An Extensive Review on Wire arc Additive Manufacturing

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ABSTRACT

Wire arc additive manufacturing (WAAM) is a production process used to 3D print or repair metal parts. It belongs to the Direct Energy Disposition (DED) family of Additive Manufacturing process. WAAM is executed by depositing layers of metal on top of each other, untill a desired 3D shape is generated. The thickness of the layer deposited is typically around 1 to 2 mm. Generally, the materials included in manufacturing are Titanium, Steel, Copper, Bronze, aluminum alloys. Properties of materials are high thermal resistance, hardness, toughness and wear resistance. And it is applied in a range fields, from marine to aerospace, chemical industries, automotive, high technology and oil & gas industries. These common defects in WAAM can also found in welding such as porosity, cracks, lack of fusion, burn trough, discontinuity, slag inclusions and oxidation. This Review paper discusses about different materials, methods and parameters that effect the properties.

Keywords: WAAM, Metal 3D Printing, Materials, Defects

INTRODUCTION

1.1 An Introduction to WAAM Process

Wire arc additive manufacturing is a process of 3D printing of metals like titanium, & its alloys and aluminium & its alloys etc. Here the raw material is in the form of wire, it is melted using arc which is generated by the MIG or TIG welding This paper studies on the process of wire arc additive manufacturing (WAAM), using of different types of materials like aluminium, titanium, Ti6Al4V etc. Observation has done on the properties of products of different methods and have been noted that many defects are occurred during the process, some of the defects are pores in aluminium material-based products, improper bonding between layers due to time delaying in the dropping of new layer in the previous layer. Those defects are reduced by the applying of different methods like Cold Metal Transfer (CMT), Near-Immersion Active Cooling (NIAC), Hot Forging Wire and Arc Additive Manufacturing (HF-WAAM). The total setup of a wire arc additive manufacturing with required equipment is show in Fig.1.

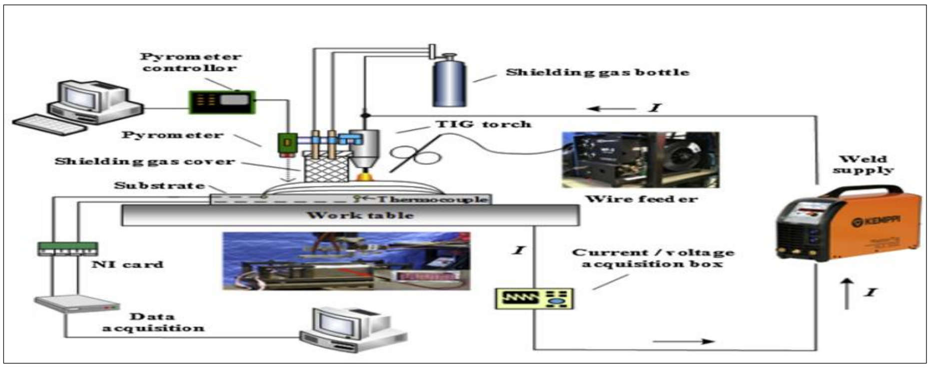

Fig.1: Total Setup of a Wire Arc Additive Manufacturing [25]

1.2 Literature Review

Jonathan Lawrence et.al. says, due to concerns over reduction of strength, elimination of porosity from wire arc additive manufactured aluminium is one of the major challenges. In line with this, the current investigation presents findings on hydrogen dissolution in solid aluminium and hydrogen consumed to form porosity [1]. Muralimohan Cheepu et.al. discussed that with no size restrictions, wire arc additive manufacturing (WAAM) offers a high deposition rate and high-quality products. For WAAM, the gas tungsten arc welding method is frequently employed Super-TIG welding is a kind of TIG welding process using C-Filler. The high deposition rate of WAAM can be obtained using Super-TIG welding to build large-scale components. The productivity of Super-TIG welding is higher than in conventional TIG welding [2]. Donghong Ding et.al. In the wire arc additive manufacturing (WAAM), active interpass cooling was introduced. components made of Ti6Al4V. The newly proposed technology contributes to higher microhardness and increased mechanical strength in contrast to normal WAAM treated material since it can create more fine-grained acicular and finer lamellae, delivering more grain boundaries and high-density within the microstructure, dislocations [3]. Leandro Joao da Silva et.al. discussed the potential of a thermal management technique, named as near-immersion active cooling (NIAC), to mitigate heat accumulation in Wire Arc Additive Manufacturing (WAAM). According to this technique concept, the preform is deposited inside a work tank that is filled with water, whose level rises while the metal layers are deposited [4]. Bintao Wu et.al. Due to the formation and growth of brittle intermetallic compounds brought on by complicated temperature profiles during solidification, realizing enhanced strength in composite metallic materials utilizing standard welding and joining methods continues to be difficult [5].

