RESIDUAL STRESSES IN CIRCUMFERENTIAL BUTT JOINTS IN THE MAIN GAS PIPELINE AT LONG-TERM SERVICE IN THE NORTH

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Fields of residual welding stresses in circumferential butt joints of the main pipeline of 530 mm diameter with 7 mm wall thickness after long-term service under the North conditions were experimentally studied. It is shown that a high level of tensile residual welding stresses is preserved in circumferential welded joints of the main gas pipeline after 40 years of service. In sites of corrugation formation the residual welding stresses may reach 87 % of base metal yield point. They should be taken into account at calculation of residual life of welded main pipelines.

Keywords: *main welded gas pipelines, circumferential butt joints, HAZ, residual tensile welding stresses, corrugation, residual life*

Service period of some sections of operating main gas pipelines Kysyl–Syr–Mastakh–Berge–Yakutsk, which were put into operation in 1967–1988, is up to 40 years. Acquisition and treatment of statistical data on failures of the main gas pipeline have been performed since the moment of its putting into operation. Analysis of the most characteristic causes for gas pipeline failures revealed that more than 50 % of failures are in circumferential welds with formation of a through-thickness crack. Studying the causes for formation of blowholes showed that the main sites of fracture are defects of welding the root weld (lacks-of-penetration, pores, slags) which are stress raisers [1].

It is known that during welding of field butt joints of pipelines a stress-strain state forms which is induced by a field of residual welding stresses (RWS). One of the features of welding circumferential welds of cylindrical shells is development of weld «sagging», i.e. radial displacements leading to narrowing of pipe diameter in the section of welded joint. This results in lowering of hoop RWS (σ_θ), and at a certain combination of welding modes, metal properties and shell rigidity parameters σ_θ in the weld can even be close to 0. Axial stresses σ_z from the shell inner side turn out to be tensile because of bending, and on the metal surface from the outer side they are compressive [2, 3]. Level of tensile RWS from the inner side of shell wall can reach the base metal yield point [4]. In study [5] circumferential residual strains of a welded butt joint of a pipe from austenitic steel 10Kh18N10T were measured using strain gauges (10 mm base). Proceeding from the obtained data tensile residual welding strains were found in 25–30 mm zone from the weld center on the pipe inner and outer surface. Thus, tensile RWS of circumferential butt joints of pipes are one of the factors strongly influencing appearance of through-thickness brittle cracks in welds.

It is known that at considerable elastoplastic deformations a practically complete relaxation of RWS takes place. In this connection, in the field of quasi-static failures RWS do not affect the cyclic strength of the welded joint. At loading of the corresponding regions of low-cycle fatigue, RWS relaxation usually proceeds quite intensively during the first several cycles [6]. At the same time, data of investigation of RWS relaxation at long-term operation of structures are practically absent. In service the fields of RWS distribution in pipe welded butt joints change as a result of an abrupt temperature gradient, structural changes and elastoplastic deformation. In this connection RWS were studied in circumferential butt joints of the main gas pipeline of 530 mm diameter, 7 mm wall thickness, which was in operation for about 40 years.

RWS measurements in the subsurface layers of the pipe on the inner and outer sides were conducted using a portable X-ray stress determination unit.

The first coil of a pipe fragment with a circumferential butt joint was cut out of a section of the main gas pipeline Berge–Yakutsk, because of formation of a corrugation in it in service. Mechanical characteristics of pipe base metal were σ_t = 501 MPa, σ_y= 383 MPa and δ = 24.9 %. By the results of mechanical testing and spectral

