM:

1) Residual stresses and distortions.
2) Some materials require shielding.
3) Low resolution.

2.9. Methods in WAAM:

It commonly consists of three types of methods

2.9.1. Gas Tungsten Arc Welding (GTAW)
2.9.2. Gas Metal Arc Welding (GMAW)
2.9.3. Plasma Arc Welding (PAW)

2.9.1. Gas Tungsten Arc Welding (GTAW):

It is also known as Tungsten Inert Gas Welding (TIG). It is an arc welding process in which the electrode used is a non-consumable tungsten electrode. The deposition rate in GTAW is in the range of 1-2 kg/hour.

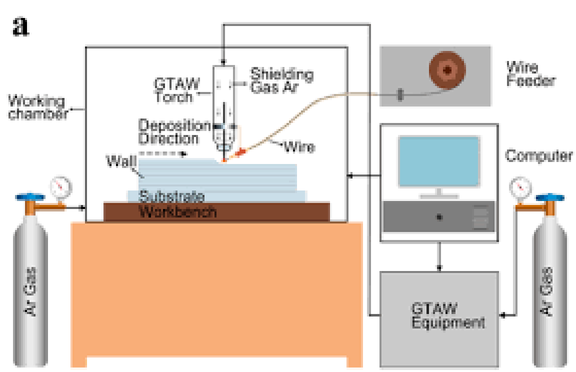

Figure 14: GTAW [11]

2.9.1.1. Advantages of GTAW:

1) There is no flux used in GTAW.
2) There is no danger of flux entrapment.
3) The operator will have better control.
4) It produces very few spatters.

2.9.1.2. Disadvantages of GTAW:

1) The cost of equipment is more.
2) MIG welding is much faster.
3) Contamination may happen due to tungsten material.
4) It has low deposition rate.
5) It requires skilled operator.

2.9.2. Gas Metal Arc Welding (GMAW):

It is also known as Metal Inert Gas Welding (MIG). It is an arc welding process in which the electrode used is a consumable electrode. The deposition rate in GMAW is 3-4 kg/hour. It has poor arc stability and produces spatter. The wire electrode would be reciprocating.

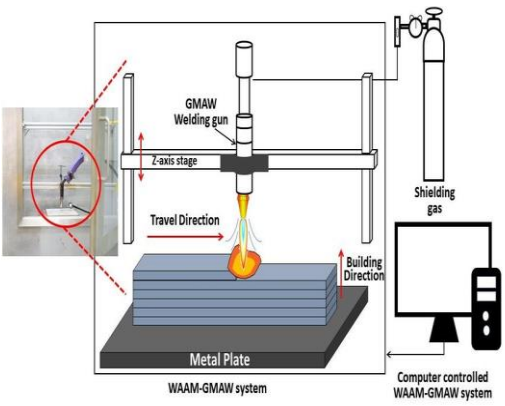

Figure 15: GMAW [12]

2.9.2.1. Advantages of GMAW:

1) It can be used for all metals and alloys.
2) It requires fewer Skills.
3) In this smaller number of defects are observed.
4) It has 2-3 times higher deposition rate.
5) It has good strength after creating the object.

2.9.2.2. Disadvantages of GMAW:

1) It is less portable.
2) The equipment used is here is very costly.
3) It is an open arc process so care must be taken.

2.9.3. Plasma Arc Welding (PAW):

It is an arc welding process in which the electrode used is a non-consumable electrode. It is similar to TIG welding. In this, the electric arc is formed to melt the wire material.

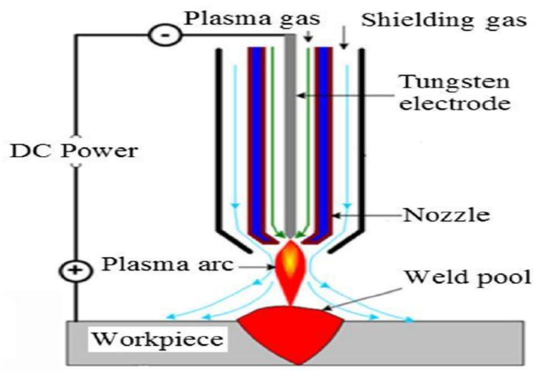

Figure 16: PAW [13]

2.9.3.1. Advantages of PAW:

1) It has greater control over the arc.
2) It has higher heat generation.
3) It can travel at higher speeds.
4) It can be easily automated.

2.9.3.2. Disadvantages of PAW:

1) It produces higher noise.
2) It requires skilled worker.
3) Equipment used in this process is expensive.

2.10. Applications of WAAM:

WAAM offers an alternative to traditional manufacturing with a scope of use in various industries such as

1) Aerospace industries
2) Marine
3) Automotive industries
4) Architecture

2.11. Why choosing WAAM by GMAW over others?

As GMAW is known for using a wide range of materials and produces good strength and durable objects. GMAW has higher deposition rates which are 2-3 times of GTAW deposition rate. It requires less skilled operators when compared to other methods. There are lesser defects observed in the GMAW method. It has scope in industries such as the automotive, marine industry. So, in this project, we have chosen the GMAW method in WAAM to create an object with fewer induced defects.

