Reasons for crack nucleation in welded joints of main gas-pipelines after a long-term operation

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Abstract. A crack of operational origin in the welded joint of the main gas pipeline is analyzed. The reasons for its nucleation and impact on technological microdefects that were formed earlier during the welding are found. Micromechanisms and stages of nucleation and propagation of the crack are investigated.

1. Introduction

The main gas pipeline 'Urengoy - Pomary – Uzhgorod' was commissioned in 1984 to supply natural gas from the deposits in the north of Western Siberia to Central and Western Europe [1]. The total length of the pipeline is 4451 km, and on the territory of Ukraine, its length is equal to 1160 km. So, in 2016, its service life will make up 32-33 years. Diagnostic measures of its current mechanical state allow detecting a significant amount of defects [2, 3].

Of particular importance under main gas pipelines exploitation is the fact that along with operating defects, they often have defects of welded joints, which are formed under a building stage (results from imperfect production technology). Typically, the fault repair requires a significant amount of work, cutting out and replacing defective parts of the pipeline. In addition, it is important to understand the real mechanisms of the weld damage, the conditions of its degradation and fracture [1-3]. We analysed a fragment of the pipeline with a diameter of 1420 mm, which was built in 1982-1983. The pipeline made of imported steel X70 is designed to work under pressure of 7.4 MPa. Pipe billets for the pipeline were produced at Khartsyzsk Pipe Plant.

The objective of this paper is to analyze the reasons for cracking in welded joints of main gas pipelines.

2. Experimental

To study the reasons of defect nucleation in welded joints as well as crack propagation from them (I), Figure 1a, b, comprehensive studies of a fragment of the main gas pipeline were conducted. They included mechanical testing (to evaluate mechanical properties of the metal in the weld zone), visual inspection, metallographic analysis (with the use of the AXIOVERT 40- MAT microscope). Thin sections were cut from a fragment of the pipe, which were then ground with sandpaper with gradual reduction in the grit. Finally, it was polished with the diamond paste. The prepared surface of the thin section was etched in the 4 % nitric acid solution in ethanol.

Mechanical testing of the specimen cut along the welded joint of the pipeline with an operating defect was performed under static uniaxial tension with the use of hydraulic testing machine R100 (Figure 1c, d). Fractographic analysis of the specimen's fracture surface was performed with the help of scanning electron microscope REM-106.

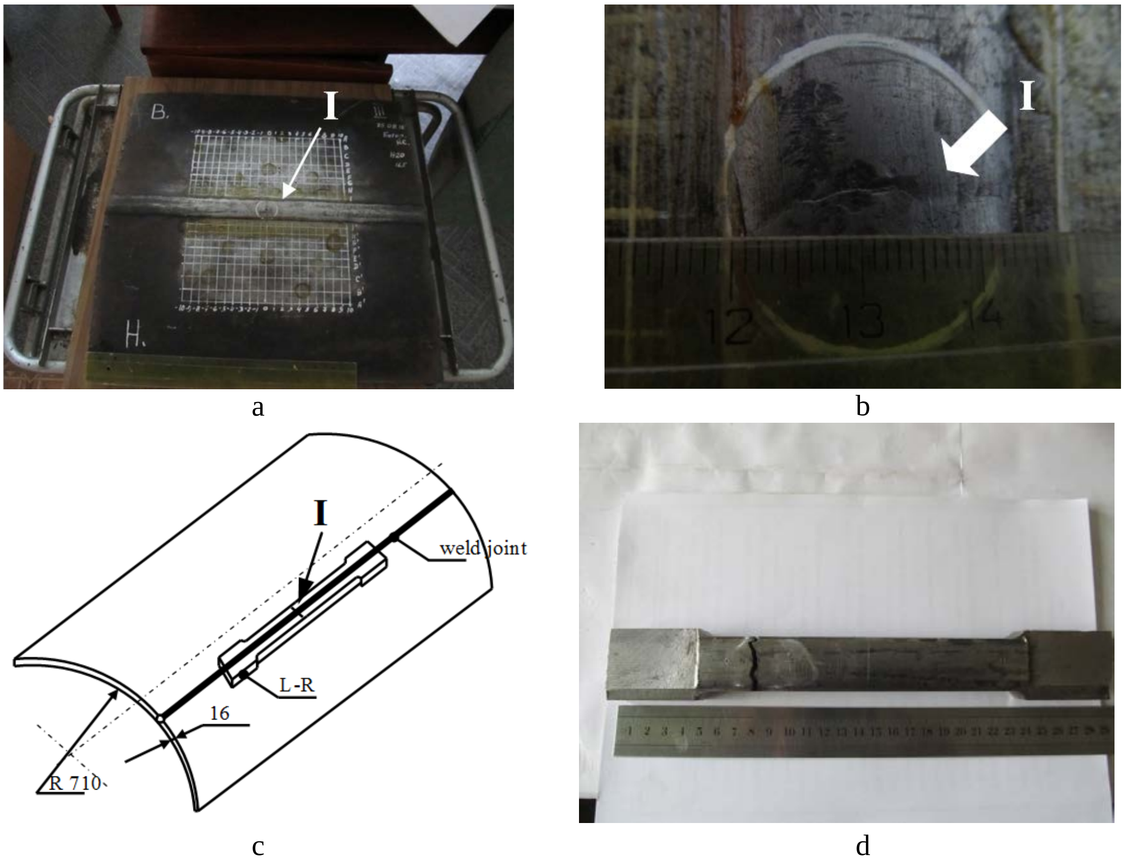
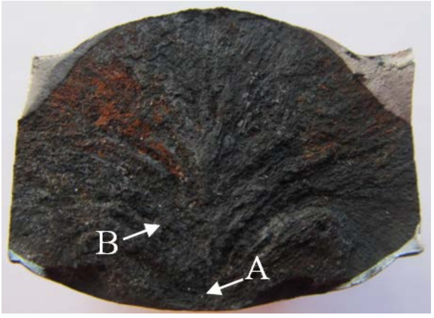