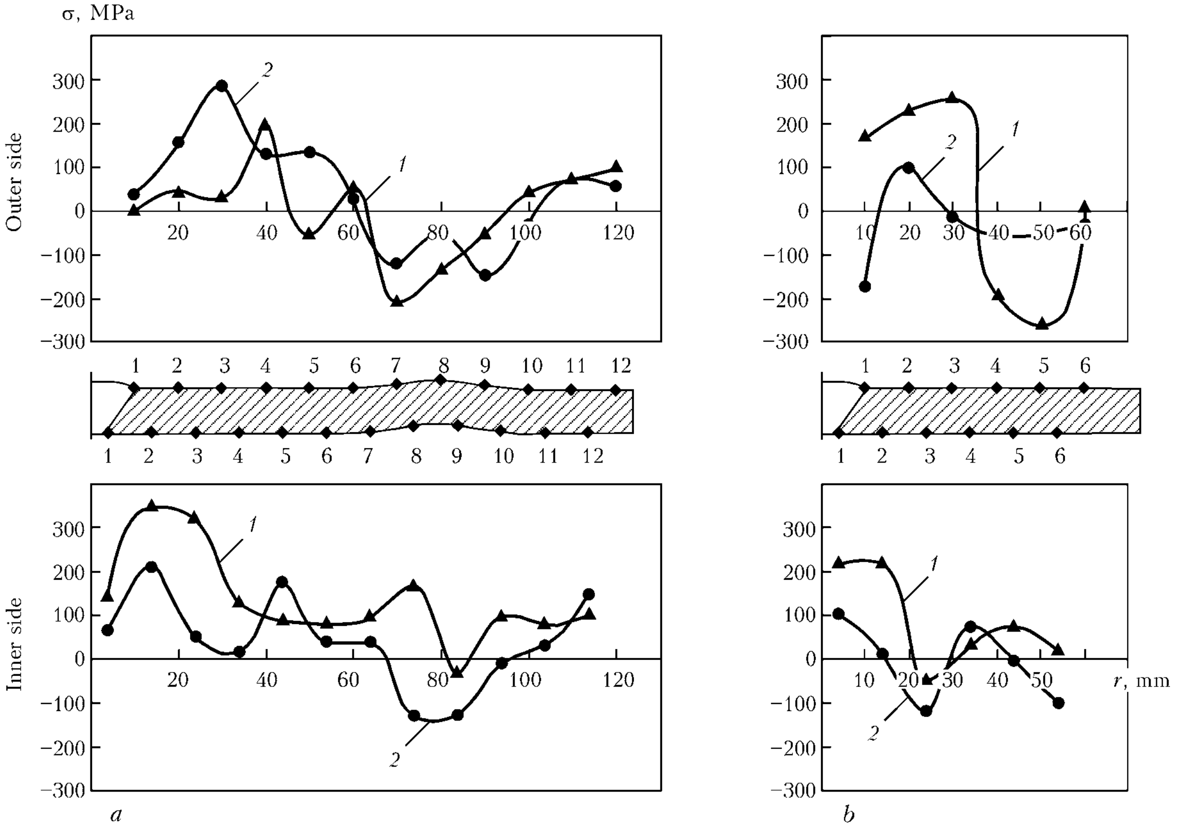

Figure 1. Distribution of residual welding stresses of circumferential butt joint of the first coil of 530 mm diameter gas pipeline from the corrugation side (*a*) and undeformed section (*b*): *1* — axial; *2* — hoop stresses

analysis, pipe metal corresponds to low-alloyed steel of 09G2S grade.

Modes of welding the main gas pipeline are given in the monograph of Prof. V.P. Larionov [7]. Welding was performed in three layers with application of Sv-10G2 welding wire (2 mm diameter) and AN-348A flux, baked at the temperature of 250–300 °C for 1.5 h, in the following modes: I_w = 440–500 A, U_w = 38–42 V, v_w = = 32–35 m/h. This ensured heat input level in the range of 1600–1900 kJ/m that is optimum to produce a welded joint with the required heat resistance. Weld reinforcement was equal to 2–3 mm with a smooth transition to base metal, weld width was 18–20 mm.

Figure 2. General view of fracture of the main gas pipeline Berge–Yakutsk

In gas pipeline service a corrugation of 520 mm length and 7 mm height formed at 80 mm distance from the welded joint. RWS measurements were conducted in the corrugation section, as well as in undeformed section from the pipe opposite side. By the results of measurements from the pipe outer side it was established (Figure 1, *a*) that considerable tensile stresses are found at 30 mm distance from weld center, reaching 300 MPa in the circumferential direction, and up to 200 MPa in the axial direction (at 40 mm distance). Near the corrugation the nature of stress variation is as follows: considerable compressive stresses are found in the circumferential and axial directions, reaching 150–200 MPa. On the inner surface of pipe wall in the near-weld zone a high level of tensile RWS is found in the axial direction, reaching 350 MPa. In points near the corrugation, compressive stresses are found in the circumferential direction (up to 150 MPa) and negligible stresses are observed in the axial direction.

