A Literature Review on Wire Arc Additive Manufacturing

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Abstract-Additive Manufacturing (AM) has shown a way to the scientific and industrial community for the direct formation of products and has also replaced the traditional approaches in some industrial contexts by minimizing the material consumption. Out of various AM processes, Wire arc additive manufacturing (WAAM) has acquired more recognition on account of peerless efficiency and benefits that mainly comprises high deposition rates, increased material efficiency, lesser lead time, better component performance and reduced inventory costs. WAAM is similar to welding, as it includes layer by layer deposition for large parts with fewer complexities. Significant research has been done in this area in order to widen its applications, especially to reap benefits attributable to high buy-to-fly ratio parts of aviation industry. This article reviews to bridge knowledge gap concerning the assessment of 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 strenuous variables in-between. In future, WAAM adoption will accelerate, as it opens the possibilities to produce heavy metal parts, providing industries the alternative which is fast and cost-effective.

INTRODUCTION

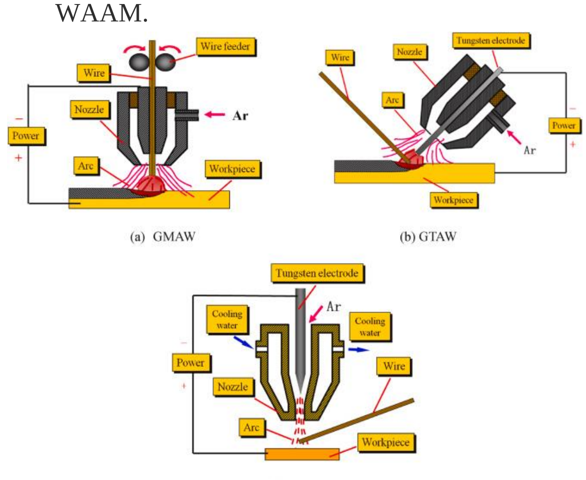
Wire Arc Additive Manufacturing (WAAM) is a production process used to 3D print or repair metal parts. It belongs to the Direct Energy Deposition (DED) family of Additive Manufacturing processes. WAAM is executed by depositing layers of metal on top of each other, until a desired 3d shape is created. It is a combination of two production processes: Welding process used for joining metal parts using an electric arc, and additive manufacturing is the industrial term for 3D printing. The production of parts using WAAM is carried out by a welding robot integrated with a power source. A welding torch attached to the robot is used to melt the wire feed stock to build 3D parts.

WAAM Hardware System:
A typical WAAM system includes,

- Computer control unit
- Arc welding machine
- Wire feeder
- A robot or a CNC system
- Welding torch
- Substrate
- Sensor unit

WAAM hardware system is mainly composed of an arc welding machine, the arc welding machine provides heat source for heating and melting the wire, and the common arc welding technologies such as

- Gas Tungsten Arc Welding(GTAW)
- Gas Metal Arc Welding (GMAW)
- Cold Metal Transfer (CMT)
- Plasma Arc Welding (PAW) can all be used in WAAM.



GTAW produces high quality welds using an open arc between a non-consumable tungsten electrode and workpiece. It is also referred to as TIG (Tungsten Inert Gas) welding. There is no slag or spatter, and it requires little post-weld cleaning. It is easily used in all welding positions and has been extensively used in the aerospace, aircraft, power generation, petroleum, and chemical industries.

As an evolutionary development, **PAW** is similar to the GTAW. The difference is that the arc is squeezed through a nozzle in PAW. As a result, the PAW arc is more focused than a GTAW arc. It improves arc stability, increases heat transfer efficiency, and promotes welding speeds. Most of refractory industrial metals, such as nickel and nickel alloys, titanium and titanium alloys, and stainless steels, can be welded with PAW.

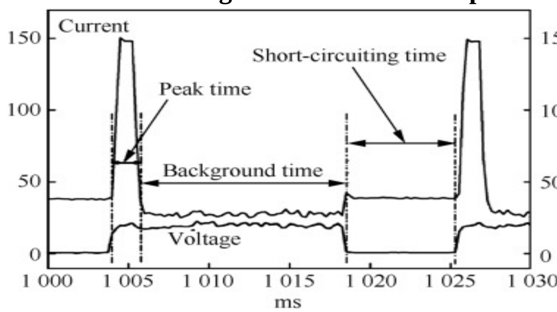
GMAW, which is also referred to as MIG (Metal Inert Gas), forms an arc between a continuous filler metal electrode and work-piece. It incorporates an automatic feeding system to transport the consumable metal wire which is normally perpendicular to the substrate. It has high melting efficiency and deposition rate, and is appropriate to weld all commercially important metals, such as copper, aluminum, and stainless steel.

