Chapter

Welding Based Additive Manufacturing: Fundamentals

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Abstract

Additive Manufacturing (AM) has drawn abundant attention over the past decades in the manufacturing and fabrication industries, especially to make part models and prototypes. This chapter introduces a potential welding based AM process called Wire Arc Additive Manufacturing (WAAM) for the fabrication of near-net shaped metal components including stainless steel components. To start with traditional AM processes, various fundamental traditional AM for the fabrication of components have been presented. Wire Arc Additive Manufacturing (WAAM) has been explained with its variants, synonyms, different welding processes to suit WAAM particularly to weld stainless steel metal; primary process selections for working with WAAM, important metals, and alloys that could be used in WAAM have been elaborated. A case study for WAAM fabrication of AISI 316 L stainless steel plate is included to introduce the fabrication of metal components using WAAM. Further, the most common defects which possibly play a vital role in WAAM components fabrication and a few of the future challenges regarding WAAM development are discussed. Fundamental information covered in this chapter could be more beneficial to beginners for the understanding of WAAM process generally including stainless steel component fabrication in a lucid tactic.

Keywords: additive manufacturing, welding, Wire Arc Additive Manufacturing, fabrication of stainless steel components, mechanical and metallurgical properties, defects, quality aspects

1. Introduction

In recent days, Additive manufacturing (AM) is often called as 3D printing and this is basically a transformative method to the conventional industrial production that takes us to the creation of light as well as strong components simply by adding the material layers [1]. This is generally called as additive layer manufacturing (ALM) because the final component is fabricated by depositing materials, usually layer over a layer. This ALM is shown in **Figure 1**. Any shaped 3-dimensional objects may be fabricated with the help of this AM concept. This is a dominant process nowadays occupied by the majority of industries over the subtractive manufacturing methods such as machining and cast forming. This is because the fabrication of components using this AM looks effortless compared with subtractive processes [2]. AM is believed to be the future of many industries, simply not

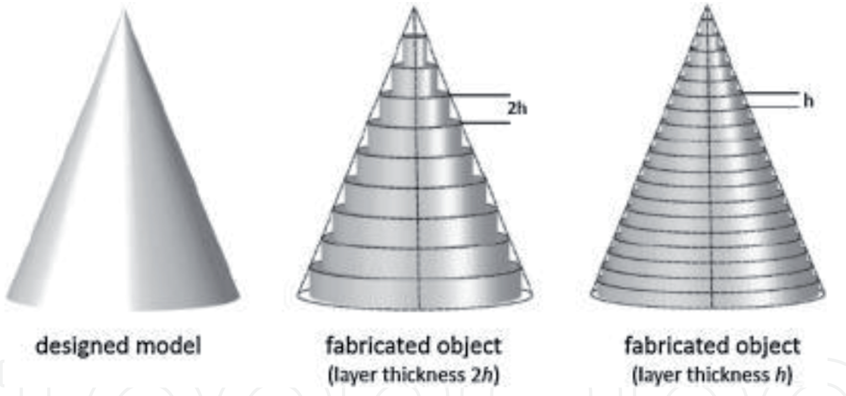

Figure 1.
Concept of additive layer manufacturing (ALM).

only in manufacturing factories but also in the construction fields. This 3D Printing technology is now widely used in the field of constructions.

1.1 Additive manufacturing processes

Selection of an appropriate process is very important among the AM processes for successful fabrication. Generally, there are number of different methods available in standard to meet the AM processes and they are listed below.

1. Binder jetting

2. Directed energy deposition (DED)

3. Material extrusion

4. Powder bed fusion

5. Sheet lamination

6. Vat polymerization

7. Directed energy deposition

To start with Binder jetting, it actually uses a 3D printer head and moves in three standard coordinates (x, y, and z axes) to print all the layers of powder material and also a liquid form one known as the binder for adhesive purposes. DED shall be employed with almost entire materials including metals, ceramics, and polymers irrespective of the weight of material for the fabrication of final components. Electric arc, laser, and electron beam shall be used for the melting of solid wire material or feedstock filaments or metal powder to deposit the melted material as layers. Wire Arc Additive Manufacturing (WAAM) is one of an arc welding based AM. Material extrusion involves the spooled polymers which may be extruded or drawn into a heated nozzle. This also builds melted material in the form of layer over a layer and finally, these layers stick either because of temperature control or chemical bonding. Powder bed fusion technology generally involves the formation of melts or partially melts layers of material cleaned by blasting away the excess powder. Many AM techniques follow this concept includes Direct Metal Laser Melting (DMLM), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Selective Laser Sintering (SLS), and Selective Heat Sintering (SHS).

