

Studying heat-affected zone deformations of electric arc welding

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Abstract. The paper studies the influence of the most common defects in permanent electric arc welds made during the welding butt joints in infield oil pipelines, onto the strength characteristics of the welded pipe material around the heat-affected zone. A specimen of a butt weld with an obvious defect was used as a subject of the study. The changes in the geometric parameters of the weld were measured with the standard means; Rockwell hardness in the heat-affected zone was determined in certain areas with justification for the weld process modes. The cause of softening was found to be an increased width of the hot spot on the one side of the weld, where an enlarged crystalline structure appears as a result of the pipe material recrystallization under the influence of heat. Changes in the geometry of the thermal action area are determined by accumulation of molten filler on the one side of the weld when the welding rate is decreased. Some recommendations are given to prevent destruction of the welded structures and appearance of emergencies in infield oil pipelines.

1. Introduction

Manual electric arc welding is widely applied in construction, repair and overhaul of infield pipelines. When building such structures, not enough attention is paid to checking the welds for conformance to their geometric parameters during pipe connections in the oil fields; the technical measures aimed to increase the strength of the weld and leading to emergencies caused by a break in the infield pipeline are often not applied [1-3]. Thus, these studies will be aimed directly at increasing the reliability of the oil pipeline connections of the type, which is common in field practice of different oil companies.

2. Studies of the heat affected zone of the weld

The paper considers a type of welding, based upon melting the pipe material by creating high temperature with an electric arc [4-5]. The research has shown that the heat-affected zone (HAZ) is heated non-uniformly across the width; the maximum temperature appearing in the vicinity of the superheated area is $T \approx 1400...1500^{\circ}\text{C}$. The characteristic curve presented in Figure 1 shows the areas of the HAZ different in their formative crystalline structure with a different grain fineness depending on the action [1].



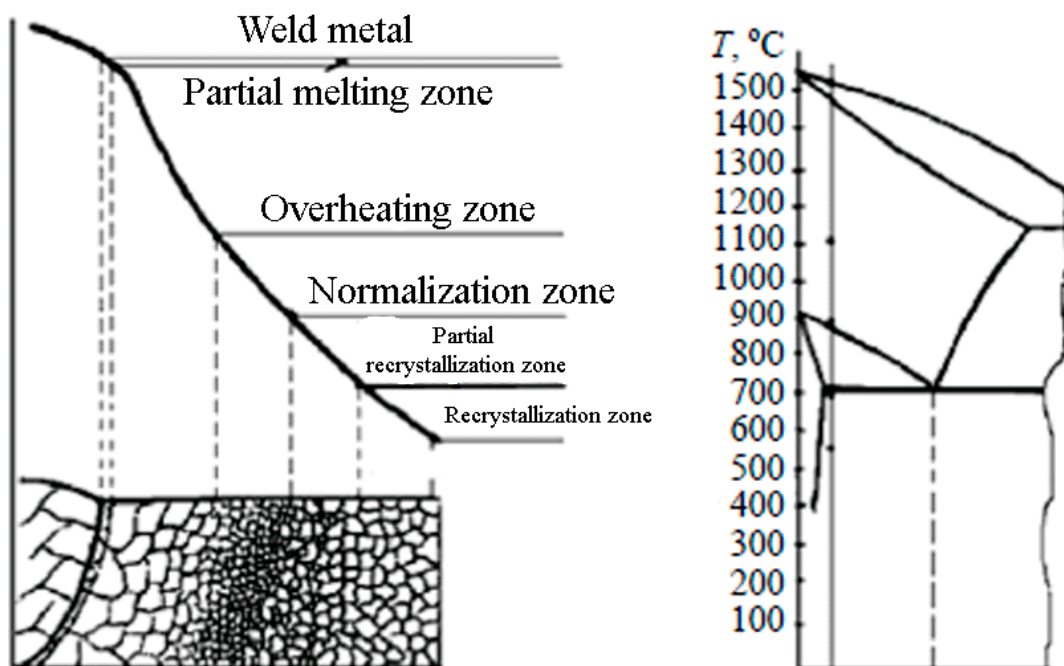


Figure 1. Heat-affected zone

Figure 2 shows the geometry of the weld in question. Figure 3 shows the studied sample of the defective weld, where distortions are clearly visible [5].