CMT, which is a modified GMAW based on short-circuiting transfer process developed by Fronius of Austria, can provide extremely low heat input and exceptionally high arc stability by incorporating an innovative wire feed system coupled with high-speed digital control. Therefore, it attracts significant attention on the application of AM in recent years.

The stability of the welding process and heat dissipation are crucial factors when manufacturing components using WAAM. The welding process must apply as little energy as possible, so that the lower layers do not begin to melt again. The welded layers must also be consistent, spatter-free, and even. If any flaws were to occur, these would be replicated in each subsequent layer. The **Cold Metal Transfer (CMT)**, meets all of these requirements.

Two process control variants of CMT are particularly well suited to WAAM. The first of these is the CMT additive process characteristic, which has been optimized for WAAM. It achieves good deposition rates and only transfers a low level of heat to the component. The CMT Cycle Step variant reduces the arc power even further using targeted deactivation during the process phase. However, more time is needed to build up the individual layers as the deposition rate is lower.

Current and Voltage waveform of CMT process

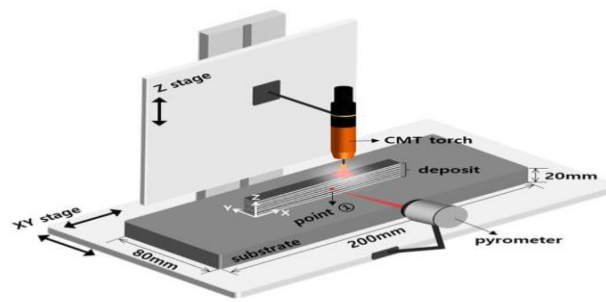


- **The peak current phase:** this is often a continuing arc voltage adore a high pulse of current causing the ignition of the welding arc simply and so heats the wire electrode to make drop.

- **The background current section:** The phase corresponds to a lower current. the current is minimized to stop the globular transfer of the tiny liquid droplet shaped on the wire tip. This section continues till short circuiting happens.

- **The short-circuiting section:** during this phase, the arc voltage is dropped at zero. At identical time, the return signal is provided to the wire feeder which supplies the wire a back-drawing force. This section assists within the liquid fracture and transfer of material into the welding pool.

CMT SETUP :



Above figure show the instrumental setup for CMT torch must have the capacity or the X and Y axis stage can be moved according to the program or machine setup so both the wire arc additive manufacturing can be possible in this method.

Advantage of CMT for WAAM

• High quality weldments with low porosity and surface defects

• Spatter free surface and less chance of thermal deformation.

• Synergic helps in maintaining arc stability and changes operation according to the filler wire.

• Cost friendly compared with powder based additive manufacturing. During multilayer deposition overflow of weld molten pool can avoided due to its optimized metal transfer which avoid collation during wall formation.

LITERATURE REVIEW

1. Silva et al: Compared CMT and CMT Pulsed mode by depositing 8 multilayers of ER309LSi and analysis the temperature cooling technique for depositing thick and strong tools for heavy applications. Taguchi method was used for DOE, for both methods welding parameter like wire feed rate, torch travel speed, current, voltage and shielding gas flow are optimally selected and Interval time for depositing minimum thickness wall is 9mins and for Maximum thickness is 42mins and the weaving frequency is 1Hz common for both process, Result of the study reveals both CMT and CMT Pulsed produces same high temperature zone and shows the CMT process is energy saving and has 60% smaller for high temperature zone.[4]

2. Gu et al., discussed about the CMT unique specification like low thermal heat input which can produce spatter free an excellent quality weld, metal transfer mode like Dip transfer in CMT pulsed and spray dip transfer in CMT pulsed advanced. ER2319 is deposited in both CMT pulsed and CMT PADV the result show that CMT PADV has more efficient deposition and also eliminate porosity and also has prefect strength and excellent plastic elongation and also suggest interlayer cold rolling can produce a prefect layer and post heat treatment can improve aluminum in WAAM.[5]

3. Shaohua Han et al., The authors investigated the combination of ER408S an alloys wire and MF6–55GP hard facing material which is deposit first four layers are deposit by ER408S and 5-8 layers are deposited by MF6-55GP which is an hard facing material both are deposit in WAAM and their microstructure and mechanical properties are investigated to find out the wear resistant compounded created by using CMT, The result shows positive approach for creating an wear resistant materials can be produced, and also residual stress and defect in surface are present more innovations are need to improve the quality. UTS test shows fractures are occurred in MF6-55GP and also have a high hardness value of 800HV.[6]

4. Muller et al. [14] compared gas metal arc weld (GMAW), cold metal transfer (CMT), and cold metal transfer-pulse (CMT-P) processes and proposed a mechanical test approach in which the WAAM built bar was TIG fillet welded between two cylindrical tensile test specimens. This was done to avoid the sample bar banding when it was fixed in the tensile testing equipment. Applying the GMAW method, the highest build up rate and the thickest bar diameter have been achieved. CMT-P yielded favorable results for surface topography, as well as the highest hardness levels, with minimal spatter ignition and lower heat input.