Thin sheets of material are laminated over one another together to fabricate a single 3D component is known as simply the sheet lamination. Laminated Object Manufacturing (LOM) and Ultrasonic Additive Manufacturing (UAM) are available technologies for sheet lamination. Vat polymerization customs a liquid resin photopolymer vat to produce a piece [3]. Layers of materials are cured by ultraviolet light by mirrors is called photopolymerization.

Even though the above-listed processes are available for AM, these processes would fall under any one type of technology from three technologies. The first technology is called *sintering* in which the powder form of material used for the fabrication is heated up to the stage well before liquefied for the creation of complex high-resolution components. The second one involves in complete *melting* in which the powder material used for the fabrication is fully melted for the creation of the part. Generally, the laser is used for the action of this melting here. The another third type of technology is referred to as *stereolithography*, in which a process of photopolymerization is employed, therefore, an ultraviolet laser is fired and directed to photopolymer resin to make torque-resistant parts that endure temperatures at both extremes [4]. These processes and technologies are used for the successful 3D printing of components of various materials.

In general, the powder-based additive manufacturing process is so familiar and commercially readily available in most of the nearby industries that fabricate the components that are smaller in size. Our matter of interest WAAM is the wire-based welding process that has emerged to date as a potential candidate for comparatively large AM metal components. The chapter provides the description on WAAM technology and its possible classification while focusing on stainless steel and various synonyms of WAAM being used worldwide have been presented. Various arc-based welding processes have been discussed and a case of stainless steel plate fabrication is given in detail. Various weld defects in WAAM fabrication are presented and a few of the future works while focusing on the fabrication of stainless steel components are presented.

1.2 Wire Arc Additive Manufacturing (WAAM) technology

The WAAM is a typical AM technology under DED technologies. Generally, in DED, the energy sources such as laser, electric arc, and electron beam are used to melt the feed material in the form of either powder or solid metal wire. Making use of the welding process would enable the heat energy of the process to focus on the metal to be melted directly. This kind of welding based melting and depositing the metal layers additively in order to achieve the final shape and size of the component is known as Wire Arc Additive Manufacturing (WAAM). Therefore, this WAAM particularly falls as one of a DED technique. This WAAM uses an appropriate welding process for melting the metal wire electrode and depositing the melted metal layers over another as in the case of Additive Manufacturing (AM) for the fabrication of metallic components and this is now being one of the fastest and growing research and development field among the almost entire area of engineering fabrication. WAAM generally uses any of the arc welding process power sources along with manipulators for automation to deposit 3D shaped metal components. Manipulations are familiarly being done by CAD/CAM based softwares. Robotic welding equipment is well suited for WAAM because it is easy to get required shape automation/manipulations. The shape of the component being manufactured is achieved by planning the path of the depositions well. This process most normally uses solid wire as a feed material. This solid wire gets melted by an electric arc and moves according to the well-preplanned paths to deposit the metal component in the desired shape. Therefore, the melted metal is deposited layer over a layer to create the required component [5]. **Figure 2** shows a welding based WAAM process for the fabrication of stainless steel plate components in which the arc generated in any

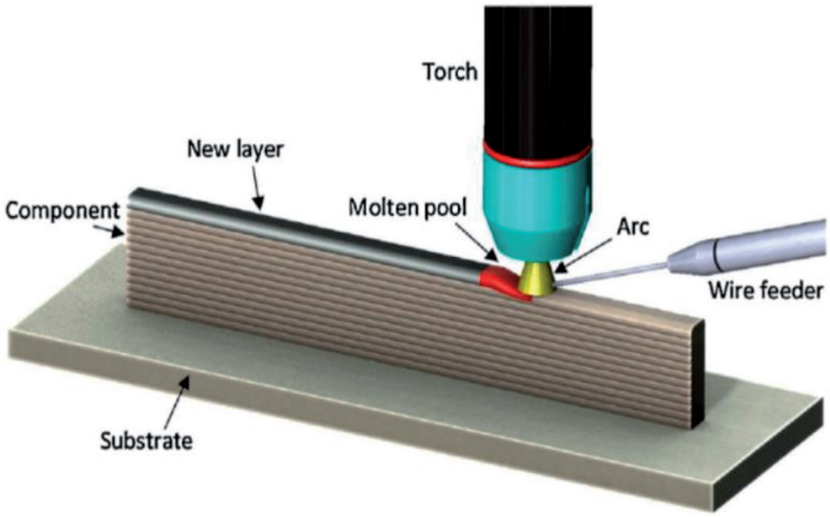

Figure 2.
Illustration of WAAM.

of the arc welding process is directed to the metal wire coming out from the feeder and the arc melts the metal wire thus deposition will be made over a substrate. Thus, the number of required deposition layers would be allowed up to attaining the required shape and size of the component [6].