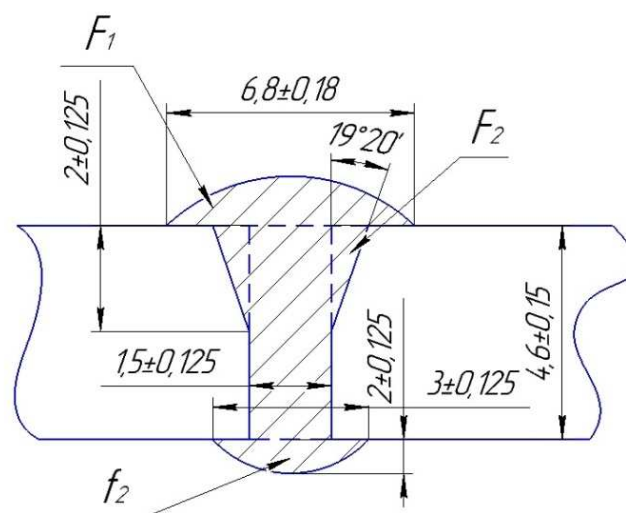


Figure 2. The geometry of the welded connection in question

The following parameters of the welding conditions were determined [4]:

- welding rate;
- voltage $U=20$ V;
- welding current.

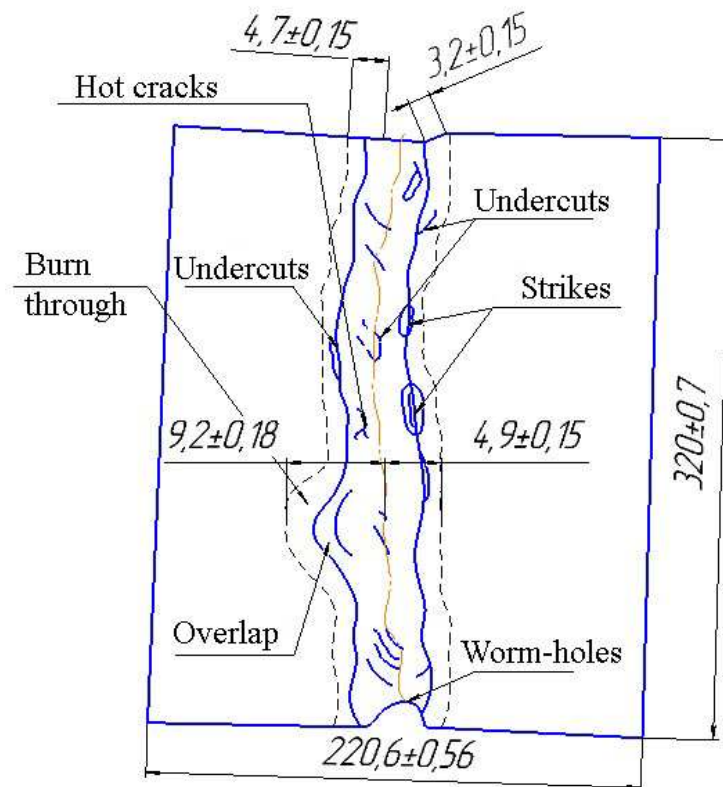


Figure 3. A defective welded connection specimen

Width of the heat-affected zone (HAZ).

To determine the size of the HAZs in question, Rockwell hardness was determined at certain points of the welded joint [6-7]. The results are given in Table 1.

