Arch. Metall. Mater. **62** (2017), 1, 99-104

DOI: 10.1515/amm-2017-0013

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# CAUSES OF THE CRACKS IN THE PIPELINE MADE OF THE 15HM STEEL

Issues referring to cracks in the pipelines made of the 15HM steel are described. Metallographic specimen of welded joints are provided. The results of impact strength tests, hardness tests and static tensile tests are given. Tests results as well as direct and indirect causes of the pipeline cracks are shown.

*Keywords:* pipeline, cracks, welding process, welded joint, welding defects

## 1. Introduction

Cracks in the welded joints are so called welding defects which entirely disqualify the steel construction for a further use. Difficulty in welding various kinds of steel contribute to the formation of cracks both during the welding process and after its completion, or in the course of the heat treatment [1-5]. Selective heating of joined materials to the melting temperature of the materials during welding followed by crystallization and cooling of the weld cause the stresses and deformations in the area of the joint [6-12, 19-20]. Cracks may also be a result of a prolonged operation of the system subjected to a high temperature of the flowing medium and vibrations [13-18]. If the possibility of deformation of the material or welds are exceeded it gets cracks in the weld or in the heat affected zone – HAZ. Types of cracks can be divided depending on the range of temperatures and their causes [2, 4]. This article describes the causes of the fatigue crack of the pipeline made from the 15HM steel.

## 2. A description of an object of the study

- Crack length of about 210 mm was created from the pipeline's side in the heat affected zone;
- The main crack extends through the entire thickness of the material along the outer border (from the material side) of the heat affected zone. HAZ from the crack's side is much wider than on the side of the collector (Fig. 1);
- The cross-section shows the final phase of the crack. Initiation occurred in the upper part of the weld (the face of the weld) and moves along the outer border of the heat affected zone and then into the zone. Definitely a wider lower part of the HAZ (Fig. 2);

Fig. 1. The main crack - a view from the outer side in the place of the welded joint

Fig. 2. The main crack from the pipeline's side extending through the HAZ – a cross section

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- In the lower generatrix of the pipeline at the place of the change of the thickness of the material are thermal shock cracks with a more visible crack of approximately 70 mm in length (Fig. 3);

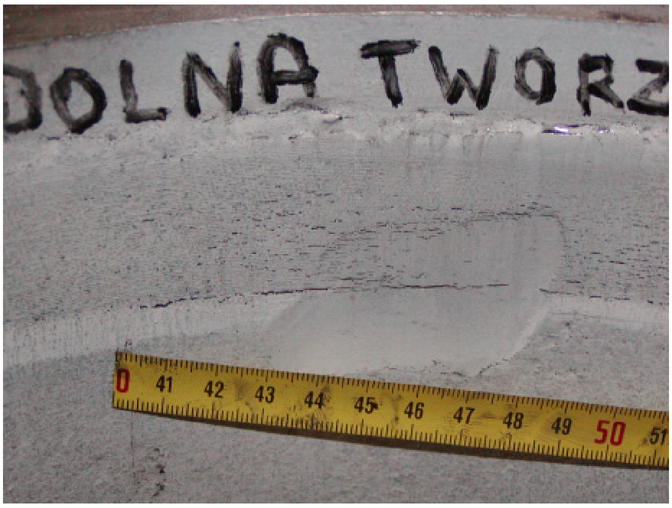

Fig. 3. Thermal shock cracks on the inside of the lower generatrix at a distance of 40 mm from an axis of the weld

- On the surface of the outer wall is visible the final phase of the crack in the HAZ from the pipeline's side (Fig. 4);