WAAM illustration may look very simple but in nature, it is not a simple process to carry out. For a WAAM process, the process parameters of the welding process are considered to control to yield desired deposition weld bead geometry there by the final shape of the component is achieved as a single component by arranging weld bead/layer over weld beads/layers. Much care should be given to the welding parameters selected more than the welding operation as these parameters are capable of affecting the quality and shape of the component being fabricated [7]. Therefore, WAAM needs a skilled operator for successful fabrication.

1.2.1 Classification of WAAM

The WAAM is a hot developing topic yet and is not classified so far clearly. But in this text, an attempt has been given for the classification of WAAM processes based on the familiar arc welding processes alone employed for stainless steels and proved to be fit for WAAM. Therefore, WAAM is here classified into,

1. Gas Metal Arc Welding (GMAW) based WAAM
2. Gas Tungsten Arc Welding (GTAW) based WAAM
3. Plasma Arc Welding (PAW) based WAAM

Selection of the welding process is based on the operator's requirement. For example, if the priority is given to a high deposition rate, GMAW process may be selected compared to GTAW even if the quality and process stability are comparatively less. If the operator is looking for an electric arc with very high energy density then PAW may be preferred that actually enables increased travel speeds and good quality weld deposits with minimum weld distortion [8].

1.2.2 Synonyms of Wire Arc Additive Manufacturing

The WAAM is presently well-known synonym for Directed Energy Deposition-Arc (DED-arc) that enables the need well to fabricate, any of the

S. no	Terms used	Used organizations
1	Welding based deposition	Southern Methodist University
2	3D Welding	Korea Institute of Science and Technology, University of Nottingham
3	Welding based rapid prototyping	University of Kentucky
4	Near-net shape manufacturing	Tufts University
5	Shape deposition manufacturing	Carnegie Mellon and Stanford University
6	WAAM	Cranfield University, University of Wollongong
7	Welding based AM	National Institute of Technology Tiruchirappalli, Coimbatore Institute of Engineering and Technology

Table 1.
Different terms used for WAAM by others worldwide.

engineering structures with very near net shapes but not to the exact shapes. As known, Wire Arc Additive Manufacturing (WAAM) is a welding based fabrication process used to 3D print metal parts. The WAAM is also used to repair the metal parts as well [9]. Cold Metal Transfer mode in the welding process is now extended particularly to avoid the problems due to heat accumulation during weld layers deposition is simply now announced as CMT-WAAM by Fronius [7], a company working vigorously in worldwide welding. Sometimes because of the reason of using solid metal, it may also be referred as Metal Additive Manufacturing (MAM) for both AM as well as welding based AM process. Hence, the WAAM synonyms include the terms such as DED-wire process, 3D Printing process, Wire and Laser AM (WLAM), Electron Beam Freedom Fabrication (EBFF), Metal AM process, Welding based AM process, and CMT-WAAM process. Many have referred to this welding based AM process by various terms [9]. They are clearly represented in **Table 1**.

2. Welding processes for additive manufacturing

The WAAM generally requires a welding process giving high deposition rates without quality and size limitations so that WAAM could become the best alternative for conventional AM processes, especially when dealing with medium and large size component fabrication. The increasing interest over the world in WAAM is mainly because of the advances in robotic controls and modern electronic control circuit systems for different welding machines [10]. The modern methods of controlled short arc processes with reduced heat input like a process called Cold Metal Transfer (CMT) technology were particularly developed for GMAW process and now has been developed by Fronius International, a company works worldwide especially for the WAAM in the name of CMT based GMAW. Tungsten Inert Gas (TIG) welding process and Plasma Arc Welding (PAW) process could be used due to the separation of mass and energy input. Also, apart from the standard welding processes, laser-assisted welding has also been available for this type of AM. The following welding processes have been experimented especially for fabrication worldwide with the focus on the best fabrication practice for fabricating the stainless steel components by WAAM [11].