Figure 1. The general view of the pipe fragment (a) and the welded joint with a crack (b), the specimen cutting scheme (c) and the fractured specimen (d); I – defect.

3. Analysis of the fracture surface of the welded joint

The analysis of the specimen fracture surface has shown that it is covered with a layer of oxide scale without a metallic luster typical of cold cracks. In our opinion, the defect is a typical cold crack, Figure 2a. It was formed in the zone adjacent to the outer surface of the welded joint.

Based on the analysis of the fracture surface in the vicinity of the macroconcentrator with the use of the scanning electron microscope, the areas of nucleation (A) and growth (B) of the defect were revealed. It should be emphasized that almost the entire surface inside the defect was covered with a layer of corrosion, Figure 2c. However, its presence does not preclude observation of a 'chevron pattern', which 'rays' are oriented at the angle of 70-80 degrees to each other, Figure 2c. Given that the edges of the chevron pattern are always oriented towards the direction opposite to the crack propagation, the concentrator which initiates fracture behind the 'convergence' of the chevron pattern was revealed. This allows us to conclude that the crack occurred in the subsurface layer of the welded joint and propagated from the outer to the inner surface.



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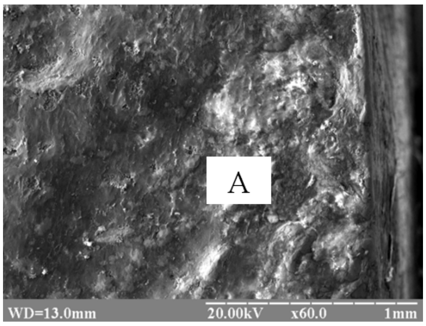

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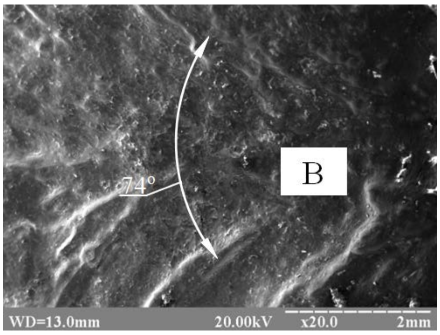