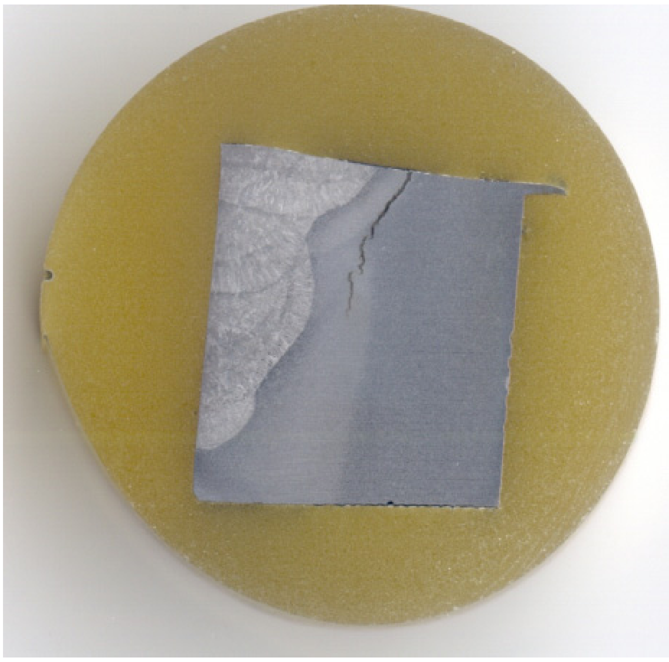

Fig. 4. The main crack from the pipeline's side in the HAZ – a cross section

- In the lower generatrix of the pipeline there is a crack of the weld from the root side of the weld in the root pass (Fig. 5);
- In the fusion line there are not any visible cracks. Heat affected zone in the grain layer is much narrower than in the lower part of the joint (Fig. 6)

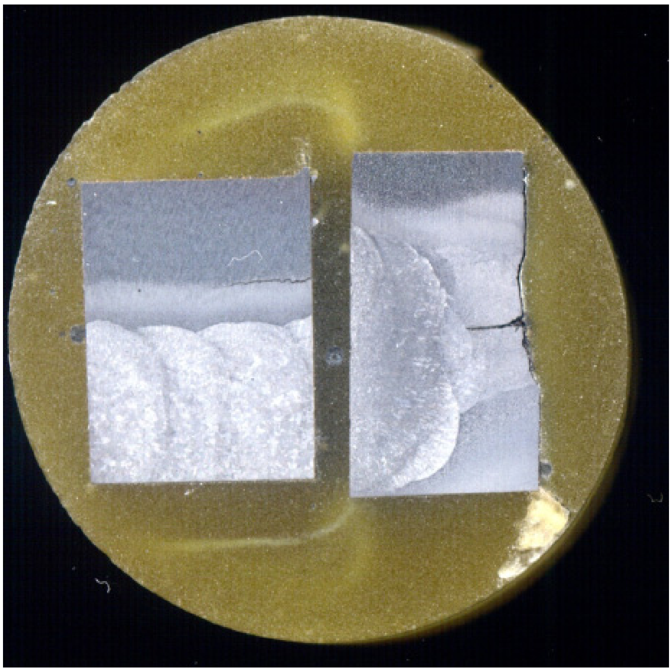

Fig. 5. The view from the face of the weld, an outer surface – a crack in the HAZ and a cross section – a crack in the weld from the root side of the weld

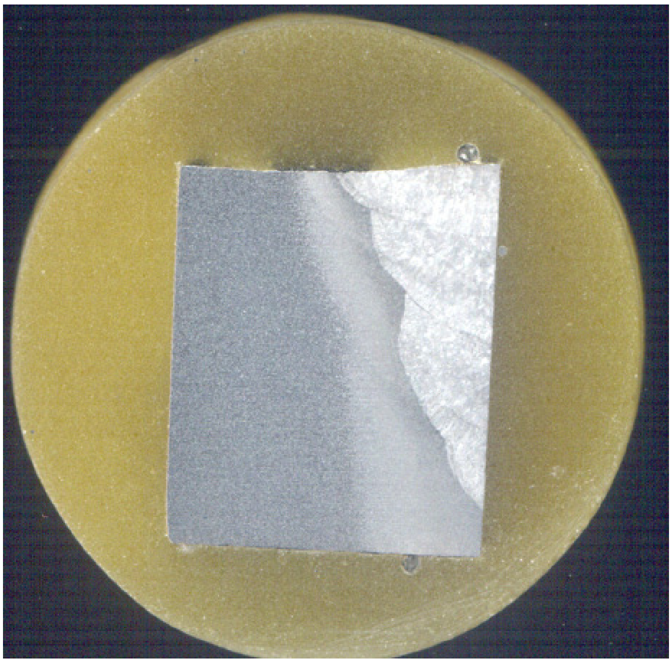

Fig. 6. A fusion line of the weld on the side of the collector – cross-section.