1. Plasma arc welding (PAW)
2. Gas metal arc welding (GMAW)
3. Gas tungsten arc welding (GTAW)
4. Submerged arc welding (SAW)
5. Skeleton arc welding
6. Laser-assisted welding

2.1 Plasma arc welding (PAW)

Plasma arc welding process shall be employed for AM using filler material for the fabrication in either powder form or wire form. This may familiarly be called as Plasma Transferred Arc Welding (PTAW), an important variant of PAW. This welding process is found to be the best process for the depositions to suit surfacing or cladding processes with several materials. The same deposition approach may also simply be extended to a very simple approach for AM as like multi-layers surfacing or cladding. This process is capable of separating the energy input and the weld metal flow entirely from the filler metal. This process is applicable to different type of materials.

2.2 Gas metal arc welding (GMAW)

GMAW is a more frequently employed famous welding process for many decades in metal surfacing, cladding, and additive manufacturing too. Thus, this process is very familiar nowadays for WAAM because of its suitability. In recent years, much focus has been given to the development of control systems for welding arc power and this leads to the development of new process variants such as CMT-GMAW [7]. Furthermore, these controlled short arc welding processes can be ranked high by innovative wire feed control to achieve control on droplets. Also, a variant called the multi-wire process has been developed particularly to improve the mass of the deposited metal.

2.3 Gas tungsten arc welding (GTAW)

This GTAW is familiarly known as Tungsten Insert Gas (TIG) welding. The important major benefit of this TIG welding process is that the separation between the filler metal and heat energy input is highly possible. The possibility for using more than a single wire during the process made TIG an well-suited process for WAAM. A variant of TIG called the pulsed TIG welding process has shown a very good melt pool shape thus to suit for additive manufacturing. Various properties of the AC-TIG and pulsed TIG welding processes are also under rigorous investigation to meet the WAAM process. It is believed that GTAW would be a great choice for WAAM in near future.

2.4 Submerged arc welding (SAW)

SAW can be a successful welding process for AM but positioning the flux plays an important role in this process because of this reason the flexibility of this process

Figure 3.
Skeleton arc WAAM.

is limited AM. For carrying the electrode and current, a welding gun and cable set are used and thus deliver the flux to the arc. The flux to be supplied depends upon the position of the gun. On the other hand, the torch is attached to the motor that is feeding wire and takes necessary actions regarding current to take tips for the reason of transmitting the welding current to filler wire. SAW would become complex by including additional devices like weavers, seam followers, and work rovers, etc. Because of these complex reasons SAW has not been identified with ease for the WAAM process.

2.5 Skeleton arc welding

Skeleton arc welding is said to be a distinct variant of WAAM. The final part would be fabricated by single dot depositions. The creation of skeleton-like structures in almost every component is possible in this method. These skeleton structures could be employed to make lightweight path-oriented designs into AM and are clever to make bionic-like structures easily. All the materials could be used in this type of WAAM provided the path planning is executed well. A typically employed WAAM by skeleton arc welding with the best path planning is represented in **Figure 3**.

2.6 Laser-assisted welding

Laser-assisted welding completely differs from the process of laser hybrid welding and this in fact typically practices the laser power lesser than 1 kilowatts and thus one of the possible benefits geometrical control of the weld deposit any few more benefits also possible. Moreover, the surface quality is also found to be enhanced while using less power during the operation. This laser-assisted welding will become the appropriate process soon preferably for WAAM.

3. Primary process selections for WAAM

Primary WAAM process selections are very much essential for confirming the rightness of the fabricated structures and this indeed requires characterization of the deposited material. Many of the mechanical, thermal, and metallurgical properties may differ in the end components because it is fabricated by using any of the welding processes. This fundamental classification may include the bases such as substrate material, electrode wire, welding processes, welding process variables, shielding gases, and automation systems for the motion [5]. Therefore, primary WAAM process selection includes the following essentials,

1. Parent plate material

2. Electrode wire

3. Welding processes

4. Welding process variables

5. Shielding gases

6. Automation systems

3.1 Parent plate material

The section of substrate material is so important in WAAM because the wettability of deposited weld beads to build the component solely depends upon the chemical composition of the substrate material over which the weld beads are deposited. If the case is of dissimilar metal, then laying the weld bead onto the dissimilar substrate is very difficult one to consider. Moreover, weld dilution of the first layer of the deposit must also be analyzed for this case. The stiffness and thickness of the substrate material will offer enough resistance to weld distortion. Therefore, a detailed study of substrate material used during the fabrication of metal components is much important.