From the results, it is evident that the values of measurements No. 2 and 3 are not the same; the values on the left side are lower. The geometric parameters of the HAZ are shown in Figure 4 and are evidence of an increased size of the superheated zone. This increase is caused by changes in the pipe material heat conductivity due to its recrystallization, facilitating transmission of a significant amount of heat energy to the material and heating the pipe material to temperature significantly higher than 830...850°C [1, 5], turning it into the molten state with further cooling in the open air.

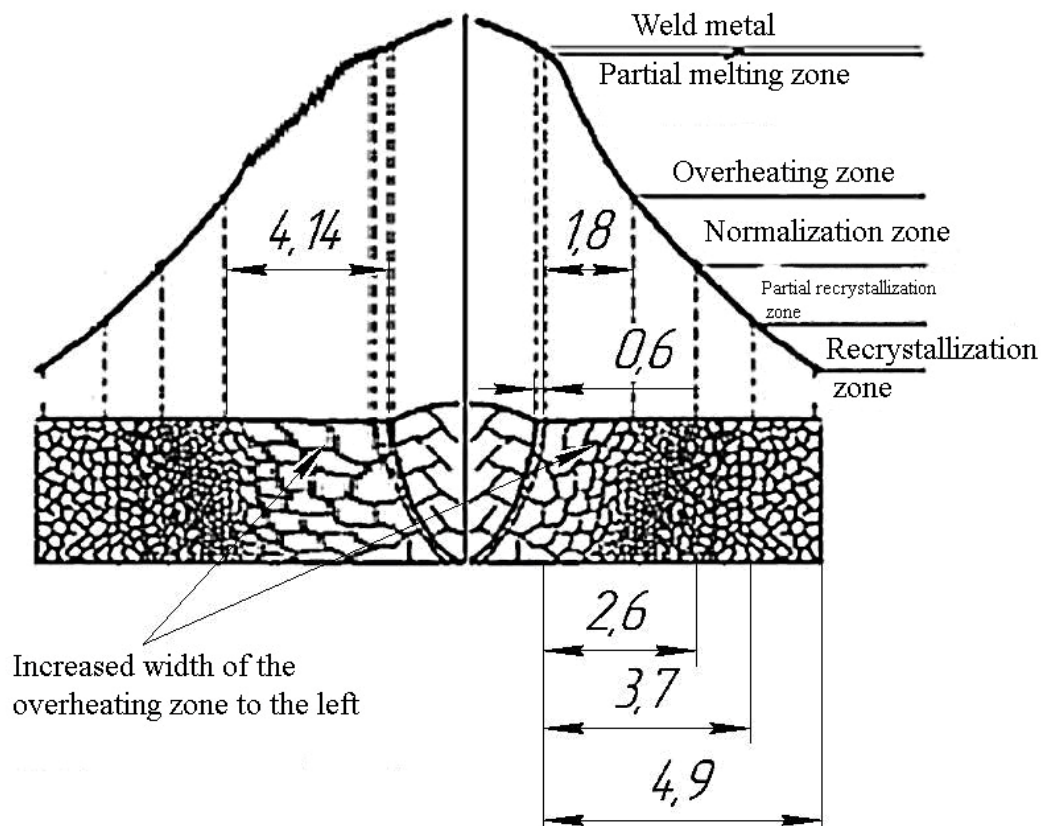


Figure 4. The geometric parameters of the HAZ

Table 1. Hardness values

Measurement no.	1	2	3	4	5	6
Left side	21 HRC	18 HRC	17 HRC	22 HRC	24 HRC	27 HRC
Right side	21 HRC	17 HRC	22 HRC	23 HRC	24 HRC	26 HRC
The hardness of the base material is 25HRC						

3. Results of studies of the heat affected zone of the weld

Heat conductivity of the pipe material depends on the grain fineness of its crystalline lattice. The reduction in the grain size decreases the heat conductivity. The initial heat, coming from the epicenter of the arc passes through a lower resistance when going through the coarse-grain structure, due to its high thermal conductivity.

Figure 5 shows a dependency reflecting capabilities of different grainy structures of the pipe material to transfer heat energy in the HAZs in question on both sides of the weld.

