Wire Arc Additive Manufacturing Perspectives and Recent Developments

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Abstract. The outstanding performance of producing complex three dimensional moulded components, which could be difficult or impossible to accomplish through traditional production processes. Additive processing in recent years has revolutionised the processing paradigm. Due to the high deposition speeds, which are substantially higher than powdered techniques, the wire and arc additive manufacturing (WAAM) is distinct among various additive manufacturing techniques that are suitable for producing large metal components. WAAM ’s efficiency is growing rapidly, and thus substantial study is ongoing. This research work will include an overview of the greatest advances in WAAM, outlining the innovations and variants in processes to monitor the microstructure, mechanical properties and defect production in the as-built components along with the most important technological materials used, and the variants of WAAM.

Key words: wire and arc additives, cold metal transfer, Active cooling technique, Shielding mechanism, aerospace.

1. Introduction
Additive processing is actually one of the main subjects in the field of technology and engineering. A significant driving force behind major breakthroughs is the potential to produce three, complicated and near-net-shaped parts in a layer-per-layer deposition process [1]. These achievements are observed either in the process itself, by designing process variants with particular objectives for the performance, but also on the materials used, as non-equilibrium solidifications occurring in the manufacture of fusion
additives may result in microstructural characteristics that are often not seen in the manufacturing processes of traditional materials [2]. Today, fusion-based additive fabrication methods are primarily concentrated on heat sources using laser or electron beam powder bed systems [3]. The deposition rate is low and lead times are increasing, despite high precision dimensional tolerances obtained with these techniques [4]. In addition, the use of powder as the supplementary materials makes the process more susceptible to defects like pores that can affect the structural integrity of the components, especially during dynamic conditions [5]. Fabrication of wire and arc additives (WAAM) uses the heat supply of an electric arc and a sturdy wiring as feedstock. Although the quality of the fabricated parts may not be greater than that attained with powder bed systems, the deposition rates are considerably higher such that large metal structural components can be manufactured in short periods [6]. WAAM is widely adopted by both academia and industry. Consequently, a variety of research papers discussed fundamental aspects of the process and its effects on the microstructure and mechanical properties of the products. In addition, some implementations also use WAAM-constructed components to demonstrate the feasibility of this technique [7]. This review will provide an overview of the major developments in WAAM which cover key topics such as process variants, WAAM materials, residual stress growth, thermal post-processing, and non-destructive testing [8]. The analysis concludes with existing implementations based on WAAM elements and includes an overview of areas where more study may be centred [9].

2. Wire Arc Additive Manufacturing

Fabrications of cord and arc additives (WAAM) facilitate the creation of near-net structure components layer by layer using arc solder and wire filler metal technologies as feedstock [10]. The research aims at evaluating the applicability for additive stainless steel parts manufacturing (AM) through two advanced robotic arc welding technologies (cold metal transfer (CMT) and Top TIG) [11]. Wire Arc Additive Manufacturing (WAAM), owing to its potential to reap the advantage of add-on-processing for the manufacture of large, medium-geometrical complex parts, has gained substantial interest in industry and the academia. WAAM uses wire and electric arc as the mechanism of the fusion to generate components in a layer by layer solution that can save substantial costs relative to powder or other forms of fusion like the laser and electron beam as represented in figure 1 [12]. Meanwhile, there is a high degree of deposition, which is the secret to the development of such materials, though major material advantages are often attained in contrast with traditional methods [13]. The manufacture of wire arc additives (WAAM) is a wired DED solution that uses an electric arc to melt the wiring feedstock and deposit one component, layer by layer. At WAAM, solidification possess a significant obstacle in material handling by fostering a large column grain microstructure [14]. This is useful for high-temperature creep resistance applications. The technology has discovered many benefits, such as increased BTF in comparison to traditional production methods, no dimensional limitations for the manufacture of parts and an inexpensive technology relative to powder-based methods in the case of expensive products [15,16].
3. Cold metal transfer based WAAM

The Cold Metal Transfer (CMT) wire and arc additive manufacturing system (CMAM) is a high-resolution build resolution development system with industrial robot operating system and 3D track simulation software that produces near-net form components layer by layer [17]. The Wire Arc flexible (WAAM) cold metal transfer based (CMT) manufacture is a cost efficient prototyping process that digitally uses arc as a heat source to fuse the wire for high-quality metal parts across a continuous overall surface. DingzhiPNT-3D route modelling software, data connexion lines, soldering power, cord feeding and running activator are the software and hardware of the WAAM device [18]. In order to replicate the molten pool over time by point-by-point control on line, surface and body, metal sections have mostly been rendered using the location, the movement, the speed and the direction of the actuator [19] repeatedly as represented in figure 2. A collection of WAAM systems was developed on the basis of the Cold Metal Process (CMM) and the CNC machine route conversion. The 3D model path has been developed with the aid of the system’s off-line 3D route simulation programme, which has the assistance of the high-precision and scalable FANUC robotics operating system to research the stability of the WAAM-CMT system with various models of aluminium alloy using WAAM [20]. CMT is distinguished by a high frequency alternation of forward wire and retraction. Advanced current dynamic wave shape produces a liquid droplet at the wire top, which with the aid of the mechanical wire retraction is unbundled at low pressure. The effect is a very low heat input, an incredibly stable electric arc, a spatter-free metal transmission and a solid solder [21]. When welding with CMT, welding, the arc length is detected and adjusted mechanically on its own.
4. Active cooling technique