D.T. Sarathchandra et.al. proposed that the Investigations have been done into how different process variables affect the production of stainless steel 304 filler wire and mild steel substrate in wire arc additive manufacturing (WAAM). Cold Metal Transfer (CMT) was used to create the deposit. The best applications for single-pass beads are remanufacturing and repair. Improving the cladding quality for additive manufacturing on the geometry of the beads [6]. Valdemar R. Duarte et.al. proposed that immediately after deposition, the material is locally forged during WAAM, and in-situ visco-plastic deformation takes place at high temperatures. The previous solidification structure recrystallizes during the subsequent layer deposition, improving the microstructure. This variation was given the term hot forging wire and arc additive manufacturing (HF-WAAM) manufacturing (HF-WAAM) because of its resemblance to hot forging [7]. L. Vazquez et.al. Says, the process is particularly suited for metallic items with a high buy-to-fly ratio and allows for the fabrication of actual geometries by overlaying weld beads. Time and manufacturing costs are important factors that affect the business case. Therefore, techniques that reduce production time while maintaining quality standards must be developed. In order to shorten the process time and control mechanical characteristics and the resultant microstructure, cooling conditions are crucial [8]. A. Rajesh Kannan et.al. proposed that the engineered components in critical environments require properties that differ with location. Insufficient understanding of wire arc additive manufacturing (WAAM) process-microstructural features correlation limits FGM structural reliability. Gas metal arc welding (GMAW) based WAAM process was used for FGM with excellent bonding [9]. Mahya Ghaffari et.al. Says, the layer by layer deposits of materials are used in additive manufacturing (AM) to produce nearly net-shaped components. This process is essential for restoring and remanufacturing damaged materials, increasing their useful lives, and assuring metallurgical connection between the substrate and deposited layers. Due to its short life cycles from flaws, AISI420 martensitic stainless steel (MSS) is frequently used in plastic molds and dies. Costs associated with replacement can be avoided by repairing them to a usable state. A lack of research exists on the metallurgical connection of wrought MSS base plates and AM deposited layers, despite reports of additive manufacturing [10].

Tatiana Mishurova et.al. Discussed, using a hybrid strategy that combines WAAM and forging, manufacturing can be more effectively run. In this way, additional structural or functional characteristics can be added in any direction without requiring the use of extra tools for eachcomponent. By combining fundamental forging techniques with compared to fully forged or machined items, geometries with a single tool set and the addition of functional elements using WAAM can reduce tool costs and material waste. (High) residual stresses produced during the construction process are one of the elements influencing the structural integrity of items made using additive manufacturing [11]. Jun Xiong et.al. proposed that, there are still certain gaps inthe strategies for achieving precise geometry control and great process stability. It is difficult to significantly increase the geometry precision of parts by only performing the current layer detection due to a significant detection lag with vision-based sensors, despite the fact that the implementation of vision sensing and closed-loop control can help to promote the levels of process automation and stability. This paper suggests a novel approach to address this problem by incorporating prior layer information into the current deposition height to speed up the response time of the control system. A passive vision sensor keeps track of the layer heights in the preceding and current layers. The primary image processing techniques used to extract the height features are edge detection, threshold division, and line fitting [12]. A. N. M. Tanvir et.al.Says the material's microhardness and tensile strength after the same annealing process (980 °C, hold times 30 min, 60 min, and 120 min). The process of annealing was shown to increase the ultimate tensile strength by 5%. After two hours of heat treatment, the yield strength improves even if it is unaltered up to one hour of annealing. The tensile strength of Inconel 625 produced using additive manufacturing appears to be influenced by the presence of reinforcing components and the precipitation of secondary phases. On the other side, there is no discernible pattern for time-based heat treatment in the average microhardness[13].LinanXue et.al. Discussed the metallic component parts created by wire arc additive manufacturing (WAAM) typically have columnar grain patterns that exhibit anisotropy in the mechanical response as well as the microstructure. This work uses Ti-6.5Al-1Mo-1V-2Zr-0.1B wires to create a thin-walled sample utilizing the WAAM technique, where 0.1 wt% B element is introduced to the near-titanium alloy [14]. G. Ravi et.al. proposeda promising, dependable free-form fabrication method for generating big components with a very low buy-to-fly ratio is wire arc additive manufacturing. This study uses a robotic metal inert gas welding technique to create a rectangular prototype Inconel-625 alloy slab. We looked at the microstructure and mechanical characteristics of solution-annealed (SA) and as-deposited alloys. The as-deposited alloy was discovered to have a columnar dendritic structure, and the gamma-nickel matrix contained intermetallic phases such the Laves phase, NbC, and carbides [15].

