Structure and strength research of polymer pipe welded joints

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Abstract. Research results of the effect of low ambient air temperatures during welding on structure and strength of polymer pipes welded joints are given. The connection of polymer pipes was made in two main ways: by hot element butt welding and socket welding. Structure studies of the material of welded joints have shown that the welding technologies developed at IOGP SB RAS provide formation of the same structure in the material of welded joints as in standard welding.

1. Introduction
Polymer pipes have numerous undeniable advantages over steel pipes, such as low weight and flexibility, simplicity and low cost of transportation and installation, absence of insulation, high durability, etc. However, during long-term operation, the weakest point is welded joints. Polymer pipes are usually connected by hot element welding, when welded surfaces are heated by their physical contact with heated tool. In this paper, two types of welding with heated tool are considered: butt welding of polyethylene pipes and hot element welding of polypropylene pipes. As the result of thermal deformation cycle of welding, different structure is formed in the material of the welded joint. The structure, in turn, affects strength of the welded joint. More detailed study of the formed structure will help establish the dependence of the strength of welded joints on the size and characteristics of structural formations. To control the quality of welded joints, various non-destructive and destructive test methods are used. Analysis of methods for quality control of welded joints of polymer pipes showed that test procedures existing in current regulatory documents are not sufficiently informative and do not give quantitative assessment of strength [1, 2].

The purpose of this work is to study the structure and strength of the material of welded joints obtained under different welding conditions. Objects of study were butt-welded joints of polyethylene pipes for gas pipelines and hot element welded joints of polypropylene pipes for water pipes. Welding of polyethylene and polypropylene pipes was carried out at various ambient temperatures, including low ones (up to minus 50 °C). There is permissible temperature range to produce welding polymer pipes. Thus, according to the current regulatory documents, polyethylene pipes for gas pipelines can be welded at temperatures from minus 15 °C to plus 45 °C, and polypropylene pipes only at temperatures above zero. At lower values it is recommended to carry out welding work in heated shelters. In IOGP SB RAS, ways of solving this problem have been proposed, that is, technologies for hot element butt-welding of polyethylene pipes and hot element socket welding of polypropylene pipes have been developed, allowing welding to be performed at ambient temperatures below the standard in the open air without building heated shelters [3, 4].
2. **Experimental part.**

The structure of welded butt joints of polyethylene pipes was studied using universal optical microscope Altami POLAR 312 (Russia). The surface of samples for microscopic studies was prepared by etching in boiling toluene vapors for 3 min. Etching surfaces in the region of the fusion line (Figure 1) were studied at × 1000 magnification.

![Study area](image)

**Figure 1.** Schematic location of researched area of welded butt joints of PE pipes.

The supramolecular structure of material of samples of joints, welded via technology developed at IOGP SB RAS at low temperatures, is most identical to the structure in research weld area, performed using standard welding mode. Sizes of spherulites vary in the range of 5–15 µm (Figures 2a and 2c). It can also be noted that spherulites are slightly deformed. This is probably caused by shrinkage of weld material, which relates to the fact that welded pipe ends are rigidly fixed. The structure of material of welded joint obtained at minus 30 °C with violation of technology is characterized by presence of crystalline formation with dimensions of 3-5 µm. Fine-crystalline structure occurs with high cooling rate of welded joint.

![Figure 2](image)

**Figure 2.** Material structure of welded joints manufactured under the following conditions: a) AAT = + 30 °C, standard welding; b) AAT = -30 °C, with violation of technology; c) AAT = -30 °C, developed technology.

Studies of strength characteristics of welded butt joints were carried out by tensile tests according to original method of quantitative assessment of strength of welding joint [5]. The essence of this technique is to create intended area of welding using pre-made template. The template is inserted between welded ends of pipes after heating operation during technological pause. After recommended time after welding, samples are made according to GOST 11262. In standard tests for axial tension, fracture took place exactly at the place of fusion. Figure 3 shows test results of welded joints of polyethylene pipes.
Figure 3. Values of destructive stress of the material of the seam of butt-welds produced at different ambient temperatures: ♦ - standard welding; ▲ - developed technology; ■ - welding with violation of technology.

As it can be seen from test results, strength of welded joints made at low temperatures by developed technology is higher than the same strength values of welded joints produced in the temperature range acceptable for welding. Strength indicators of welded joints obtained in violation of the technology are lower than the same indicators of welded joints made at low ambient air temperatures according to the developed technology and joints welded in the allowed temperature range. However, you should pay attention to the fact that at temperatures above 30 ºC there is slight decrease in strength. This is probably because in this case cooling of welded joint is already too slow and crystalline formations in the structure of the material grow up to 50-100 microns. Thus, the formation of too small spherulites (up to 5 μm) in the material structure, as well as too large (up to 100 μm) negatively affects strength of welded joint of polymer pipes.

