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VERIFICATION OF THE MATERIAL PROPERTIES OF THE STRUCTURE ELEMENTS OF COMPRESSOR STATION FOR THE NEEDS OF THEIR REDESIGN

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This paper discusses the importance and complexity prediction of fatigue life in connection with reconstruction or rebuilding of compressor station and in connection with degradation of material and change of its static and fatigue mechanical characteristics. The subject of the research is the piping ring, which was removed above a T-module of a turbocompressor of compressor station. The paper brings partial results of testing and analysis of the macrostructure and mechanical properties of the base material and the material in the weld area of removed piping ring.

Key words: piping systems, mechanical properties, fatigue fracture, macrostructure.

INTRODUCTION

Compressor stations are a part of technological equipment of strategic importance used for the transport and distribution of gas. They represent the typical constructions of the gas industry.

Considering their specific nature they can represent serious potential danger during a state of emergency. It is therefore of particular relevance to perform regular monitoring and checking in terms of strength and life. Any failure can lead to serious environmental disasters, severe economic damage and loss of life. Piping systems of compressor stations (Figure 1) are typically strained as a result of pressure pulsations (surge), pipe effects and other non-stationary phenomena [1].

In addition, time varying random process of stress occurs during operation in every piping system also due to other reasons.

This could be for example a system shutdown, or an operation start of the system, pressure changes due to operation issues and the like. In this way they can in long-term effect contribute to the depletion of life and forming of fatigue limit state.

In the specific considered case it was also important to assess the reliability of operation of the compressor station in connection with its rebuilding and reconstruction. This was mainly about the possibility of operating at compression ratios greater than 1,39 up to values in the range of 1,42 ÷ 1,43, and using vibroisolation elements. Furthermore, cracks were found on parts of individual piping systems, formation of which was assumed due to improper welding technology. Welding technology represents one of the main factors decreasing fatigue limit in the location of failure. This in turn can affect safe operation of a piping system as a whole.

In certain justified cases it is possible to repair a piping damaged by fatigue, corrosion or by other serious means in a non-destructive manner. One such method is the technology of split pressurized sleeve [2, 3]. In an extreme case it is possible to apply this solution even without reducing the pressure in the piping.

Prediction of residual fatigue life and therefore conclusions on safe operation of a technological complex in the future can be given only on the basis of full-scale experimental tests and measurements during the effect of random process of stress.

During prolonged use under the effect of operating factors, such as heat, conditions of static and dynamic loading, possibility of deformation, and others, metal of piping is prone to changes in mechanical properties, particularly to reduction in the reserve of ductility and

Figure 1 Part of a technological system of a compressor station for gas transport

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an increase in brittleness. This phenomenon has been tagged as “metal aging” [4].

The mentioned phenomenon and interaction of material must be taken into account when stating the conclusions of residual life based on experimentally determined degree of fatigue damage of structural elements of piping systems. An integral part of relevant expertise is therefore the assessment of the state or the degree of degradation of used construction material, including welds, changes in their mechanical properties, etc.

SUBJECT OF THE RESEARCH

Strength and life of the examined piping systems was closely tied to the critical points of the construction, such as piping joints, primarily realized by welds. Analysis of the material and fatigue properties and analysis of the structural composition therefore needed to be performed on used welded joints as well as on base material.

Mechanical properties and analysis of used construction material were determined by tests on corresponding specimens. These were acquired from a pipe section 720 x 22,2 mm, as shown in Figure 2. The piping ring was removed above a T-module ring – an inter-pressure turn to a turbocompressor, as shown in Figure 3.

