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Optimization of wire feed for GTAW based additive manufacturing

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ABSTRACT

The problem of deposition accuracy is encountered during gas tungsten arc welding (GTAW) based additive manufacturing when wire is fed in side direction. A mathematical model was developed to calculate the wire flying distance in arc zone, according to which displacement compensation was designed to ensure the size accuracy. When arc length was 5 mm and vertical distance of wire tip to tungsten electrode was larger than 3 mm, the horizontal distance between melting wire tip and axis of tungsten electrode was 3.5 mm. The displacement compensation was verified to be effective by forming cross-angle. The model can also be used to achieve bridging transfer, which is beneficial for smooth layer appearance.

1. Introduction

Compared with laser and electron beam additive manufacturing, wire and arc additive manufacturing (WAAM) has unique superiorities in shape deposition efficiency and product cost. Baufeld et al. (2011) thought that it is suitable for near net shape forming large sized components. The low investment cost of equipment and the popularization of arc welding make WAAM the most promising techniques in industrial application. The separate processes of energy input and materials input during gas tungsten arc welding (GTAW) are beneficial for smooth layer appearance, especially for aluminium and its alloys. Wang and Kovacevic (2001) indicated that cleaning action of the cathode plays a crucial role during GTAW based additive manufacturing aluminium alloy, which helps to remove the oxide formed on layer surface. Such phenomenon allows the molten metal to wet the substrate smoothly and helps to maintain the stable arc on the molten pool surface by providing ionized Al vapor as arc medium.

For aluminium and its alloy, cleaning action of the cathode is necessary, but that has more significant influence on materials input and arc stability during gas metal arc welding (GMAW) or cold metal transfer (CMT) based additive manufacturing. Discontinuous materials input and arc blow are furtherly exacerbated by thermal pinch effect of aluminium alloy. These go against forming smooth layer appearance. GTAW based WAAM is more suitable for additive manufacturing aluminium and its alloy. To obtain uniform layer size and appearance, heat input should be regulated during layer upon layer deposition because of the heat accumulation effect. During GTAW based WAAM process, heat input adjustment does not change arc length and the deposition rate can be controlled independently by adjusting wire feed speed, which mean that the two separate processes of energy input and materials input make WAAM control easier by comparing with GMAW or CMT based additive manufacturing. However, GTAW based WAAM usually suffers deposition accuracy problem at the start position, where the as-deposited weld bead would shift a little from the preset position causing by wire feed in side direction. Such wire feed manner tends to produce gap defect in cross- or T-type structure and lead to deposition failure. So far this problem has not drawn any researchers' attention, but in WAAM process, it is quite important to ensure the final structure accuracy.

Gap defects occurred in a deposited structure are shown in Fig. 1, where a bridge was deposited to connect two cylinders. The gap appeared at the arc striking position, which implies layer start position shift. Furthermore, such defect cannot be corrected by the succeeding layer deposition.

Wire feed manner design could be one of the methods to eliminate the defect. However, it is usually kept unchanged (i.e., side feeding with fixed angle and height) during process parameters optimization. The nature of WAAM is shaping process with short-range free flow in molten pool, continuity and stability of material input will contribute to achieve smooth and flat layer appearance, which is a constrain to wire feed adjusting. If wire feed manner is varied to eliminate the gap defect, the deposition process may

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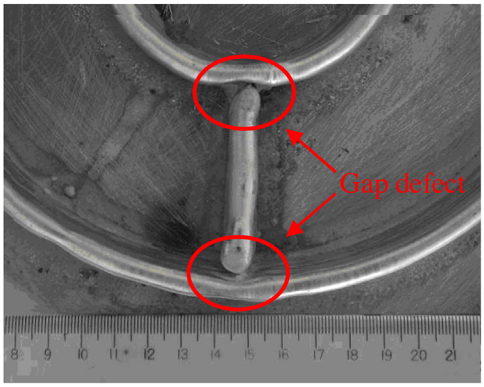

Fig. 1. Gap defects resulted by start position shift when depositing "T type" structure.

become unstable and result in surface appearance defects, such as humping and gouging.

So wire feed manner can not be set arbitrarily because it has relation with layer appearance in manner of materials input. That is, surface quality is the premise of layer size accuracy control. The surface quality is determined by the matched heat input and materials input. Ouyang et al. (2002) fabricated 5356 aluminium alloy cylindrical parts with perfectly acceptable surface quality using GTAW method. A machine vision sensor was used to monitor and control the arc length, and the height of deposited layer is regulated by optimizing travel speed in order to match heat input to preset wire feed manner. Wire feed manner is denied to be varied, or the regulation should be recalibrated.

