Study of the Effect of Focusing and Oscillation of Electron Beam on the Structure and Properties of Welded Seams

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Abstract. This paper presents the results of a study of the effect of focusing and oscillation of the electron beam on the structure, and the properties of welds made of heat-resistant pearlitic steel. Electron-beam welding using a static beam does not provide a uniform weld structure. According to the results of microhardness measurement, the weld metal has a high hardness with values on average 500 HV. The reason for this may be insufficient intensity of the mixing processes and insufficient residence time of the weld pool in the molten state. The use of electron beam sweeps during welding leads to a decrease in the microhardness of the weld metal to values of 450 HV. Also, the application of electron beam sweeps improves the weld geometry - a smoother transition from the upper part of the weld to the middle, more rounded shape of the root of the weld.

1. Introduction

Often, the use of electron beam welding technology with the use of a static beam results in welded joints with a number of defects inherent in this welding method, namely, the porosity of welded joints, defects in the root portion of the weld, the occurrence of cold and hot cracks, as well as uneven structure the width of the welded joint.

Recently widely used technology of electron-beam welding with various dynamic effects on the electron beam, which provide improved formation of the weld and the almost complete absence of defects. Such dynamic effects include the oscillation of an electron beam along various trajectories, the splitting of an electron beam into several thermal sources, and the modulation of current and focusing. The use of such technological methods contributes to obtaining defect-free welded joints, forming a homogeneous structure of welds when welding dissimilar materials, and the absence of porosity of welds during electron beam welding [1-6].

In this paper, studies were conducted on samples of heat-resistant steel of pearlite class 20Cr3MoVW. Electron-beam welding was carried out using electron beam oscillations along various paths and different beam focusing, as in welding steels and alloys prone to the formation of quenching structures, to obtain a uniform structure of the welded joint, to improve the mechanical characteristics, to avoid defects, it is advisable to use electron beam oscillation along different paths.

The choice of electron beam oscillations is due to the fact that to obtain a favorable structure and properties of the compound, mixing and complete penetration of the material is required. In order to obtain good mixing and eliminate root defects in this case, the most favorable method of oscillation are X-shaped oscillations. They allow you to capture metal in a wider range on either side of the joint, which other basic types of reamers, such as circular and longitudinal, do not allow.
2. Welding Using Various Electron Beam Focusing

The welding of samples with an electron beam with different focusing was carried out according to the modes indicated in Table 1.

| Sample number | Focus type       | Focusing current, mA | Beam current, mA | Accelerating voltage, kV | Welding speed, mm / s |
|---------------|------------------|----------------------|------------------|--------------------------|-----------------------|
| 1             | under focus      | 790                  | 63               | 60                       | 5                     |
| 2             | sharp focus      | 800                  | 43               | 60                       | 5                     |

As a result of welding, two welds were obtained, their macrosections are presented in Figures 1, 2.

![Figure 1. Sample No. 1](image1)

![Figure 2. Sample No. 2](image2)

When using an under-focused beam, the width of the seam and the heat-affected zone increases. When using sharp focusing, the width of the seam and the heat-affected zone are reduced, but the root of the seam has a pronounced peak shape, which is an unfavorable factor.

The study of the microstructure showed that the resulting welds have a non-uniform structure in width and more uniform in depth. The microstructure of the obtained welds is shown in Figures 3, 4.

The formation of such a heterogeneous microstructure is most likely due to the different crystallization temperatures and the insufficient residence time of the weld pool in the liquid state. The resulting inhomogeneous structure of the welded joint is the cause of the non-uniformity of properties, which is clearly seen in the measurements of microhardness along the width and depth of the seam. Microhardness graphs are presented in Figures 5 and 6, the measurement step distance is 0.17 mm.

From the obtained results it is seen that when welding with an electron beam with sharp focusing, the width of the seam and the heat-affected zone are reduced. However, when welding with an unfocused beam, the microhardness values across the seam width are more uniform in comparison with the seam welded with sharp focusing of the electron beam. It is also worth noting that the microhardness values of welds are at the same level - 500 HV. This suggests that a change in the focusing of the electron beam does not have a significant effect on the microhardness of the welded joint, but only affects the final geometry of the weld.
Figure 3. Microstructure of the welded joint of sample No. 1: a - seam; b - fusion line; c - HAZ; d - base + HAZ.

Figure 4. Microstructure of the welded joint of sample No. 2: a - seam; b - fusion line; c - HAZ; d - base + HAZ.
Figure 5. Microhardness graph across the width of welded joints.

Figure 6. Microhardness graph for the depth of welded joints.

3. Welding Using Electron Beam Oscillations along Various Paths
The welding of samples with an electron beam with different types of oscillations was carried out according to the regimes indicated in Table 2.
As a result of welding, two welds were obtained, their macrosections are presented in Figures 7, 8.

Table 2. Welding modes.

| Sample number | Oscillation type | Focusing current, mA | Beam current, mA | Accelerating voltage, kV | Welding speed, mm / s |
|---------------|-----------------|---------------------|------------------|--------------------------|-----------------------|
| 3             | 813             | 65                  | 60               | 5                        |                       |
| 4             | X-shaped        | 813                 | 60               | 60                       | 5                     |
The macroscopes of the obtained samples show that when using the scanning of the electron beam in the form of two lines with a point, the width of the seam and the heat-affected zone increases. The root of the seam has a less peaked shape in comparison with the seam welded by a static beam. There is also a smoother transition from the top of the seam to its middle. When using the X-shaped sweep, the width of the seam increases slightly, and the heat-affected zone decreases.

The study of the microstructure showed that the resulting welds also have a non-uniform structure in width and more uniform in depth, however, when measuring microhardness, its values in the same areas are less than the microhardness in the weld welded by a static beam. Microhardness graphs are presented in Figures 9 and 10, the measurement step distance is 0.17 mm.

The use of an electron beam scan reduces the microhardness values in a welded joint. The best sweep is the X-shaped sweep of the electron beam as the resulting geometry of the welded joint is the most optimal. However, it is worth noting that when using different types of oscillations, the level of microhardness is at the same level - 450 HV. This suggests that the sweep geometry does not have a significant effect on the microhardness of the welded joint, but only on the final geometry of the weld.
4. Conclusion
Electron-beam welding of steel 20Cr3MoVW with the use of a static beam does not provide a uniform weld structure. According to the results of microhardness measurement, the weld metal has a high hardness with values on average 500 HV. Presumably the reason for this is the insufficient intensity of the mixing processes and the insufficient residence time of the weld pool in the molten state.
The use of electron beam scans in welding steel 20Cr3MoVW leads to a decrease in the microhardness of the weld metal to values of 450 HV. Also, the application of electron beam sweeps improves the weld geometry - a smoother transition from the upper part of the weld to the middle, more rounded shape of the root of the weld. However, when using the sweep in the form of two lines with a point, the width of the seam and the heat-affected zone significantly increase. When using the X-shaped sweep, the width of the seam increases slightly, and the heat-affected zone decreases.
The results obtained are comparable with the results of previous studies in [4], [5]. The uniqueness of this work lies in obtaining the results of the regularity of the effect of focusing and oscillation of the electron beam on the structure and properties of welds when welding a specific class of steel, namely for heat-resistant steels of pearlite class.

Acknowledgments
The study was carried out with the financial support of the Government of the Perm Territory in the framework of the scientific project No. C-26/794 dated December 21, 2017.

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Figure 10. Microhardness graph for the depth of welded joints.