Bintao Wu et.al. Says, to reduce part distortion in the wire arc additively made Ti6Al4V process, active interpass cooling with compressed CO2 was creatively used. To investigate the impacts of active interpass cooling on the thermal behaviours, geometric characteristics, and distortion levels of deposit, a comparison between simulation and experimental data was conducted. As a result of enhancing heat dissipation and decreasing heat accumulation within the deposition, the results demonstrate that active interpass cooling with CO_2 gas is a useful technique for lowering wire arc additive manufacturing (WAAM)-part distortion [16]. Gianrocco Marinelli et.al. Says, due to the ability to provide several complementary material qualities within the same structure, functionally graded components are typically favoured for harsh and essential service conditions. A developing technology called wire + arc additive manufacturing is particularly suited to the creation of reliable graded structures. Molybdenum to tungsten and tantalum to molybdenum functional gradients were successfully placed as an integrated structure [17]. Chen Zhang et.al. Topologically optimized aluminium alloy structures are increasingly being used in modern aeronautical structures due to their lightweight requirements. The best manufacturing method for the structures is additive manufacturing (AM). According to Derekar (2018), wire arc additive manufacturing (WAAM) of large and complicated components has significant cost and efficiency benefits. In order to produce finer microstructures, low porosity, and high strength for the WAAM aluminium alloy, repeated heat cycle effects and surface oxide remelting must be considered. New strategies are required to enhance WAAM aluminium alloys [18]. Yuri Yehorov et.al. Proposed a method for evaluating the possibility for production cost reduction in wire arc additive manufacturing (WAAM) based on the combination of wire feed speed and travel speed. An Al-Mg alloy multilayer-non-oscillated single pass wall was used in a number of tests. The top layer undulation and lateral surface waviness were used to evaluate the wall's quality. We introduced the ideas of Surface Waviness and Buy-to-Apply indexes. For a specific wire feed speed (WFS), which corresponds to a constant current, the range of travel speed (TS) that produced layers of acceptable quality was initially identified [19].ChuanchuSuet.al.Says,by layering metal alloys, additive manufacturing (AM) makes it possible to produce intricately formed metal components. For large-scale metallic components, WAAM is a well-liked method that uses an arc as a heat source. great material utilization rates, cheap production and equipment costs, great equipment adaptability, and scalability are only a few of its benefits. The outstanding internal stability and mechanical capabilities of WAAM products meet the demands of industrial enterprises and attract attention [20].

A. N. M. Tanvir et.al. proposed that using a layer-by-layer stacking mechanism, this WAAM technique uses arc welding to melt a wire into a three-dimensional (3D) object. In the current work, Inconel 625, a Ni-based superalloy wire, is melted and coated additively using a wire arc additive manufacturing (WAAM)technique based on cold metal transfer (CMT) [21]. YuriiYehorov et.al. In order to prevent unidirectional grain development in wire arc additive manufacturing (WAAM), a novel approach that involves cycling the torch back and forth, similar to the switchback welding technique, is proposed and tested. A series of tests using the CMT (cold metal transfer) technology were planned to look at three wall-like build-ups that use different deposition patterns, including in one-way direction, reverse direction, and switchback [22].Qingfeng Yang et.al. By reducing production procedures and preventing material waste, wire arc additive manufacturing can satisfy the development goal of energy conservation and high efficiency. Additionally, it theoretically permits quick prototyping of any complex shape [23]. Chengde Li et.al. The process known as wire arc additive manufacturing (WAAM), which is appropriate for big, medium, and complex items, melts metal wires and constructs solid objects layer by layer. It offers quick processing cycles, high stacking body density, and good forming efficiency. For the aluminium alloy WAAM, the cold metal transfer (CMT) procedure has drawn attention [24]. Bintao Wu et.al. Says This study created thin-walled Ti6Al4V structures using wire arc additive manufacturing (WAAM), and then used laser profilometry, optical microscopy, SEM, hardness testing, and mechanical tensile testing to analyze interpass temperatures, surface oxidation, microstructural evolution, and mechanical properties [25].