3.2 Electrode wire

The electrode wire to be used for the component fabrication by WAAM is driven by technological aspects based on the welding process concerned. The selections of electrode wire during WAAM are considered instrumental to the fabricated components performance. The wire gauge and the number of wires to be fed to the electric arc at a few of the welding process parameters definitely affect the performance measures such as the deposition rate, and the heat transfer behavior in the weld pool. This can brought welding defects like lack of fusion. The defects in the wire surface, like diameter variations, cracks, and some scratches could result in porosity within the deposited component. It has been proved that making use of high-quality wire results the lesser porosity in the welds. To handle carefully these defects, wire selection is very much important in WAAM fabrication.

3.3 Welding processes

The welding processes considered with foremost importance for WAAM depending upon the feasibility and cost benefits may be among Gas Metal Arc Welding (GMAW) process, Gas Tungsten Arc Welding (GTAW) process, and Plasma Arc Welding (PAW) process. Few more welding processes have been also available as discussed in Section 2, but the suitability for WAAM is very high for the above said frequently used welding processes. The selection of a suitable welding process depending on the component to be fabricated is already discussed in Sections 1.2.1 and 1.2.2 above.

3.4 Welding process variables

Several welding process variables are available for different welding processes. These welding process variables are deciding the final quality of components fabricated by WAAM. Therefore, a key care to be taken for the selection of appropriate welding process as well as welding parameters. Sometimes these variables may show the combined effect when selected together. Familiar process parameters of welding processes to consider include welding current, voltage, open-circuit voltage, wire feed rate, welding travel speed, welding electrode, diameter, electrode angle, substrate material, electrode dip to substrate distance, and more. The operator has to take much care while selecting the combination of welding process variables to yield the best quality in the fabricated components [12]. Also, the care must also be given over the range over which each selected parameters are to be operated to achieve defect-free components.

3.5 Shielding gas

The purpose of using the shielding gas in welding based WAAM is to protect the molten metal during welding against surrounding atmospheric elements. An acceptable flow rate of shield gas is essential to cover the hot weld deposit in WAAM to separate the atmospheric gases and to prevent the action of detrimental oxide, nitride, and porosity formation and porosity. This shield zone could be taken to the side walls also during the fabrication of WAAM components. A very high flow rate could lead to reduced weld penetration. Most commonly used shielding gases are argon, carbon dioxide, helium, nitrogen, hydrogen, and mixers of these gases.

3.6 Automation systems

Automation is the heart to deliver WAAM fabrication from welding. Cartesian coordinates (x, y & z axes), robotic arm, and manipulator like kinematic machines have been available for providing necessary motions to the weld-torch for attaining build shaped structure. The repeatability with accuracy in such motions will lead to achieve desired geometrical, physical properties of the weldment. The high volume of material may be needed to be post-processed, if the motion system is not accurate. This would detrimentally decide the cost of WAAM. CNC machine movements have been employed for WAAM and are believed to be cost-effective approach and would be a hybrid process as the motion for building components and machining to achieve the final component shall be done on the same machine at a stretch.

4. Metals and alloys for Wire Arc Additive Manufacturing

WAAM processes exactly use available electrode wires of materials that are produced by the welding industries and readily available in the spooled form in alloys as feedstock to welding processes. The materials to choose for WAAM process are completely based on the application requirements. For example, some materials may be preferred by automotive industries, aerospace industries, and so on [5, 13]. To cover these application requirements, the following familiar metals are available for WAAM.

1. Nickel-based alloys
2. Aluminum alloys
3. Chromium alloys
4. Titanium alloys
5. Stainless steel alloys
6. Other pure metals

WAAM community suggests that the Nickel-based alloys as the most popular materials for the fabrication by welding process due to their weld ability and high strength at elevated temperatures. Nickel-based alloys are widely used in aerospace, petrochemical, chemical, and marine industries due to their exceptional strength and oxidation resistance at high-temperature ranges. In WAAM, alloys such as Inconel 718 and Inconel 625 have been proved to be feasible alloys so far for WAAM processing. Fabrication trials for many different series of aluminum alloys have been carried out already using Al-Cu (2xxx), Al-Si (4xxx), Al-Mg (5xxx) and also using many alloys. The WAAM is mainly a justifiable process for structures as the cost of manufacturing the small and simple aluminum alloy component by conventional machining processes is comparatively less. Though many of the Al alloys such as Al 7xxx and 6xxx are still challenging to weld for WAAM fabrication due to the reason of turbulent melt pool and defects, the rigorous activities are being undertaken regarding aluminum alloys because of the superior benefit that additively manufactured aluminum alloy parts have inferior mechanical properties compared to those machined from billet material. In order to achieve higher tensile strength, most of the as-deposited aluminum parts undergo post-process heat treatment to refine the microstructure. Compared to other alloys these alloys are cheaper and easily available, the WAAM of these components gaining enormous interest irrespective of fabrication complexity.