## 3. Metallographic examination

Metallographic examinations were carried out in selected areas of the material of the pipeline with the welded joint cut away from the pipeline on the outer surface and in the cross-sections (Fig. 7-11).

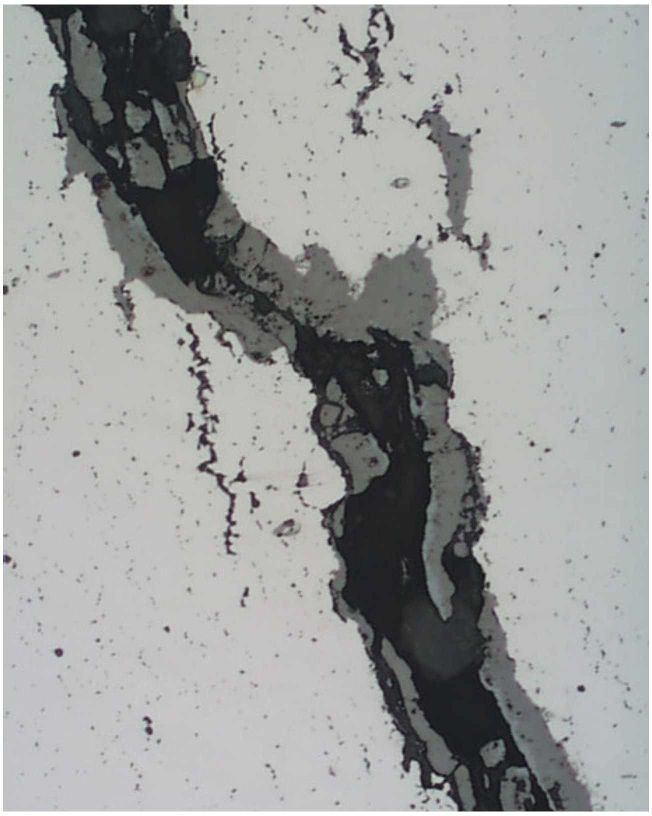

Fig. 7. Material / HAZ – the main crack (on the transition line of the HAZ – pipeline's material, parallel to an axis of the welded joint) with the grid of oriented microcracks partially filled with oxidation products. Unetched metallographic specimen. Zoom 200×

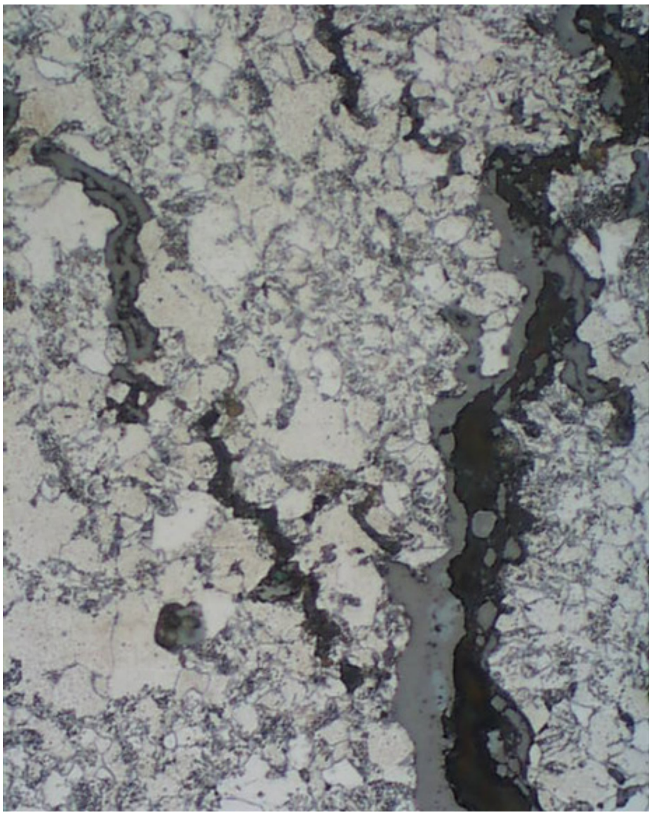

Fig. 8. HAZ – the bainite type of a structure. The disintegration of the primary structure, grids of intercrystalline macro and microcracks, and the chains of creeping micropores on the grain boundaries. Zoom 500×