Zengxi Pan et.al. Says due to their mechanical qualities, biocompatibility, and corrosion resistance, titanium and its alloys are being used in more and more applications. The most widely used alloy is Ti-6Al-4V, however typical fabrication techniques are expensive, which restricts their use in commercial applications [26]. Malcolm Dinovitzer et.al. The Hastelloy X alloy welding wire and 304 stainless steel plate used in the study were used to assess the effects of process parameters on TIG-based WAAM specimens. We calculated the travel speed, wire feed rate, current, and argon flow rate using the Taguchi method and ANOVA. The biggest influences were travel speed and current, with increasing speed resulting in less melt through depth and roughness [27]. Gianni Campatelli et.al. Due to its flexibility and process capabilities, additive manufacturing (AM) has been gaining market share in the creation of metal parts. AM seems to be especially well suited for small batches, such as prototypes or highly personalized parts (such as prostheses used in surgical implants). In this regard, wire arc additive manufacturing (WAAM) is a method that enables the layer-by-layer manufacture of three-dimensional components [28]. Chen Zhang et.al. Says Al-6Mg alloy parts were additively manufactured using a cold metal transfer (VP-CMT) arc power source with multiple arc modes. Using scanning electron microscopy and electron backscattered diffraction, the microstructures were studied. Even equiaxed grains with variable orientation of 20.6-28.5 m in size were produced using the VP-CMT mode, despite the presence of much larger columnar grains in samples produced using other arc modes [29]. Yong Xie et.al. Discussed, the contemporary titanium industry has expressed worry over additive manufacturing because it offers a different way to produce complex components that are close to net shapes. Due to its rapid deposition rate, minimal equipment investment, and low operational cost, wire arc additive manufacturing (WAAM) has the most promise for producing large-scale Ti alloy products [30].

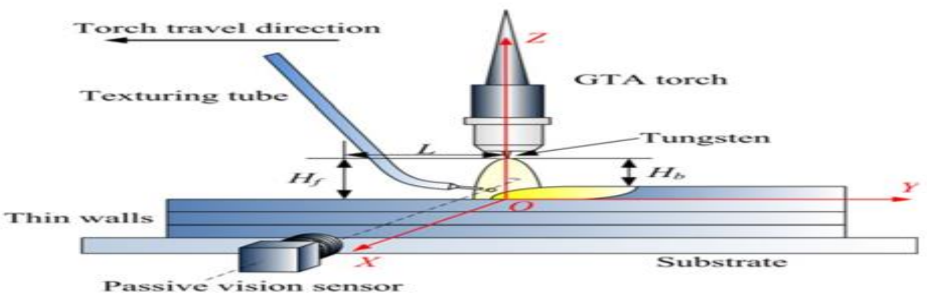

Fig: - 2 Schematic diagram of wire arc additive manufacturing process with passive vision sensor

CONCLUSION

In conclusion, the extensive review on wire arc additive manufacturing (WAAM) has shed light on the significant advancements and potential of this additive manufacturing technique. Throughout the analysis, it became evident that WAAM offers numerous advantages, including cost-effectiveness, high deposition rates, and the ability to work with a wide range of materials. Its application in various industries, such as aerospace, automotive, and maritime, demonstrates its growing importance and versatility.

The review also identified several challenges and limitations that must be addressed to fully unleash WAAM's potential. Issues like porosity, residual stresses, and surface roughness require further research and development to enhance the overall quality of the fabricated parts. Additionally, process optimization and control mechanisms are essential for ensuring repeatability and consistency in production.

Despite these challenges, the potential of WAAM to revolutionize manufacturing processes is undeniable. With continuous innovation and research, it holds the promise of transforming the way we design, fabricate, and utilize complex metal structures. As this technology continues to mature, it is likely to find even broader applications and contribute significantly to the advancement of additive manufacturing as a whole. This extensive review underscores the importance of continued investment in research and development to overcome the current limitations and unlock the full capabilities of wire arc additive manufacturing. With its impressive array of benefits and a vast array of potential applications, WAAM stands poised to revolutionize the manufacturing landscape in the coming years.

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