Additions of chromium to iron and aluminum as an alloying element have been to improve the anti-corrosion properties of the structure and could be a potential candidate for increasing the lifetimes of the various corrosive environment applications. Titanium alloys contain a mixture of pure titanium and other chemical elements and these alloys have high tensile strength and toughness at the wide range of temperatures. They are generally lighter in weight and pose superior anti-corrosion properties. However, the high cost and processing limitations make these alloys to use in superior areas such as military and aerospace applications, sports, and bio-medical industries. WAAM is highly attempted for the fabrication for these areas with cost benefits. Stainless steel originally referred to as rustless steel, is a group of ferrous alloys that contain a minimum of approximately 11% chromium, this has made stainless steel as rust-free together with heat-resistant properties. Different types of stainless steel generally include the elements such as carbon, aluminum, silicon, nitrogen, sulfur, nickel, titanium, copper, selenium, niobium, and molybdenum. Sensitization is a major problem in austenitic type of stainless steels comparing ferritic steels and martensitic steels. Apart from this, residual stress, metallurgical properties, weld distortion and thermal properties of the WAAM manufactured components are to be taken with much care for the successful lifetime of components. Other metals such as magnesium, bronze, and many more intermetallic structures could be possible with this WAAM process but care must be given to improve the properties of such fabricated structure components.

5. Fabrication of components using WAAM

WAAM has already proven that it could fabricate medium to large-sized components as well because of high deposition rate welding processes. Similar to AM technologies, WAAM could produce uniform, defect-free metal components are a key reason for the selection of WAAM. Moreover, WAAM is not simply a prototyping technology and most of the present day's attention is on using this WAAM as a transformation to a viable and cost-effective fabrication. Fabrication of a metallic plate component by Welding based Additive Manufacturing (WAM) is explained for an easy understanding of WAAM fabrication.

As an example, the low-carbon high-strength steel (AWS A5.28 ER110S-G) metal plate as shown in **Figure 4** is fabricated by WAM. The experimental apparatus is a GMAW based WAAM setup available at the Coimbatore Institute of Engineering and Technology, Coimbatore. The experimental process consists of a welding torch mounted on a linear manipulator system. An Ador makes GMAW power source based experimental setup was employed to deposit the metal over the parent plate. The feedstock material was AWS A5.28 ER110S-G filler wire, a low-carbon high-strength steel wire electrode with a diameter of 1.2 mm. The metal plate was built on a mild steel substrate plate. The GMAW parameters such as voltage, current, wire feed rate, gas flow rate, and welding speed were considered as the primary parameters and those values were kept as 20 V, 100 A, 4 m/min, 12 l/min, and 4 mm/s respectively for the fabrication of decided plate component. Totally 15 numbers of weld beads were deposited and this structure is capable of giving 10 × 100 mm desired dimensions plate component after a small machining operation. This is the reason why the WAAM component is famously described as a near-net component.

After the fabrication of this plate-shaped component, a lot of properties such as surface waviness, weld bead dimensions, height of each layers, and weld bead angle are evaluated essentially to speak about the geometrical specifications of fabricated component and similarly, mechanical properties such as tensile strength, ductility, fatigue strength, corrosion rate, hardness, and microstructural evaluations are essential to be carried out in order to meet the quality and quantity benefits of fabrications as well.

