Electron beam welding features of cermet membranes

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Abstract. Electron-beam welding features of metal-ceramic elements of membrane type are considered in this paper. Influences of welding speed and angle of entry of electron beam (in the lower position) on the formation of metal-ceramic membranes weld joints are shown. The macro and microstructure researches of weld joints were carried out. Electron beam welding mode parameters providing the high quality of the weld joint are determined. An appropriate weld joint is established to be formed at high welding speed and small angles of beam entry, herewith the welding on the descent promotes better removal of slag phase from weld metal.

1. Introduction

At present, using of metal-ceramic filter elements of membrane type is widespread in many industries: nuclear, chemical, medical, etc. [1] due to high requirements for level of ecological compatibility and economy of production.

Membrane type filter demonstrates high degree of cleaning. Also, numerous tests have shown that experimental samples of membranes can withstand not only work at high pressures up to 30 MPa and temperatures up to 600°C, but also at large working pressure fall (up to 1.9 MPa) [2-5]. But as practice shows, such filters have short service life. The reason for this is the fragility of glue seam that bonds filter elements to each other.

In this regard, to improve operation properties of the product, it is proposed to give up glue seams in favor of fusion welding. However, the thickness of welded elements does not allow to use commonly used welding methods, so it is advisable to use concentrated energy flows (in particular an electron beam), as a source of heat.

The purpose of this work is to develop a method of electron beam welding of membrane filter elements, which provides an increase in the life of membrane filters.

2. Description of construction, scheme and research methods

The filter element is a bellows-type construction of metal-ceramic membranes, wire netting and two flanges (Figure 1). The metal-ceramic membrane consists of substrate made of corrosion-resistant 316L steel (with average pore size of 5 μm and thickness of 200 μm) and thin ceramic layer of titanium dioxide (TiO₂) (with average pore size of 0.2 μm and thickness of 5 μm) (Figure 2). Wire netting, which diameter is equal to 0.25 mm is also made of 316L steel. Wire netting has a cell size of 0.5 mm and a thickness of 0.55 mm.
Figure 1. Filter element: 1 – blind flange, 2 – metal-ceramic membrane, 3 – wire netting, 4 – outlet flange.

Figure 2. Test sample (a) and microstructure photo (b) of metal-ceramic membrane.

All structural elements joints in this construction can be divided into 3 main types: joints of metal-ceramic membranes with each other, the joint of metal-ceramic membranes with a flange, and the joint of metal-ceramic membranes with intermediate wire netting. This work is devoted to the third type of joints – the joint of metal-ceramic membranes with intermediate wire netting.

Two schemes were used to perform welded joints of membranes: with horizontal and vertical position of samples. In the first case, the working surface of membranes was placed horizontally (it was perpendicular to the electron beam) (Figure 3 (a)), and in the second case – vertically along the beam (Figure 3 (b)) [6-8]. For the welding in vertical position of specimen the angle of beam entry was changed from 0° up to 90°.

The ELA-15I power complex with accelerating voltage of 60 kV was used for welding. The electron gun was positioned vertically. The electron beam had a sharp focusing (at a working distance to the product of 150 mm). Electron-beam welding modes parameters are presented in Table 1.

The subsequent research of all welded joints structure was performed.
Figure 3. Schemes of welding in horizontal (a) and vertical (b) position of the sample: 1 – sample, 2 – arbor, 3 – substrate, 4 – welding gun, 5 – electron beam, 6 – direction of movement, 7 – stepping motor.

Table 1. Modes of electron-beam welding of membranes with wire netting.

| Number of mode | Sample position | Accelerating voltage $U$ (kV) | Beam current $I$ (mA) | Welding speed $V$ (m·h⁻¹) | Angle of beam entry (deg) | Direction of rotation       |
|---------------|----------------|-------------------------------|---------------------|--------------------------|--------------------------|-----------------------------|
| 1             | Horizontal     | 3                             | 30                  |                          | —                        | —                           |
| 2             | Horizontal     | 5                             | 60                  |                          | —                        | —                           |
| 3             | Vertical       | 3                             | 30                  | 90                       |                          | —                           |
| 4             | Vertical       | 5                             | 60                  | 90                       | —                        | —                           |
| 5             | Vertical       | 25                            | 1500                | 0                        | Welding on the descent   | —                           |
| 6             | Vertical       | 25                            | 1500                | 0                        | Welding on the rise      | —                           |

3. Results of studies

As a result of studies, it was established that at vertical position of samples all the welds obtained had the same width and depth equal to 1 mm. Figure 4 shows the macrostructure of welded joints obtained at vertical position. However, unstable joint formation is observed at low welding speeds (modes 3 and 4). Moreover, the additional problem consisting in the disruption of weld’s continuity and a significant change in the depth of penetration in the re-melting zone, where the weld is closed, was detected.
Figure 4. Macrostructure of welded joints, obtained at the modes 5 (a) and 6 (b): 1 – membrane; 2 – wire netting.

An appropriate uniform welded joint is formed at high welding speeds and angles of beam entry close to 0º (modes 5 and 6). But, as studies of microstructures of such weld showed (Figure 5), numerous slag inclusions are observed in the structure of weld metal as a result of destruction of ceramic layer (TiO₂) and its mixing with liquid metal. The size of these inclusions is from 2 to 5 μm. Slag inclusions in the weld structure are observed much less often during the process of welding on the descent. In this case, coating destruction area is limited only by the cast zone of weld joint (Figure 6).

Defects in the form of lack of fusion caused by high deformations were observed in weld joints obtained at horizontal position of samples (modes 1 and 2). In addition, ceramic coating of lower membrane under the influence of temperature was destroyed in this case, which does not meet the requirements for filter’s surface.

Figure 5. Microstructure of weld joints at high welding speeds on the rise (a) and on the descent (b).
4. Conclusions
1. It is difficult to obtain a high quality of weld joint at horizontal position of the sample, because ceramic coating is destroyed in this case, and it is unacceptable for filter’s design.
2. Welded joint continuity is broken during weld's closure at low welding speeds and vertical position of the sample.
3. An appropriate uniform welded joint is formed at high welding speeds and small angles of beam entry. At the same time, welding on the descent promotes better removal of slag phase from weld metal.

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