Investigating the mechanisms of shape distortion of the heat-affected region during electric-arc welding of oilfield pipelines

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Abstract. The article studies the issue of the influence of the most encountered in practice defects of welded joints of a one-piece joint, formed in the process of applying a weld when connecting oilfield pipelines to a joint by electric arc manual welding, on the strength characteristics of a welded joint by scrutinizing the condition of the pipe material close to the heat-affected zone. As a test sample, a butt welded joint with obvious defects was used. The geometric parameters of the welded joint were measured using standard means and the hardness of the heat-affected zone was determined by the Rockwell method in certain areas with justification of the welding process. The reason for softening is established. The change in the geometry of the heat-affected area is due to the accumulation of filler material during its melting on one side of the weld with a decrease in welding speed. Recommendations are given for the prevention of the destruction of welded structures and the occurrence of emergency situations in oilfield pipelines.

1. Introduction
In the construction of infield pipelines and their subsequent overhaul or maintenance, electric arc manual welding is widely used. During the construction of such structures, due attention is not paid to checking welds for their geometric parameters in the process of connecting pipes in the oil fields, and technical measures are not taken to increase the strength of the welded joint, which often leads to emergency situations caused by a rupture of infield pipelines [1–3]. Consequently, this research will be directly aimed at improving the reliability of welded joints of oil pipelines, repeatedly occurring in the activities of oil companies.

2. Results and discussion
The article considers a variety of the welding process, which is based on the melting of the pipe material when creating high temperature in an electric arc [4–5]. Studies show that the area of the heat-affected area is heated unevenly over the entire width (the maximum temperature occurs in the region of overheating T ≈ 1400–1500 °C). The dependence shown in Figure 1 demonstrates the regions of the heat-affected area that differ in their forming crystal structure with different grain sizes depending on the action [1].
3. Experimental
Figure 2 shows the geometry of the weld under consideration. Figure 3 shows a sample study of a defective welded joint, on which distortions are clearly visible [5].

The following welding parameters were defined [4]
- welding speed;
- voltage U = 20 V;
- welding current.

To determine the dimensions of the considered thermal-affected zones, Rockwell hardness measurements were carried out in certain areas [6–7]. The obtained data are displayed in the Table.

According to these data, it is clear that the measurements No. 2 and 3 do not coincide, a decrease in the readings on the left side is obvious. The geometric parameters of the heat-affected area are shown in Figure 4, which indicate an increase in the size of the overheating zone. This is due to a change in the thermal conductivity of the pipe material as a result of its recrystallization, which contributed to
the transfer of excess heat energy to it, which heated the pipe material to a temperature significantly higher than 830–850 °C. [1, 5], turning it into a molten state with further cooling in the open air.

**Figure 3.** Sample of a defective weld

**Table 1.** Hardness values

| Measurement | 1   | 2   | 3   | 4   | 5   | 6   |
|-------------|-----|-----|-----|-----|-----|-----|
| Left side   | 21 HRC | 18 HRC | 18 HRC | 22 HRC | 24 HRC | 27 HRC |
| Right side  | 21 HRC | 18 HRC | 22 HRC | 23 HRC | 24 HRC | 26 HRC |
| 25HRC – base metal hardness | | | | | | |

**Figure 4.** Geometric parameters of the heat-affected zone
The thermal conductivity of the pipe material depends on the grain size of the crystal lattice. Reducing grain sizes reduces thermal conductivity. The initially generated heat propagating from the epicenter of the electric arc has less resistance when passing through a coarse-grained structure, which is caused by high thermal conductivity.

Figure 5 shows the dependence reflecting the ability of various granular structures of the pipe material to transfer thermal energy in the considered areas of thermal impact on different sides of the weld.

![Figure 5. The ability of the pipe material to transfer thermal energy depending on the grain size of the structure](image)

As a result, different regions of the pipe material have different heating, but the completely final structure of the pipe material is formed at \( t = 723 ^\circ C \). Peripheral areas demonstrate significant grain growth (Figure 6). A distinctive feature of the overheating region is that the beginning of cooling of the pipe material in the considered region begins with a maximum value, compared with other regions which crystallization occurs at the lowest temperature (red cooling curve). Therefore, the maximum temperature difference is formed in the region of overheating, which creates the condition for the enlargement of the structure of the crystal lattice (Figure 6) [1].

Thus, the reason for the softening of the weld is an increase in the width of the overheating zone. With a decrease in the speed of movement of the electrode, overheating of the metal occurs, followed by a increase in its thermal conductivity. The overheating zone has an enlarged grain structure caused by excessive heat transfer due to the influx of filler material. The results of the study show that even a slight decrease in the speed of electric arc welding leads to a several-fold increase in the width of the most dangerous section of the heat-affected region [8–10]. In such a fragile section of the heat-affected region, the grain sizes are significantly larger than the grain sizes of a metal that is not included in this section, which increases the risk of weld joint failure.
Usually, in the oil and gas fields of Russia, the necessary attention is not paid to correcting and preventing errors that a welder makes during manual electric arc welding. To prevent defects in welded joints, the following control methods are proposed:
- external control of the welded joint and verification of the geometric parameters of the seam;
- physical methods for studying the weld (ultrasonic, magnetographic, X-ray scanning, etc.);
- testing of pressurized infield pipelines for density and strength by gas, hydraulic or pneumatic pressure;
- testing of oil pipelines, the joints of which must be airtight, for density using kerosene, compressed gases, vacuum chambers, ammonia, as well as gas-electric leak detectors.

Figure 6. Fe—Fe3C diagram indicating the cooling curves of the areas of the heat-affected area

4. Conclusion
To reduce the residual stresses that form during welding, in practice, immediately after welding, the following methods of processing welds and joints are used: thermal, mechanical, thermomechanical. To prevent the occurrence of corrosion phenomena on welded structures, it is necessary to carry out machining of the welds to remove the remaining slag, and also use various protective coatings, for example, primer paint.

Carrying out a set of measures aimed at preventing the destruction of welded joints of field pipelines is advisable, since when a pipeline ruptures, oil is lost, environmental damage is noticeable and wells are idle during repair work.

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