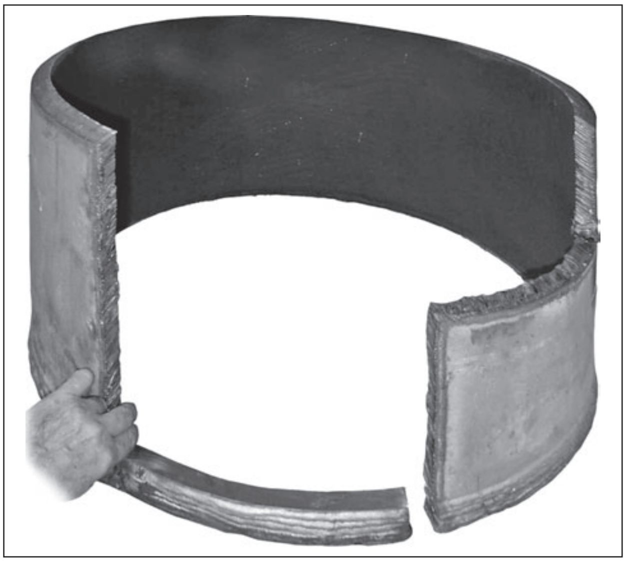

Figure 2 Piping part as source of specimens used in material tests

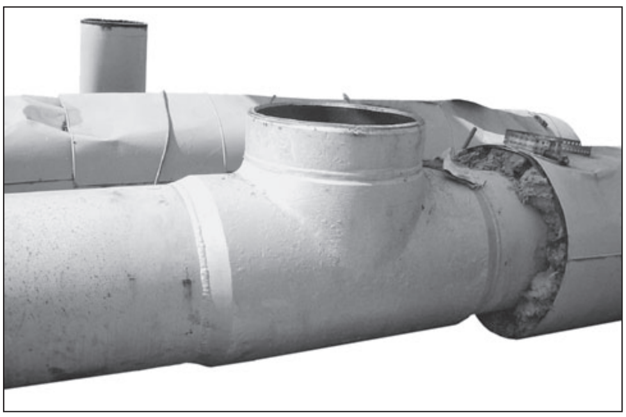

Figure 3 T-module ring – an inter-pressure turn to a turbocompressor

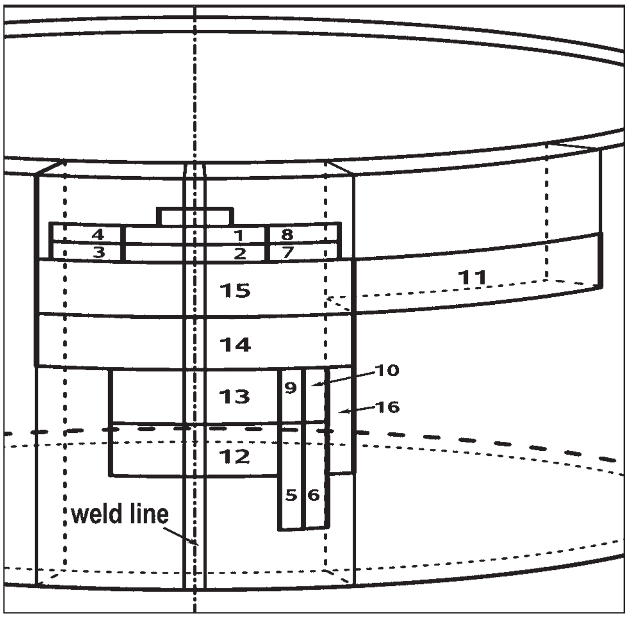

Figure 4 Identification of location of the specimes used in individual material tests

Sampling was done so that quantitative data about the properties of base material, material of welding metal and transition area of the weld could be determined. Figure 4 illustrates the identification of location of the specimens used in individual material tests. Performed were static tensile tests of the welding joint in direction perpendicular to the pipe axis and of the base material in direction perpendicular as well as parallel with the pipe axis. In addition, dynamic tests by impact in bending with type Charpy V notch, tests of fatigue properties in tension and bending of the base material and the welding joint.

RESULTS OF INDIVIDUAL ANALYSES

Results of the tests for modulus of elasticity are shown in Figure 5. These were acquired by experimental measurement using strain gages and testing machine

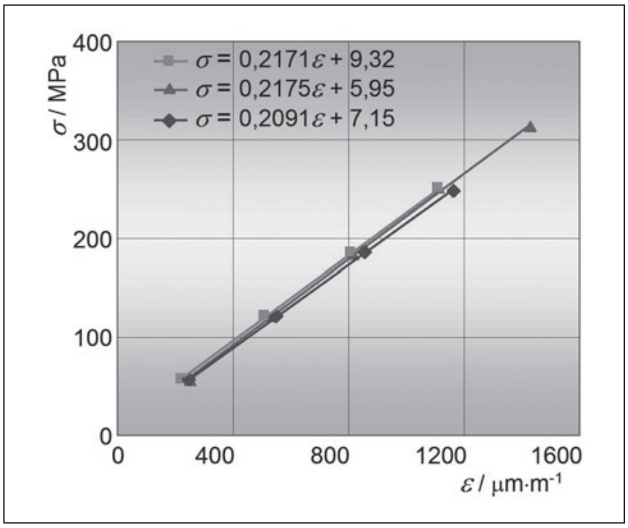

Figure 5 Experimentally acquired relationships for determination of modulus of elasticity E of the piping material

on a specimen similar to the one used in tensile test, removed from the ring in location 16 (Figure 4).