In order to minimise heat accumulation and cope with limitations surrounding deposition duration, geometry problems and mechanical anisotropy properties, thermal control is a critical factor in wire arc additive manufacturing [22]. From the point of view of the process, the variable polarity Cold Metal Transfer technique, a derivative of a CMT Advanced Gas Metal Arc (GMA), is a prominent alternative, without lowering the rate of deposition, which decreases the heat transmitted in a deposition sheet as shown in figure 3. In the other side it is a promising method to extract heat from a part under construction for handling the component thermally with the use of a technique called Near Immersion Active Cooling (NIAC) at all deposition periods [23]. In order to carry out thermal management, Da Silva et al. develop and tested a technique called Near Immersion Active Cooling (NIAC) for heat flux control within the preform in order to prevent heat accumulation [24]. In this technique, deposition is allowed in a tank as the preform increases the volume of liquid (usually water) and the key regulatory parameter is the difference between the coolant liquid lamina and the present deposition rate, continuously separating [25]. Owing to the heat accumulation evasion, the inter-pass temperature remained low and almost constant when NIAC was used, and their results indicate a substantial decrease in the pre-form temperature during deposition [26]. This capacity makes for limited to no dwell times (improvement of productivity) and has a beneficial influence on the resulting geometrical and mechanical characteristics.
Figure 3. Active cooling technique of WAAM

5. Shielding mechanism of WAAM
Since large-scale metal modules with relatively high deposition rates are commercially feasible, substantial progress is being made in studying the method of wire additive arc manufacturing (WAAM), as well as the microstructure and mechanical properties of manufactured components [27]. For the assessment of WAAM, the method and its applications have been related to a wide variety of materials. The first concept uses a closed chamber for a strong inert gas shielding environment, comparable to laser Power-Bed Fusion systems [28]. The other configuration uses current or specifically developed local gas safety systems to improve the total work envelope by the robot mounted on a linear track. Multiple process parameters, such as soldering current, soldering voltage, feeding level, ambient temperature, gas flow rate shielding are correlated with deformation and residual pressure [29]. During the wire arc additive (WAAM) processing of titanium alloys, a shielded atmosphere is required to avoid oxidation. The introduction of local shielding will make the WAAM process more stable, but traditional devices provide insufficient protection through air conditioning [30]. The shielding of the gas is one of the most influencing factors, as the effect of depositing on the first layers without shielding gas, with decreased voltage and current affects bead geometry, the process stability, mode of transfer and bead appearance, in order to minimise grime penetration [31].

6. Materials
In general, WAAM can be fitted with any material that is usable as a welding cable. Stain, aluminium, titanium and nickel alloys are among the most common as shown in figure 4. Their strong incorporation into the aerospace industry leads to increasingly enhanced Titanium based and Nickel based alloys [32]. The desire to expand this method to integrate aerospace component mass manufacturing is then focused on the potential to manufacture large parts with a low buy-to-fly (BTF) ratio [33]. Subtractive methods are used in these materials, for their highly precise strength, heat and electrochemical compatibility with advanced composite materials. During manufacturing pieces, various heating and cooling processes take place in the deposited material and can result in different grain structures in their height [34]. The regulation of the grain structure is important because it decides the mechanical characteristics of the material [36]. The WAAM sections typically consist of large column grains shaped from an epitaxial growth substrate in the standard direction of build-in, with the highest temperature gradient, which reduces the need for nuclear sites [37]. In general, the WAAM component comprises large columnar grains. This form of growth contributes to anisotropic characteristics that may affect multiaxial load conditions. Equated grains are beneficial because they can reduce the vulnerability of cracks while increasing ductility, which contributes to (near) isotopically components [38,39]. Thus it is important to
use add-ons that can conduct thermal treatments and thermotherapies after WAAM. The use of inoculants to refine the grain structure is another method to control the microstructure [40].

7. Applications
In the development of many stiffened panel designs used in aerospace applications, WAAM has been identified as a promising alternative to conventional methods [41]. WAAM features allow the production of large components made from high value materials with medium complexity components [42]. This technology is also feasible for industrial applications such as aerospace, transportation, defence, moulds and dies, marine and nuclear energy. The aerospace and automotive sectors have increasingly used topologically designed structures, which minimise weight while retaining the functionality of the component to improve its performance [43]. WAAM provides the possibility to manufacture topologically designed components before they become very costly, high material loss and long lead times by traditional technologies [44]. Today, the aerospace industry relies on the manufacture, due to the complexity involved with the subtractive processes used in these products, of complicated titanium and nickel alloy components making the WAAM process for manufacturing cost-effective [45]. Titanium constitutes 93% of the structural weight of the Lockheed SR-71 Blackbird, and about 90% of the forging weight had to be withdrawn during development by machining [46]. Norsk Titanium supplied the first WAAM-approved titanium additively assembled part when mounted on the Boeing 787 Dreamliner by the federal aviation administration. Norsk Titanium processing decreased waste, use and commodity costs by up to 30 percent and time saving by 75 percent compared to forging after machining [47]. In the nuclear sector where sections with high heat and corrosion resistance are needed, non-based alloys and stainless steels are commonly used [48, 49]. WAAM is a good choice to substitute a few parts of the nickel elements that are less needed with stainless steel, thus providing for cost and weight reduction [50].

8. Conclusion
In manufacturing as well as automobile industry, the development of complex formed parts through Wire Arc Additive Manufacturing has become more convenient and simple. In order to optimise the microstructures and mechanical properties of the constructed components, several process variants have been recently developed. In addition, WAAM already has more important manufacturing alloys such as titanium, aluminium, nickel and stainless steels, with outstanding performance, which show the feasibility of the technology to manufacture custom-made large metallic components. In processing, WAAM would deliver minimized production costs and development time, with improved design flexibility as well as simpler and cheaper suppliers of replacement parts. Hence this technology would
be a great boon to manufacturing as well as automobile industries to develop enormous applications in our day to day life.

9. References

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