Thus, corrugation formation results in appearance of considerable tensile stresses in the HAZ of the weld on the inner and outer subsurface layers.

In the section from the opposite side on pipe outer surface (Figure 1, *b*) a high level of tensile and compressive stresses is found in the axial direction, reaching 250 MPa at maximum. On the pipe inner surface RWS level at 15 mm distance is equal to 230 MPa.

Second coil was cut out of the main gas pipeline section, where the accident occurred. It consists of complete opening of metal along the pipeline from the outer side with numerous branches of the crack in the site of field circumferential joint (Figure 2). After the accident fracture fragment of the total length of 2160 mm were collected. Circumferential weld was broken in the transverse direction into four individual sections: 1010; 235; 315; 127 mm, respectively. Total weld length around the perimeter is equal to 1687 mm. Fracture was of explosive nature without ignition. Cracks propagated by tearing mechanism in the sites of crack arresting, developing into the shear mechanism with ductile components.

Investigation of pipe fracture surface showed that the fracture nucleus is located on the pipe inner side, normal to the circumferential weld in the HAZ in the site of joining of base metal and weld, and has a considerable extent and length of time of crack growth. Fracture surface is indicative of long-term propagation of the crack.

Crack stopped at transition to base metal that is demonstrated by the transition zone. Then the crack started moving in-depth of base material, where radial scars were observed, originating from this zone and later on going into the main crack which had a chevron pattern. Crack propagated for a longer time and more uniformly in the direction normal to base metal, under the impact of maximum tensile stresses, which are characterized by fatigue ridges. It stopped directly in the weld that is indicative of sufficient resistance of weld metal to crack propagation, compared to base metal.

As fracture nucleus is located from the pipe inner side normal to the circumferential weld, RWS in the pipe inner near-surface layers were studied in the HAZ. Fracture ran through the gas pipeline upper part, so that a sample of 600 × × 700 m size was cut out of the section with the circumferential weld remaining in the trench. By measurement results the level of circumferential RWS at 15 mm distance from weld center reaches 210 MP, that is equal to 65 % of the yield point. Chemical analysis of pipe steel revealed that steels of two different grades 09G2S (pipe 2) and 17G1S (pipe 1) were used. As is seen from Figure 3, RWS distribution relative to weld center is nonsymmetrical. Unsymmetry of RWS distribution is attributable to different chemical composition of the pipes.

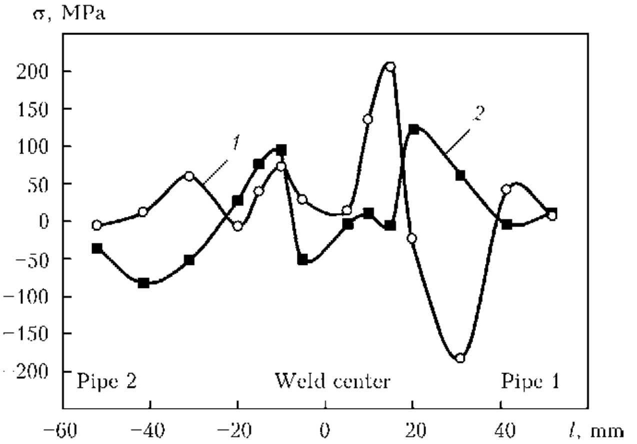

Figure 3. RWS distribution in circumferential butt joint in the second coil of 530 mm diameter pipeline: *1* — hoop; *2* — axial stresses

Thus, conducted investigations showed that in circumferential welded joints of the main gas pipeline of 530 mm diameter a high level of tensile stresses is preserved after its 40 year service. In the sites of corrugation formation RWS can reach 87 % of base metal yield point. Maximum level of hoop stresses in the sample cut out of the section of main gas pipeline, where the accident occurred, reaches 65 % of the yield point. Therefore, RWS should be taken into account at calculation of the residual life of circumferential welded joints of the main pipelines, and the degree of their influence on fatigue strength depends on pipe material.

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