For the fatigue properties tests specimens were removed from the detached ring from location 11 and specimens containing weld from locations 12, 13 for test by flat bending and from locations 14 and 15 for tensile tests (Figure 4). Shape and size of the test specimens were selected so that the transition area of the weld was located in the thinnest part of the specimen. Tests were performed on a testing pulsator, which allowed dynamic tests during alternating symmetrical bending at loading up to 400 Nm. In first stage of the tests stress amplitudes σ_a = 240 MPa were selected. In this mode, specimens remained undisturbed even at $2{,}6\times10^6$ cycles. In second stage, the amplitude was increased to level σ_a = 450 MPa, which for given material already represents an area of low-cycle fatigue. Specimens failure occurred at level 8×10^3 cycles, with the shape of fatigue fracture according to Figure 6. Fatigue crack initiated at the edge of the test specimen according to Figure 7, in location of welding joint imperfection. Nature of the fracture line is illustrated on Figure 8 on the left. Fatigue crack spreading was also influenced by inclusions in base material and by rows of perlite. Secondary cracks parallel to rows of perlite are visible in Figure 8 on the right.

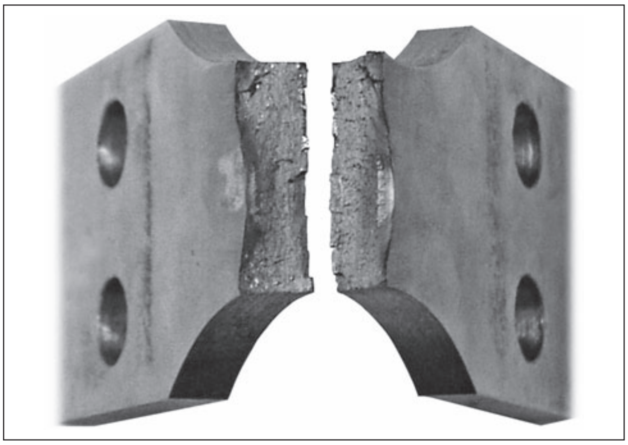

Figure 6 2 parts of specimen after the low-cycle fatigue test

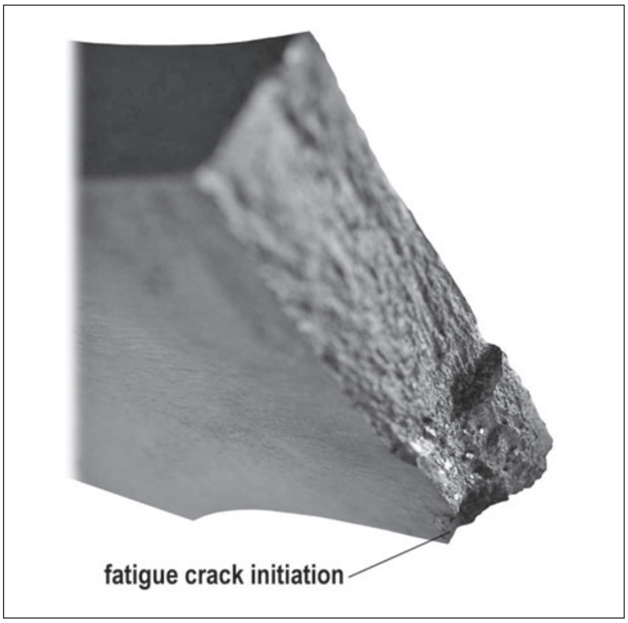

Figure 7 Test specimen failure during cyclic stress

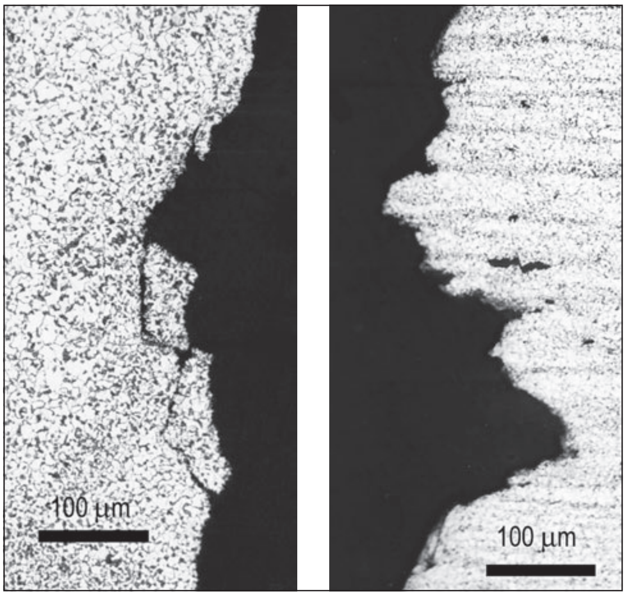

Figure 8 Profile of the fracture line on the failed test specimen and on the specimen with secondary cracks

The results of metallographic analysis show that under given conditions of stress initiation of fracture process occurred in the area of weld metal and the spread of the fracture itself took place in base material.