5. Seung Hwan Lee et al., used Gaussian process regression (GPR) for WAAM optimization method for improve the quality and productivity of the deposited © June 2021| IJIRT | Volume 8 Issue 1 | ISSN: 2349-6002 IJIRT 151767 INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN TECHNOLOGY 717 shape the following parameters like wire feed and travel speed are finalized for depositing STS316L and deposition angle with set to be at 90˚ and the result shows that the GPR method can be used for finding the optimal parameters for depositing WAAM depending upon the welder experience and by this method it can improve the performance of WAAM involving diverse materials and shapes.[10]

6. Rodrigues et al., in this paper review the current status and improvement in WAAM and Highlighting procedure tendencies and editions to govern the microstructure, mechanical residences, and disorder era within side the as-constructed parts; the maximum applicable engineering substances used; the primary deposition techniques followed to reduce residual stresses and the impact of post-processing warmness remedies to enhance the mechanical residences of the parts. A critical factor that also hinders this era is certification and nondestructive checking out of the parts, and that is discussed. Finally, a standard angle of destiny improvements is presented.[11]

7. Zhong et al., Investigated unique AA2050 wire is used within side the additive production of thin straight wall deposits. Excellent formability is completed via way of means of adjusting the warmth enter the use of a VP-GTAW process. AA2050 Al–Li alloy WAAM components and tested the microstructure and mechanical properties.[13]

8. Li et al. [55] reported a growth of the secondary dendrite arm spacing and of the Fe-phase when the heat input, generated by the WAAM with CMT process for Al-7Si-0.6Mg, increased. The increase of the heat input, with corresponding decrease in welding speed, has determined an increase of thickness and layer height, as well as an increase of the size of primary alpha-Al grain size and eutectic Al-Si grains. As regards the mechanical properties, such as UTS, YS, and elongation, it was pointed out that the heat input has a crucial role in modifying them.

9. Chuanchu Su., Experimented torch angle and observed weld molten pool by using high speed camera. The author states the depositing in different angle produces different bead and defects at the angle 10˚ to 20˚ bead quality is good and with less porosity.[14]

10. Thapliyal: The author mentioned the impact of technique parameters at the soundness of constructed and it in addition offers perception into the problems encountered all through the technique and the future attitude of the WAAM constructed aluminum alloys.[15]

11. Rodrigues et al., investigated the high strength low alloys in WAAM which can be suitable in industries and power plant and also experimented the heat input factor which affects the cooling rate interlayer pass and resistance time measured using infrared camera and SEM is reveals the microstructure and electron backscatter.[16]

12. Chakaravarthy et al., studied torch angle influence in orientation of wall formation and topology in multilayer wall formation and also investigated the surface waviness of the SS316L wire by using the cold metal transfer.[18]

13. Jafari et al., they reviewed the recent development, process planning design and guiding design like patterns with pattern can be used for direct deposition according to the structure which can properly utilized and post treatment guiding, and geometric planning cold rolling methods used to maintain uniform shape and also discussed future needs to improve in WAAM.[8]

14. Chandrasekaran et al. [16] investigated the suitability of functionally graded material (FGM) fabricated as the optimal material for marine risers using the CMT technique of WAAM. The materials used in the experiment were ER2209 with ER70S-6 C-Mn steel. The tests conducted on the FGM part confirmed higher strength determined by the martensitic formation at the interface and negligible porosity. Due to the chromium content of 20–22% present at the interface, the corrosion rate has been improved by 12 times for duplex SS as compared to C-Mn steel.

15. Abdullah Wagiman et al., Author explored the CMT produces a spatter and porosity on the cross section of weld bead they analysised that bead geometric show high heat input makes the bead width larger and smaller bead width on lower heat input. They stated that rapid cooling makes finer grains and slow cooling cause coarse grains.[17]

CONCLUSION

Based on a large number of recent articles published in the wire arc additive manufacturing field, this review article provides an overall view of the progress made and information useful to researchers worldwide interested in obtaining new findings. To enhance the acceptability and the applicability of the WAAM process for a wide variety of custom-made large size metallic builds performed from materials such as Ti-6Al-4V alloy, Inconel, Chromium, having properties close to the wrought or cast parts, more experimental research to improve the knowledge is needed. Besides, exploring the possible applicability of the WAAM process for repairing large metallic structures would be advantageous in terms of maintenance and service costs.

The advantages of CMT-WAAM have piqued the interest of many industrial experts and researchers for further developments in this technique; thus, the recent advances performed in this sector have been summarized in the last section of this manuscript. This article suggests that CMT-WAAM can be a viable alternative for high-quality manufacturing and offers a vision for the future of this technology.

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