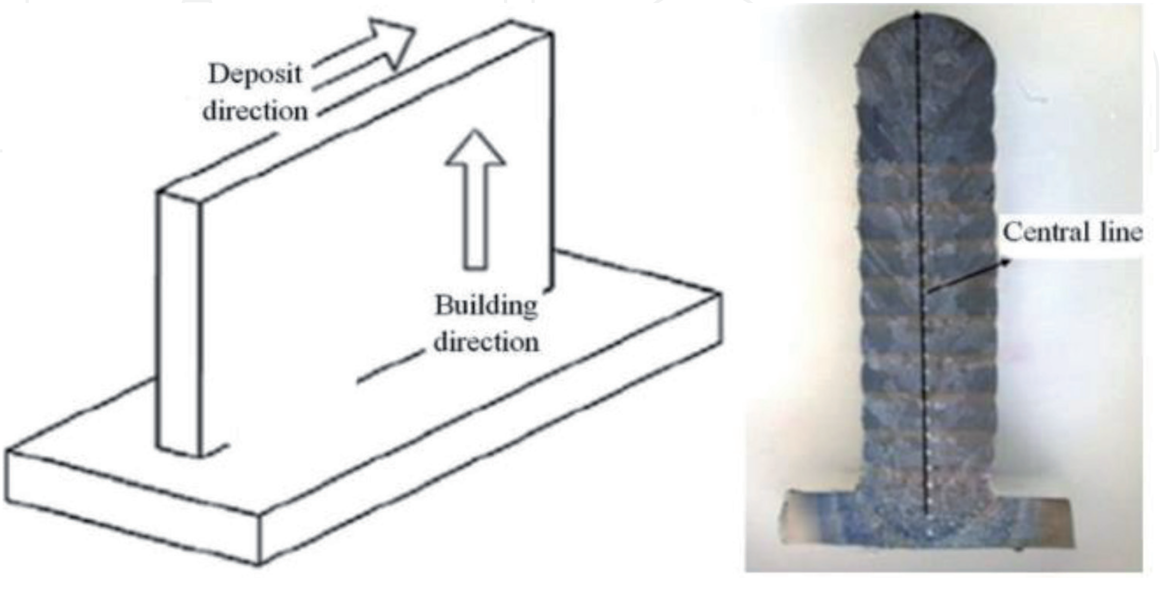

Figure 4.
Fabrication of components using WAAM.

6. Most common defects in WAAM components

It has been seen that WAAM is a welding based fabrication method and components are being made to any shape and size according to the requirements. Therefore, everyone might think that the properties of WAAM fabricated components would match with the conventional welding process. But this fact is not true because the welding process will be carried out for many purposes such as different weld joining and weld cladding, etc. Almost in all the like cases, it is obvious that the weld bead would be limited to only a single in most of the cases and if needed, in peculiar cases few weld beads would be needed to accomplish the process needs. The WAAM case especially while fabricating stainless steel components is entirely different because of the reason that the entire component is manufactured by depositing the weld beads. In this case, many more weld beads to be deposited especially in layers according to the component being fabricated [11]. Therefore, the weld beads may get different properties than the normal welding. There is a strong possibility of more defects in WAAM fabricated components.

Though the meaning of these weld defects in WAAM components are similar to the welding process, it should be understood that there is highly possible to receive more amount of weld defects here since many more required number of weld beads are accumulated together to form the final component. As the components are fabricated with defects by WAAM, it is very tedious to meet the quality and performance-wise factors with the components manufactured in conventional methods or traditional AM processes. Therefore, it is strongly recommended to look for options to reduce these defects during the fabrication of metal components in WAAM [14]. The most common possible few of the weld defects in WAAM based