2.12. Mechanism of WAAM:

Wire arc additive manufacturing is a process in which the heat energy from an electric arc is used for melting the electrodes and depositing layer over layer for wall formation in order to form a component. Due to high deposition rates this method is found to be advantageous and efficient as it produces large parts with good structural integrity, reducing the wastage of raw material, and less consumption of energy when compared to other additive manufacturing techniques. The process is generally controlled by a robotic arm and the required geometry is built upon a substrate and the part can be cut once finished. The wire is melted and extruded in the form of beads on the substrate. As the beads fuse together, they create a layer of metal material. This process is repeated and is done layer by layer until the component is built.

2.13. Process parameters:

In WAAM, there are several factors that are to be considered for determining material characteristics. These include parameters such as travel speed, wire feed rate, working distance, arc voltage, current etc.

2.13.1. Travel speed:

Travel speed is one of the parameters which influence the material deposition rate and quality of deposited layer. The travel speed is inversely proportional to the deposition rate of the material which means if travel speed is more, then the material deposited will be less, so thickness of material deposited is also less.

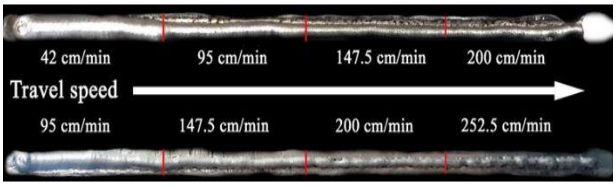

Figure 17: Effect of travel speed [18]

2.13.2. Wire feed rate:

Wire feed rate is directly proportional to the deposition rate of material which means when the wire is fed at faster rate(more feed rate) then the material deposited is also more. The wire feed rate is generally 8.1 m/min for Al-Si and 6.1 m/min for Al-Mg-Mn alloys.

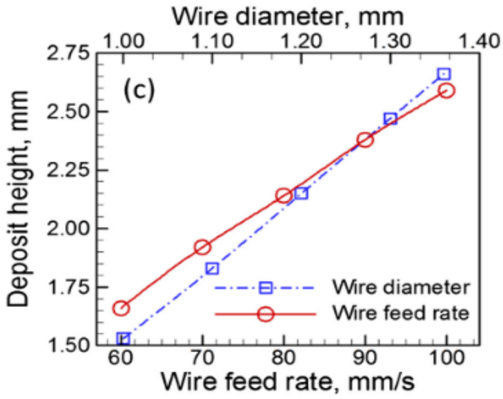

Figure 18: Effect of wire feed rate [19]

2.13.3. Working Distance:

If the gap or the distance between the nozzle and substrate (base) is more, then deposition rate of material decreases, especially for high dense materials. So, working distance is inversely proportional to the material deposited.

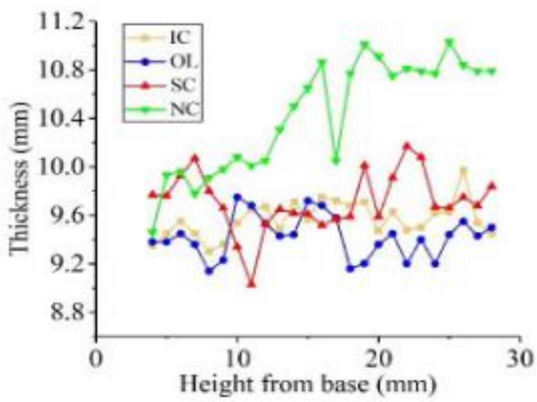

Figure 19: Effect of working distance [20]

2.13.4. Arc voltage:

When the arc voltage is increased, then the deposition rate of the material also increases because the temperature required to make the wire into molten form is achieved faster by increasing the arc voltage. Thus, arc voltage is directly proportional to the rate of deposition of material. The maximum voltage is 23V.

2.13.5. Current:

The input current is directly proportional to the rate of material deposition. When the input current is increased, the rate of material deposition also increases. The current is about 160A.

3. CONCLUSION

We have concentrated on various research papers on wire arc additive manufacturing technology and from these papers we have gathered theoretical information on WAAM technology. From the research papers that we have referred, improvements are to be done in certain areas so that WAAM can become an alternate method for conventional production method, such as casting and forging. The solidification of heat-treated alloys after final object is created plays an important role in WAAM technology.

WAAM technology is versatile, reduction of process time, with desirable mechanical properties. Lots of research needs to be carried out in WAAM technology to study influence of process parameters, material transfer, post heat treatment effect during solidification of the layer and environmental influence, controlling of residual stresses and distortion.

4. FUTURE SCOPE:

We want to study the feasibility of WAAM metal deposition as layer over layer using mig welding. Deposited material will be tested to observe adequacy of mechanical and metallurgical properties of the printed material.

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