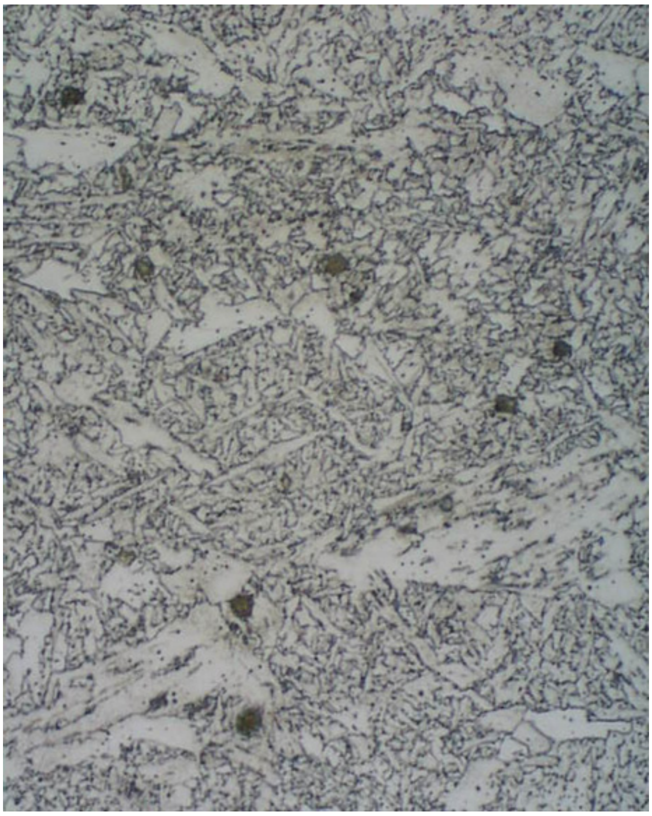

Fig. 9. The weld – a bainite type of a structure with a ferrite grid on the borders of a former austenite. There are visible single creeping micropores. A partial disintegration of the primary structure. Zoom 500×.

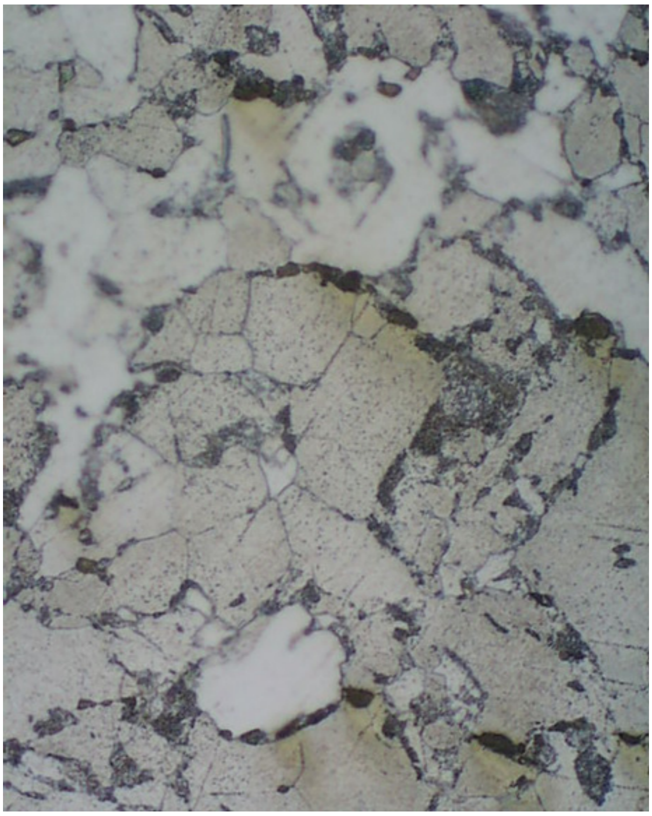

Fig. 10. A base material of the pipeline – a disintegration of the primary structure, grids of intercrystalline macro and microcracks, and the chains of creeping micropores on the grain boundaries. Zoom 500×