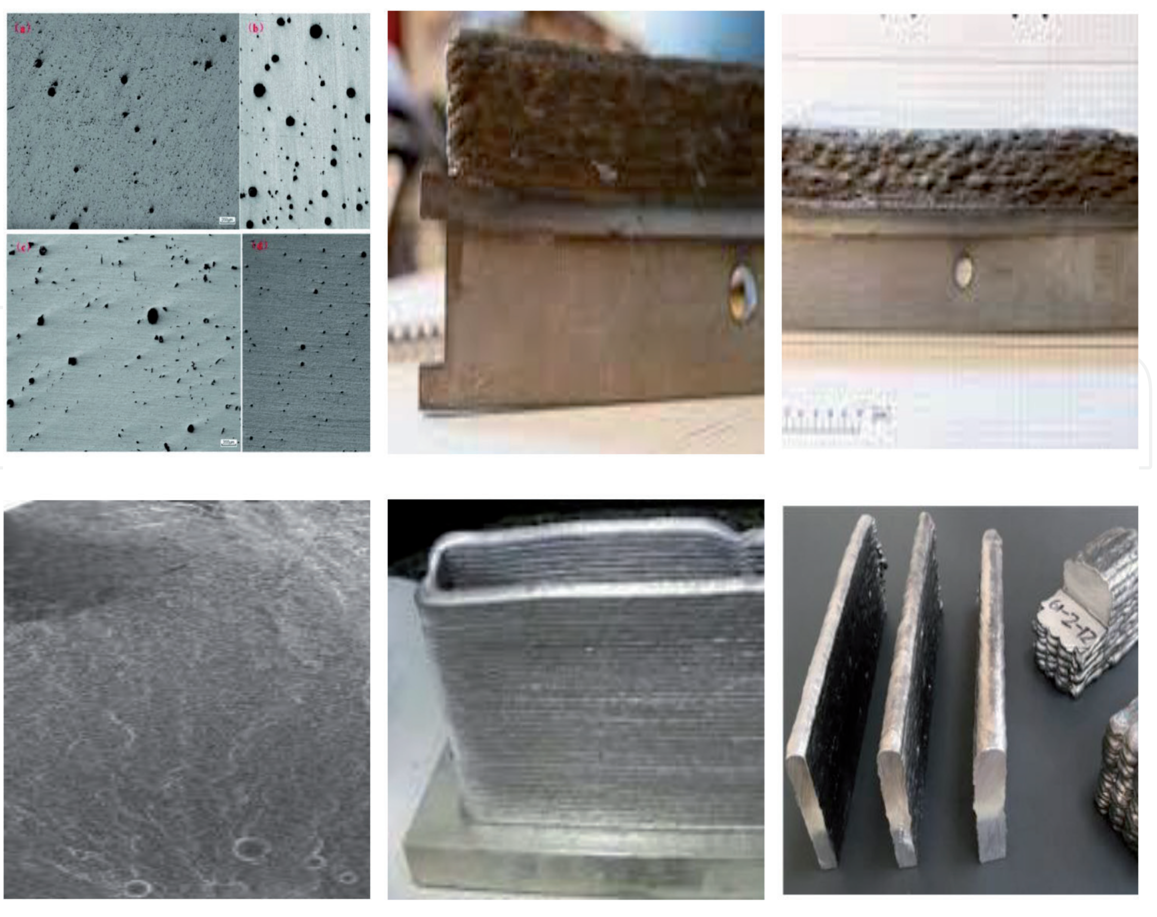

Figure 5.
Various defects in WAAM components.

fabricated components are listed below. Also, the weld defects that arise during WAAM fabrication are represented in **Figure 5**.

1. Porosity

2. High residual stress

3. Solidification cracking

4. Fatigue

5. Oxidation

6. Poor surface finish

7. Delamination

8. Deformation

7. Future challenges

Ready acceptance worldwide in many of the fabrication industries among the market for the welding based additive manufacturing of the numerous near net-shaped component fabrication is a noteworthy message to the research community for attending the forthcoming challenges associated with real-time fabrication of stainless steel components in WAAM. Some of the future challenges have been pointed below [5, 15].

- The development of strategies and processes to overcome the materials processing limitations in WAAM.

- The heat input from the welding torch to melt the weld material to be controlled carefully because this issue leads to many of the weld defects.

- The ease of integration with existing welding equipment and the adaptability of the process to the range of materials to be produced.

- As WAAM is purely a commercial manufacturing process for the fabrication to provide high versatility, it will be more important that the few of the additional processes are to be identified and they are capable of enhancing quality in multiple materials.

- It has been discussed that path planning in WAAM plays a main role in the successful fabrication, therefore path planning skills for the operators are to essentially be improved.

- Effects on material properties are to be kept towards increasing trend as far as possible for the WAAM fabrication in live always.

- Some of the material removal processes are likely to be developed and few are to comprise for the future successful WAAM.

- Minimizing inhomogeneous material properties attributed to geometrical changes without any compromise.

- Technical advancements to manipulate grain size and solidification mode in the fabricated part is needed for WAAM to advance.

- Simulation software to develop computational simulations regarding the numerical analysis.

- Post-processing time and cost for WAAM component are to be addressed fundamentally in order to take WAAM to next level.

- Knowledge of development machine and material properties will also help in feature addition.

- The urgency of highly capable WAAM machines that may combine manufacturing processes from a number of process classes to competently transform many raw materials into ended parts with minimal post-processing.

8. Conclusions

The concept of WAAM is now well spreading across the globe due to its wide acceptability by leading industries and crucial sectors for the fabrication of stainless steel and other metal components of interest at good cost benefits but without compromising the quality. This text clearly states the fundamentals of WAAM. The AM technique was well illustrated followed by its different classifications and techniques. The working of Wire Arc Additive Manufacturing (WAAM), a variant AM process has been written in lucid manner. Classifications of WAAM have been given with importance of familiar and capable welding processes experimented worldwide followed by synonym terms practiced across the different research group nations. The welding processes frequently used for WAAM have been well presented followed by various key welding process parameters. Moreover, the well-exercised materials of different alloy classifications have been detailed. As an example of fabrication, the details about the fabrication of metal component using GMAW based WAAM has been presented. Most common welding defects frequently occurred have been presented with the causes for easy understanding followed by some of the challenges for future to address for the successful fabrication of variety of metal components using this welding based AM. It is believed that the information furnished here would be supportive for the budding engineers and industry personnel who want to learn the AM fabrication using WAAM.

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