Figure 9 shows microstructure of the transition area. Microcracks were identified in the area of the welding joint, specifically on the intersection of weld metal (Figure 9 left) and heat affected area (Figure 9 right).

Weld metal is entire, shaped as “X” and comprised of multiple layers (Figure 10).

Microstructure of the base material (Figure 11 left) is ferrite-perlite of ferrite grain less than 0,015 µm. Characteristics of structure correspond to a state after

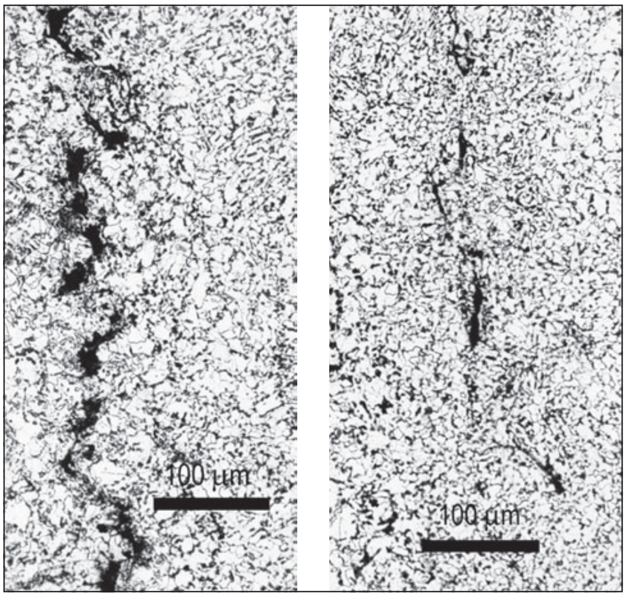

Figure 9 Microcracks in the area of welding joint and in the transition area

Figure 10 Cross-cut section of pipe wall with welding

annealing. Figure 11 in the middle illustrates transition from the heat affected area to the area of weld metal. Transition is smooth; ferrite-perlite structure is coarser with oriented arrangement. Figure 11 on the right shows microstructure in the area of weld metal. Structure consists of ferrite and perlite with directed arrangement of perlite. Structure also contains small cement particles.

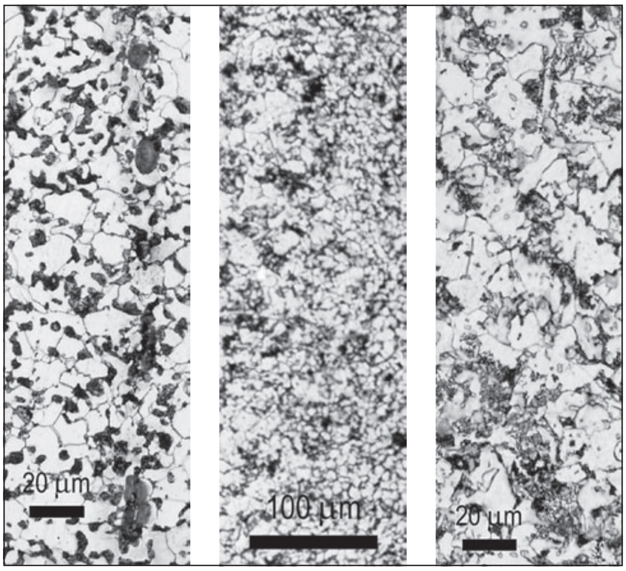

Figure 11 Microstructures: base material, heat affected area and weld metal

DISCUSSION

Tests of the mechanical properties of the material showed that the behaviour of the structure corresponds with a state after annealing, as confirmed by the results of metallographic analyses. The used materials and welding joints could be in terms of static and fatigue mechanical properties considered as satisfactory. Determined values of mechanical characteristics were also relatively consistent with the data available from the manufacturer. Tests of fatigue properties revealed that although the fatigue crack spread through base material, its initiation in the welding joint indicates lower quality of welds. In terms of resistance to fatigue failure welding joints were thus confirmed as critical points even when taking into account their lower quality.

CONCLUSIONS

In this manner we obtained important knowledge saying that, beside lower quality of some welds, mechanical properties of the base material and the material in the weld area remained unchanged. Degradation of used construction materials did not occur even after several years of operation under strained conditions. It is possible to conclude that the applied material in terms of the state of its properties and structure could contribute to reducing the fatigue life only to a minimal extent.

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