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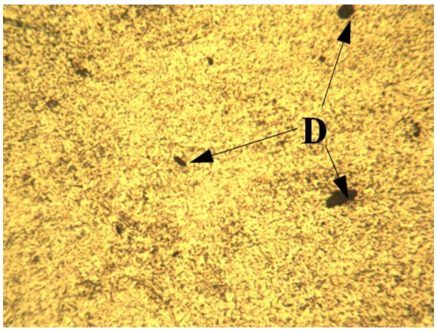
Figure 2. The general view of the opened crack in the welded joint, and the zone of its start (b) and propagation (c)

4. Metallographic analysis of the welded joint and discussion

The microstructure of the pipe X70 steel of the gas pipeline ‘Urengoy- Pomary-Uzhgorod’ cut out in different directions was studied in [1]. It is established that the microstructure consists of ferrite, fine pearlite and belongs to the ferritic-pearlitic class. The grain size corresponded to the 9-11 rank according to GOST 5639-82.



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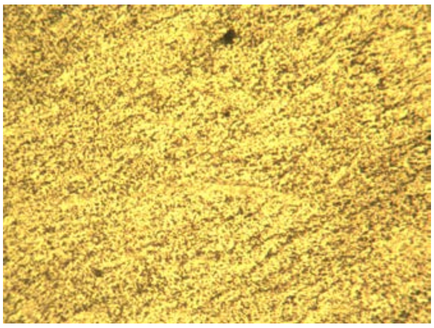

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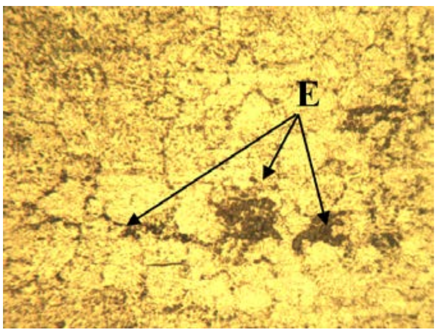

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Figure 3. The microstructure of the welded joint – ferrite-bainite mixture (×100); D – microdefects, E – damaging at the boundaries between ‘coarse grains’.

Fine crystallites of the 'ordered' structure were found in the structure of the welded joint. These crystallites can serve as an indicator [2, 4] of the direction of crystallization of the weld metal from a liquid state, Figure 3a. The structure of the weld metal represents a ferrite-bainite mixture, Figure 3b. In the vicinity of the area, where the crack nucleation took place, a weld overheating region was found, where 'coarse grains' were found. Their shape accounted for a significant length of weakened boundaries, and contributed to the formation of laminations during the crack formation process, Figure 3c. Metallographic studies conducted on etched thin sections allowed revealing small micropores in the area of crack propagation, which may serve as evidence of hydrogen impact on the weld material [5]. Defects of this type are known, which were found in the vicinity of a through transverse crack in the pipeline with a diameter of 1420 mm. The estimated technological reason for their formation is very rapid and uneven cooling of the welded joint. While analyzing metallographic images taken from the area of the welded joint, it was found that most probably the crack emerged on the surface of the welded joint in the areas with coarse grains. Numerous micropores with a diameter of a few micrometers and cracks oriented along the boundaries between several grains served as additional factors [6], which contributed to the formation of a macrodefect.

In our opinion, cracks were formed in the weld zone under the influence of damage accumulated in the grain boundaries [7, 8]. This damaging took place in the first hours after welding, however, it was scattered and could not coalesce, because the level of welding stress at the site was inadequate for its growth. After mounting the pipe in the pipeline, the local growth and coalescence of microdefects took place under the influence of operational factors. To our mind, this technological effect could be the 'imposition and summation' of welding and technological stresses, resulting in the localization of microdeformation processes. The additional impact could result from hydrogenation of the welded joint. Therefore, from the analysis of the damage, we can conclude that the defect was formed due to adverse structural and mechanical factors: the size of austenitic grain, a significant gradient of the grain structure in the weld zone, and the 'consolidation' of grains.

5. Conclusions

The analyzed crack of the welded joint was of the operational origin; however, its nucleation is a result of the impact of the earlier created technological microdefects that were formed during the welding. Fractographic and metallographic studies allowed revealing the area of crack nucleation and micromechanisms of crack propagation. The study of microstructural features of the weld zone and its comparison with the crack growth mechanisms made it possible to reveal the reasons of its origin, stages of nucleation and the growth of a macrodefect.

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