In the situation without feedback control, the matched heat input to materials input can be obtained by process optimization on the premise of stable materials input in manner of bridging transfer. By using this method, Wang et al. (2013) deposited two Ti-6Al–4V straight walls with 6.8 mm thick using GTAW based WAAM. As expected, the wall surface showed uniform fluctuation resulted by layer by layer deposition. However, the accuracy of start position was not mentioned. Baufeld et al. (2009) deposited cylindrical and rectangular parts, in which the weld gun travelled along closed path and did not encounter the layer size accuracy problem. They made efforts on process optimizations to ensure consistent layer appearance, in which the wire feed manner was kept unchanged. If only to obtain smooth and consistent layer appearance, the above mentioned process optimization is workable. However, it can not be achieved when considering both stable layer formation and structure accuracy. Thus, it is reasonable to set wire feed manner as a variable during process optimization, i.e., this problem would be readily solved by consider both the start position shifting and stable forming process (For wire feed, it means stable materials input).

GTAW based additive manufacturing of aluminium alloy is conducted, which focuses on layer size accuracy and droplet transfer behavior from the view point of wire feed manner regulation. To avoid start position shift happening and ensure smooth layer appearance, wire feed manner is set as control variable during process optimization. A mathematical model is developed to calculate the wire flying distance in arc zone, according which displacement compensation at the arc striking position could be set. Besides, threshold condition of bridging transfer is also developed from this model.

2. Experimental procedures

A GTAW welding machine (EWM, Tetrix 521 Synergic AC/DC) with wire feeder was used for the experiment. Fig. 2 shows the wire feeding unit and the related parameters about wire feed manner.

Fig. 2b defines the height of wire rotation axis to substrate, *h*, of which the increment Δh denotes the wire vertical adjusting tolerance and θ the wire feed angle. Both h and θ will be cooperated to determine droplet transfer mode: bridging or globular transfer.

A computer numerical control (CNC) machine tool with four axes was used as manipulator, where welding torch was installed on the moving arm in downward position. Arcing and wire feeding are started simultaneously by integrating arc striking, extinguishing and wire feeding commands into CNC program. The experiment was conducted using a Φ1.2 mm 5A06 aluminium alloy wire, which was deposited on the substrate with dimension of 300 × 200 × 15 mm. The wire feed direction is always in front of the welding arc. A water-cooling backing plate was used to extract heat from the substrate. The deposition direction was unaltered and all started at the same position to facilitate comparing the shift of weld bead start position. Argon (99.99%) was used as shielding gas. Rectangular pulse AC power mode was adopted with peak and background current set as 160 A and 100 A respectively, and the pulse frequency was set as 50 Hz. The other related welding power supply parameters are listed in Table 1. In addition, diameter of tungsten electrode used in all experiments was Φ3.2 mm, wire feed speed was 2 m/min, and the travel speed was 300 mm/min. The droplet transfer is observed using high speed video camera (Phantom V310). Frame number of high-speed camera is 4000 fps.

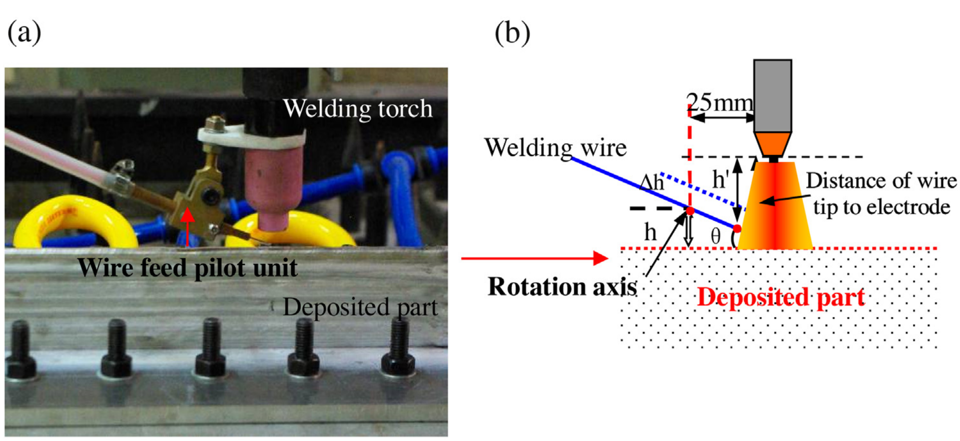

Fig. 2. Wire feed unit showing (a) site photo and (b) schematic illustration of the parameters.