As a result, different areas of the pipe material have different temperature, but the final structure of the pipe material is formed at $t = 723^\circ\text{C}$. The peripheral parts reflect the areas with a significant increase in grain size (Figure 6). A distinctive feature of the overheating area is that the early cooling in this area starts from the maximum value, in comparison with other areas where the crystallization proceeds at the lowest temperature. (red cooling curve). It all adds up to the maximum temperature difference being in the overheating zone, creating conditions for enlargement of the crystalline lattice structure (Figure 6) [1].

Thus, the reason for weld softening is the increased width of the overheating zone. When the electrode movement speed is reduced, there is an overheating of metal with further increase in its heat conductivity. The overheating zone has an enlarged granular structure due to increased heat transfer

caused by overlap of the filler. The results of the research show that even an insignificant reduction in the arc welding rate leads to an increase in the width of the most dangerous part of the HAZ several-fold. Inside this brittle zone of the HAZ, the grain size is significantly larger in comparison with the grain size of the metal outside the zone, thus increasing the risk of weld destruction.

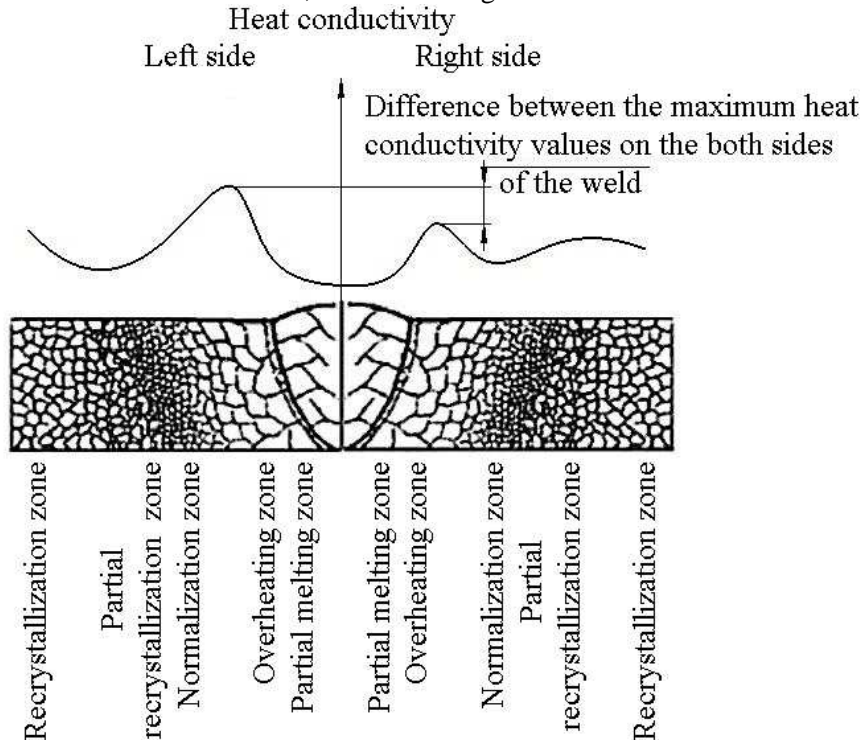


Figure 5. The heat transfer capability of the pipe material depending on grain fineness of its structure