Hot element socket welding of polypropylene pipes was carried out at different modes: at temperatures above zero by standard technology, at temperatures below zero developed at IOGP SB RAS and at temperatures below zero by standard welding, i.e. with violation. The material structure of obtained welded joints was studied on electron scanning microscope JEOL JSM-7800F. The surface of samples for research was also prepared by etching in boiling toluene vapors. Figure 4 shows micrographs of sample material structure.

Figure 4. The structure of the material of the weld zone (fusion zone): a) welding at 23 ºC; b) welding at minus 30 ºC; c) welding at minus 30 ºC, developed technology

Type and size of supramolecular formations in structure of the material of welded joints produced at minus 30 ºC by the developed technology (Figure 4c) is most like the structure of welded joint obtained at room temperature by standard welding (Figure 4a). The structure is spherulitic, sizes of
Spherulites vary from 3 to 8 microns. In the process of welding at low ambient temperatures, violation of cooling rate is naturally high, and therefore the structure in the area under study is characterized with unformed small spherulites with sizes of 2-3 μm and the presence of frozen amorphous part (Figure 4b). That is, it can be concluded that the developed welding technology, which provides the same thermal process and cooling rate, contributes to the formation of structure in welded joint material the same as at the allowed temperature range of the welding production.

Studies of the strength of hot element welded joints were carried out by tensile shear tests using the original method, which allows to quantify the strength at the place of fusion of welded parts [6]. The essence of the technique lies in the stretching of standard sample, where the test hot element weld is in the middle of the sample. The sample was made according to Figure 5. On the coupling 1, an incision 2 was made to the point of fusion, parallel to the edge of the coupling. On the inner wall of the pipe 3 was cut notch 4, parallel to the edge of the pipe. The distance between slots 2 and 4 was calculated in such way that cross-sectional area of tested part A of hot element welded joint was equal or less than the minimum cross-sectional area of the sample outside the zone of the hot element joint. In shear tensile tests, the sample was fractured along the weld seam in area A.

![Sample for determination the strength of hot element welding under tension](image)

**Figure 5.** Sample for determination the strength of hot element welding under tension (the direction is indicated by arrows)

Welded joints obtained under different welding conditions of polypropylene pipes were tested. Test results are shown in Figure 6.

According to the results of mechanical tensile shear tests, breaking stress of hot element welded joints produced at temperature of minus 35 °C by the developed technology is not inferior to the strength of welded joints obtained by standard welding at room temperature.
Figure 6. Destructive stress of welded hot plate joints of polypropylene pipes at various ambient air temperatures (AAT)

3. Conclusion
Studies of structure and strength properties of the material of welded joints have shown that the developed technologies for hot element butt welding of polyethylene pipes and hot element socket welding of polypropylene pipes ensure the formation of the same material structure of welded joints as during welding in regulated ambient temperature range.

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References:
[1] E.V. Danzanova, Issues of quality control of welded joints of polyethylene pipes for gas pipelines, Oil and Gas Business. 1 (2009) 1-9. Access mode: http://www.ogbus.ru/authors/Danzanova/Danzanova_1.pdf
[2] A.I. Gerasimov, E.V. Danzanova, G.V. Botvin, Testing of welded joints of polypropylene pipes, Vestnik ESSUTM. 66 (2017) 38-42.
[3] N.P. Starostin, M.A. Vasil’eva, E.V. Danzanova, O.A. Ammosova, Butt welding of polyethylene pipes at low temperatures, Welding International. 27 (2013) 318-320.
[4] N.P. Starostin, A.I. Gerasimov, G.V. Botvin, E.V. Danzanova, Welding of polypropylene pipes at negative temperatures, Construction of unique buildings and structures. 55 (2017) 7-18.
[5] A.I. Gerasimov, E.V. Danzanova, G.V. Botvin, RF Patent 2465560 (2012)
[6] A.I. Gerasimov, E.V. Danzanova, G.V. Botvin, Research Methods for Seal of Streams Polymer Pipes, Proceedings of the 12th International Conference on Mechanics and Materials (MRDMS-2018): AIP Conference Proceedings 2053, 030018 (2018); DOI: 10.1063 / 1.5084379 https://doi.org/10.1063/1.5084379