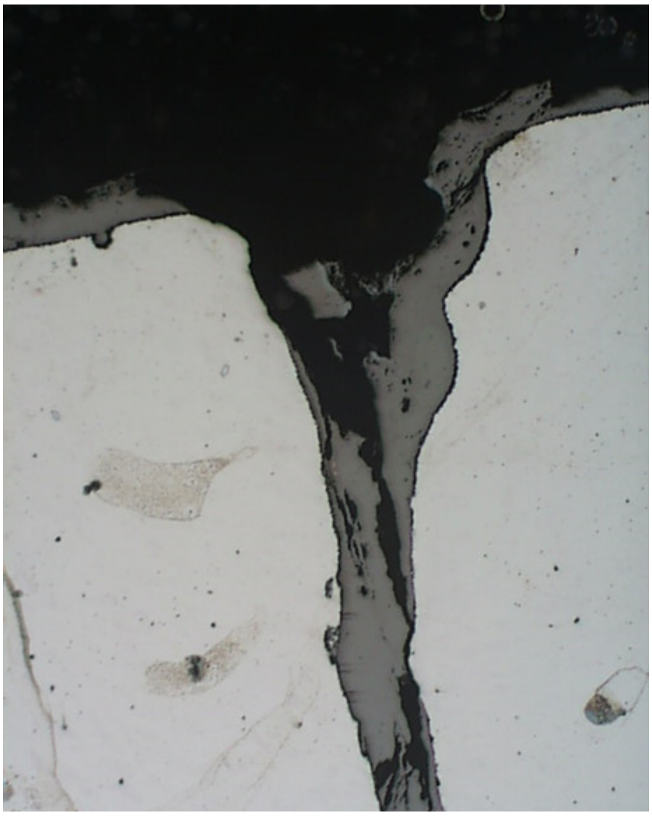

Fig. 11. A material of a welded joint (bottom generatrix – the root of the weld). A visible thermal shock crack with a distinctive wedge shape with the rest of the corrosion products. Unetched metallographic specimen. Zoom 50×

## 4. Hardness test

| No. | A place of measurement | Hardness measured, HV | | | Average hardness HV | Material |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| | Weld | 188 | 190 | 196 | ***191*** | 15HM |
| | HAZ from the attemperator's side | 202 | 209 | 212 | ***208*** | |
| | HAZ from the pipeline's side | 168 | 170 | 174 | ***171*** | |
| | Attemperator's material | 166 | 169 | 172 | 169 | |
| | Pipeline's material | 148 | 152 | 152 | ***151*** | |

## 5. Impact test

Impact test was done in accordance with the EN 10045-1 standard. There were samples taken from the section of the pipeline, in an amount of four pieces in the transverse section (TS) and longitudinal (LT). The following results are an average of four measurements.

TABLE 1

Results of the impact test

| No. | Sample code | Material | Heat | Direction, place of sampling | An initial energy of the hammer, J | An energy used to break, J | Fracture % | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ductile | Brittle |
| | 1/LT | 15HM | — | LT | 300 | 104 | 83 | 17 |
| | 1/TS | 15HM | — | TS | 300 | 79 | 90 | 10 |

## 6. Static tensile test

TABLE 2

The results of the static tensile test

| No. of a sample, position | Sample code | Size [mm] | $F_p$, kN | $F_m$, kN | $R_p$, MPa | $R_m$, MPa | $L_O$, mm | $L_U$, mm | $A_5$, % | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample no. 1 | ***According to the PN-EN 10002-1 + AC1 standard*** | 29,0 | 42,5 | 369 | 541 | 50 | 65,8 | 32 | 15HM |
| | Sample no. 2 | | 29,0 | 42,5 | 369 | 541 | 50 | 65,8 | 32 | 15HM |
| | Sample no. 3 | | 29,5 | 42,0 | 375 | 535 | 50 | 65,7 | 31 | 15HM |