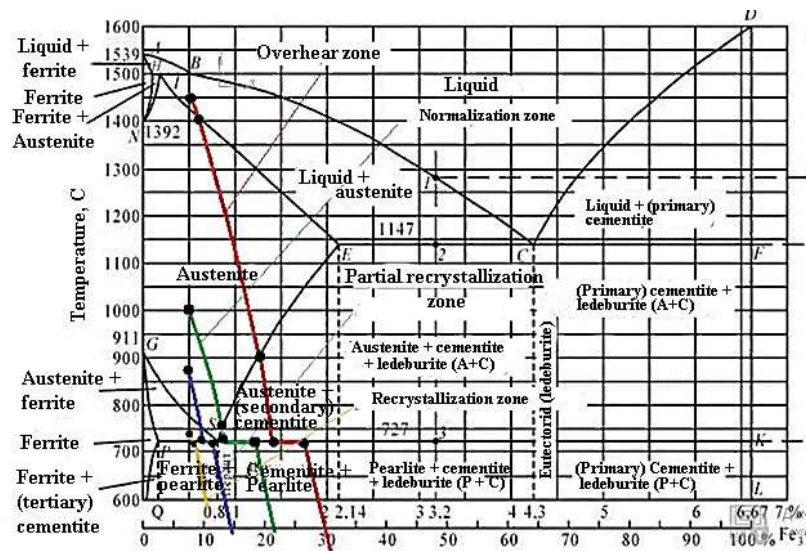


Figure 6. Fe – Fe₃C diagram with cooling curves for zones of HAZ

4. Proposed preventive measures against weld defects

Usually, not enough attention is paid to rectification and prevention of errors committed by a manual arc welding operator in the Russian oil fields. To prevent the weld defects, the following methods of control are proposed:

- visual control of the welded joint and checking the geometric parameters of the weld;

- physical methods to assess the weld (ultrasound, magnetographic inspection, gamma-ray and X-ray inspection, etc.);
- testing the infield pipelines under pressure for their tightness and strength with gas, hydraulic or pneumatic pressure;
- testing the oil pipelines with air-tight welds for tightness with kerosene, pressurized gases, vacuum chambers, ammonia, as well as gas-electric leak detectors.

To lower the welding residual stress, the following methods of treatment are regularly applied to the welds and welded joints: thermal, mechanical, thermal-mechanical treatment. To prevent corrosion on the welded structures, it is necessary to subject them to a mechanical treatment of the welds to remove slug residue and to use different protective coatings, such as priming paints.

5. Conclusions

Application of a complex of measures aimed at prevention of destruction of the welded joints in the infield pipelines is necessary, because otherwise breaks of the pipeline are possible, leading to a loss of oil, a significant harm to the environment and a well downtime during the repair works.

References

- [1] Mazlov V L, Suleimanov R I, Petrov V A, Minnivaaleev A N 2012 Conditions of the pipeline system of Rosneft-Yuganskneftegaz in Mamontovo region. *Issues in collection, treatment and transportation of crude oil and petroleum products* **90** (4) 71-76
- [2] Khabibullin M Ya, Suleimanov R I, Sidorkin D I and Arslanov I G 2017 Parameters of Damping of Vibrations of Tubing String in the Operation of Bottomhole Pulse Devices, *Chemical and Petroleum Engineering* **53** 5–6 <https://doi.org/10.1007/s10556-017-0350-6>
- [3] Khabibulin M Ya, Sidorkin D I 2016 Determining oscillation of the production tubing during an impulse pumping of liquids down borehole. *Scientific papers of NIPi Neftegaz SOCAR*. **3** (3) 27-32 <https://doi.org/10.5510/ogp20160300285>
- [4] Demchenko M V, Sisanbaev A V, Kuzeev I R 2017 Research of state of metal welded joint by deformation and corrosion surface projection parameters. *Nanotechnologies in Construction: A Scholarly Internet Journal*. **9**(5) 98-115 <https://doi.org/10.15828/2075-8545-2017-9-5-98-115>
- [5] Zernov V V, Zaytsev M B 2014 Stress field in the HAZ of welded joints. *Regional architecture and construction*. **1** 136-143
- [6] Khabibulin M Ya, Arslanov I G 2014 *Design of oil field equipment*. (Ufa: USPTU Publishing)
- [7] Khaustov S V, Kuzmin S V, Lysak V I, Fedyanov E A 2008 Calculation and experimental method to determine temperature profiles in explosion welding HAZ. *Annals of the Volgograd State Technical University* **3**(3) 50-57