Influence of Thermal Limiters on the Formation of the Dendritic Structure of the Welded Stainless Steel Layer

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Abstract. In the work the influence of thermal limiters on the formation of a dendritic structure of the stainless steel AISI 304L layer deposited by electric arc welding in argon medium was investigated. The structure of the billets was investigated in the mode of differential interference contrast. The analysis of the obtained structures showed that the use of thermal limiters in the form of graphite skids allows to obtain a uniform structure in billets without sharp transitions between the deposited layers.

1. Introduction

One of the most promising directions for the manufacturing of metal products with complex shape is additive manufacturing. The product is formed by layer-by-layer metal surfacing in accordance with the three-dimensional model created in the computer design programs [1]. Metal powders [2-4] or wire [5-10] are used for surfacing. The heating source is the electronic beam [2,3], laser beam [3,4] or electric arc [5–10]. The technology of additive manufacturing of products by electric arc surfacing using a melting electrode in the protective gases blanket is one of the least costly and most productive technologies for depositing products [10].

Manufacturing of products from various metal powders by their surfacing by electronic or laser beam allows to get a product with high accuracy of size tolerance [11]. However, such technologies have a number of disadvantages, among which low product manufacturing rate [12]. Also, when working with metal powders, a large risk of obtaining defects in the form of pores arise, which reduces the operational properties of the product [13].

The technology of layer-by-layer surfacing products of electric arc welding in an inert gas blanket using welding wire allows to get a more homogeneous and high-quality filtered layer [14]. The accuracy of finished products obtained by this method is lower than when using an electron welding or laser beam welding of metal powders, but the rate of precipitation of the material is significantly higher. This allows to receive details of large sizes in a short time. In this regard, this method is widely popular in various industries [15].

The choice of welding wire material with layer-by-layer surfacing of electric arc welding is essential, stainless steel occupies a special position [16]. Stainless steel is widely used for the production of details in the chemical and energy industries, aircraft industry, and rocket production.

The purpose of this work is to investigate the influence of thermal limiters on the formation of a dendritic structure of products obtained by a multilayer surfacing welding stainless steel wire AISI 304L in argon.
2. Methods

In fig. 1 shows a three-dimensional model of a billet obtained by multilayer electric arc welding of AISI 304L stainless wire in an argon environment with the use of thermal limiters in the form of graphite skids.

![Three-dimensional model of the billet](image)

Figure 1. Three-dimensional model of the billet obtained by layer-by-layer arc surfacing: 1 - steel substrate made of stainless steel, 2 - forming graphite skids (thermal limiters), 3 - billet

AISI 304L brand stainless steel welding wire was used for layer-by-layer surfacing of billet. This brand of welding wire has a reduced carbon content and is intended for welding products that operate in a wide range of temperatures from -196 to 350 °C. Analogues of this brand of welding wire are brands of wires from corrosion-resistant chromonichel steels: 03Cr18Ni11, 08Cr18Ni10Ti. Table 1 shows the chemical composition of the using welding wire.

| C   | Mn    | Si    | Cr    | Ni    | P      | S      |
|-----|-------|-------|-------|-------|--------|--------|
| max 0.03 | 1.40-2.10 | 0.65-1.00 | 19.5-21.0 | 9.00-11.00 | max 0.030 | max 0.020 |

The billets were obtained by multi-layer electric arc welding with a melting electrode AISI 304L with a diameter of 0.8 mm in argon blanket, the welding current of the \( I_w = 100 \text{A} \), the tension of the arc \( U = 20 \text{V} \), the polarity reverse. In fig. 2 shows images of transverse cuts of billets.

![Transverse cuts of billets](image)

Figure 2. Transverse cuts of billets obtained by layer-by-layer electric arc surfacing: a - without limiters, b - with the use of forming graphite skids.

Figure 2 shows that the use of forming graphite skids allows to get a ready-made billet with higher accuracy geometry, i.e., the outer surface of the resulting billets is smoother and will require less finishing costs.
3. Results and discussion

In fig. 3 shows the images of dendritic structures of fusion zones in transverse sections investigated billets. From fig. 3 (a, b) it can be seen that when welding without the use of thermal limiters, there are sharp transitions between the fusion zones caused by the increased heat sink from the weld sample. When using forming graphite skids (Fig. 3 b, d), due to the restriction of heat removal from the side walls of the billet and the redistribution of heat along the billet, a uniform transition between the deposited layers is observed. Also, when using graphite skids, there are no pores in all layers of the deposited billet. The absence of a similar type of defects suggests that the billets grown using graphite skids will have higher values of physicomechanical properties compared with samples grown without the use of thermal limiters.

Figure 3. Optical images of the structures of the billets obtained in the mode of differential interference contrast: a - the transition between stainless steel substrate and the first deposited layer, without limiters; b - the transition between the stainless steel substrate and the first deposited layer, with the use of thermal limiters; c - the transition between the 1st and 2nd deposited layers, without limiters; d - the transition between the 1st and 2nd layers, with the use of thermal limiters.

In fig. 4 it can be seen that when using forming graphite skids, a multiple increase in the size of dendrites in the obtained samples is observed. When using graphite runners, the width of the dendrites can increase by 5 times compared to samples made without using graphite runners.
Without the use of graphite skids

Using graphite skids

| Transverse section | Longitudinal section |
|-------------------|----------------------|
| ![Transverse section](image1) | ![Longitudinal section](image2) |

Figure 4. Dendritic structures of the transverse sections of the 2nd layer of the samples obtained by the method of layer-by-layer surfacing under various technological modes

**Conclusion**

Thus, the use of thermal limiters in the form of graphite forming skids in the manufacture of deposited billets by electric arc welding in the protective environment of argon allows to obtain a finished product with a homogeneous structure and sufficiently high surface quality. It is necessary to carry out follow up studies on the investigation of heat distribution in a deposited billet using thermal limiters and influences on the mechanical properties of the obtained billets.

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