## 7. Description of the tests' results

1. Impact tests at room temperature showed no decrease in an impact strength compared to the data contained in the PN-75 / H-84024 standard for seamless pipes. The nature of the ductile fracture is between 83÷90%.
2. Tests of mechanical properties performed at room temperature i.e. tensile strength $R_m$, yield point $R_e$ and elongation $A_5$:
   - show an adequate tensile strength $R_m$ of the steel 15HM for seamless pipes – according to the PN-75 / H-84024 standard,
   - comply with a minimum yield strength $R_p$ for the above mentioned steel,
   - elongation $A_5$ for the 15HM steel is higher than a required minimum value – according to the PN-75 / H-84024 standard.
3. Tests of chemical composition showed that a material of the pipeline corresponds to the type of the 15 HM steel, while the weld composition is suitable for welding this type of the material.
4. The results of the hardness tests (averaged measurements) made on the material attemperator, pipeline, weld, HAZ

from the collector's side, and the HAZ from the pipeline's side are within the limits laid down in the PN-75 / H-84024 standard.

5. The tests and structural analysis showed that:
   - HAZ from the pipeline's side directly on the main crack corresponds to the structural changes SIII and physical degradation DV class. A degree of exhaustion was determined at 100%;
   - base material in the vicinity of the main crack of the pipeline corresponds to the structural changes class SIII and physical degradation DIV. A degree of exhaustion was determined at 85%;
   - base material of the pipeline (bottom generatrix) corresponds to the structural changes SII / SIII and physical degradation DI class. A degree of exhaustion was determined at 45%;
   - a weld corresponds to structural changes SII and physical degradation DII class. A degree of exhaustion was determined at 45%
6. Macroscopic tests showed that:
   - the main crack was formed along the outer boundary of the HAZ (from the side of the material) and extends through the entire thickness of the material – the crack length approx. 210 mm;
   - in the lower generatrix of the pipeline at the place of changing the thickness thermal shock cracks were observed;
   - There are not any visible cracks from the collector's side in the fusion line

## 8. Summary

The results of tests and measurements of the elements of the communication pipeline allow to reach the following conclusions:

- An immediate cause of the welded joint damage was probably a combination of internal stresses of both the pipeline and the weld, and additional permanent stresses caused by an improper operation of fixtures as well as the variable stresses caused by the wrong compensation of the thermal expansion. An accumulation of such a large amount of stresses could lead to a considerable excess of an allowable stress. A confirmation of such an actual state of stresses was a very large displacement of the ends of the pipeline after cutting off a damaged welded joint.
- An indirect reason of a damage of the welded joint was a process of creeping caused by a long-term influence of elevated stresses and a high temperature on the material of the welded joint. Creeping effects in the form of micro- and macro-cracks are visible especially in the transition from the HAZ into the base material in the pipeline.
- In addition to the above-mentioned defects there are also fatigue cracks (thermal shock cracks). These are typical cracks for this type of areas of communication pipelines located in the area of the collector of the lower generatrix of the pipeline probably caused by an improper operation of the nozzles or cracked protective T-shirts. The scale of observed fatigue cracks, however, is disproportionately smaller than the cracks that caused damages.
- It is necessary to ensure that the correct heat treatment was performed during the welding process and after its completion.
- In order to avoid future failures of this type of communication pipelines it is routinely recommended as a diagnostic test to do the following:
  - an inspection (especially fastening elements);
  - magnetic examinations of girth welds and bends of elbows;
  - ultrasonic testing of girth welds and elbows in order to determine a presence of cracks;
  - structural examinations of the weld material and the outer surface of the bends of elbows by the triafol replicas method;
  - measurement of the thickness of the walls' elbows and the measurement of their deformation (diameter).
- In addition, because of the type of damage that led to the failure, it is also recommended to check the routing of pipelines, inspection and measurement of a reaction of fastenings, which are the following:
  - determine whether the route and the location of the pipeline are consistent with the documentation;
  - measuring a position of the pipeline in the cold and hot states (preferably geodesic);
  - calculation of the hysteresis of the pipeline's displacement (benchmarks required)
  - measurement of the fastenings response (dynamometrical) in the cold and hot states;
  - determine whether a condition and location of fasteners are in accordance with the documentation.
  - If, in the future, this type of the joint will be made, it is vital to examine the WPS carefully.

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