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A WET-STEAM PIPELINE FRACTURE

PRELOM CEVOVODA ZA VLAŽNO PARO

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The operational reliability of a system determines the system's availability and costs during its lifetime. Taking care of the reliability usually starts with knowledge of the operating conditions that need to be considered during the design, fabrication and maintenance of the system. In the case of a system or component failure, it is necessary to know the causes and the degradation mechanisms. An analysis of a fractured low-pressure wet-steam pipeline from a heat exchanger was performed. The fracture was located in the fillet weld's heat-affected zone. Visual testing, chemical analysis, hardness measurements and metallographic examinations were carried out. The fracture surface was quite damaged, and so the number of fatigue-crack propagation cycles could not be determined. An examination of the microstructure revealed that the fatigue crack occurred in the heat-affected zone, where the plasticity and toughness had been diminished due to the material overheating at the welding. As a result of the fracture analysis the industrial facility concerned extended the scope of its inspection of wet-steam pipelines.

Key words: pipeline, fracture, examination, fatigue failure

Zanesljivost obratovanja je lastnost sistemov ali komponent, ki določa njihovo razpoložljivost in stroške v trajnostni dobi. Skrb za zanesljivost je tudi poznanje pogojev obratovanja, ki jih je treba upoštevati med konstruiranjem, izdelavo in uporabo sistema. Pri okvari sistema ali komponente pa je treba natančno poznati vzroke in mehanizme degradacije. Zaradi tega je bila opravljena analiza preloma nizkotlačnega cevovoda za vlažno paro izmenjevalnika toplote. Prelom je nastal v toplotno vplivani coni zvarjenega spoja. Izvedena je bila vizualna kontrola, kemijska analiza, meritve trdote in metalografska preiskava. Površina celega preloma je bila precej poškodovana, zato na njej ni bilo mogoče ugotoviti v koliko korakih je nastala utrujenostna razpoka. Preiskava mikrostrukture je odkrila, da se je prelom cevi izvršil v območju, kjer je bila plastičnost, z njo pa tudi žilavost, zmanjšana zaradi spremembe mikrostrukture pri varjenju zaradi pregretja materiala. Na osnovi rezultatov analize preloma je bil v industrijskem obratu povečan obseg kontrole cevovodov za mokro paro.

Ključne besede: cevovod, prelom, preiskave, utrujenostni prelom

1 INTRODUCTION

Reliability is defined as the probability that a certain system will operate for a given time and under given conditions without failure. Therefore, if a failure occurs it is wise to analyse the system and determine the probable cause of the failure[1]. In the case of metals, one of the most commons reasons for failure is fatigue. Fatigue failure is the phenomenon leading to fracture under repeated or fluctuating stresses that are less than the tensile strength of the material. There are three stages of fatigue failure: initiation, crack propagation, and final fracture[2]. The initiation site is always very small, never extending for more than the size of a few grains around the origin. The point of initiation is located at a stress concentration and this stage may be extremely small, and so difficult to distinguish from the succeeding stages of propagation and crack growth. However, after the original crack is formed, it becomes an extremely sharp stress concentration that drives the crack even deeper into the metal with each stress cycle. Whenever there is an interruption in the propagation of a fatigue fracture, characteristic marks or ridges may be observed.[3] As the propagation of the fatigue crack continues, gradually reducing the cross-sectional area, it eventually weakens the material so much that final, complete fracture occurs.

After 25 years in operation a failure occurred in a low-pressure wet-steam pipeline. This failure was not a catastrophic one, but it was severe enough to halt the operation of the system. **Figure 1** shows a sketch of the pipeline and the position of the fracture. In this case the fracture occurred in the heat-affected zone of the flange's fillet weld.

The dimensions of the tube were ϕ 60 mm × 4.8 mm. No other data were available about the tube material or the welding procedure used.

2 EXAMINATION

The fractured part of the pipeline was cut away from the broken tube and the flanges. There are a number of

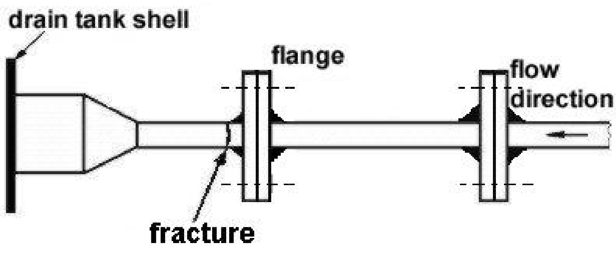

Figure 1: Sketch of the wet-steam pipeline with the fracture
Slika 1: Skica cevovoda mokre pare z mestom preloma

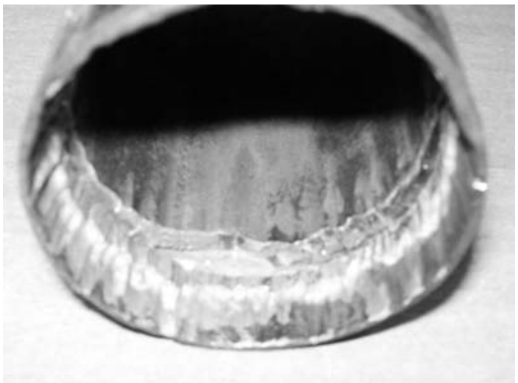

Figure 2: Tube with fracture and erosion-corrosion damage
Slika 2: Cev s prelomom in poškodbami zaradi erozije – korozije

methods available for the detection and analysis of fatigue cracks[4]. In this case it was decided to carry out a careful visual examination, a chemical analysis, hardness measurements and a metallographic examination.

3 RESULTS AND DISCUSSION

3.1 Visual examination

A visual examination of the inside area of the fractured tube revealed a substantial loss of metal, which is shown in **Figure 2.** The minimum thickness of the tube was 3 mm. The affected area was smooth with wavelike countours[5]. The minimum distance between the affected area and the fracture was of 6 mm. Flanges are not shown on **Figure 2**, becouse they were cut off.

The metal loss is oriented along the direction of the wet steam's flow and it is a classic feature of erosion-corrosion, which can be defined as the accelerated degradation of a material resulting from the joint action of erosion and corrosion when the material is exposed to rapidly moving droplets of water in a steam flow[6].

Figure 3 shows the tube's fracture surface. One area of the initial crack is marked with the number 1, and it is shown in more detail in **Figure 4**. It is clear that the initial crack propagated in the circumferential direction more quickly than in the radial direction.

Figure 3: Tube fracture surface
Slika 3: Površina preloma cevi

Figure 4: Fatigue crack surface
Slika 4: Površina utrujenostne razpoke

The microstructure in the initial and fatigue-crack propagation area is typical for an overheated steel. In the area subject to the highest temperature the microstructure consists of a mesh of ferrite around large grains of pearlite with many Widmanstätten ferrite needles. Such a microstructure has a low deformability and a low toughness and as such has a low fatigue strength.

Ridges are visible on the fracture surface marked with the number 2 in **Figure 3**. The details are shown in **Figure 5**.

The ridges are parallel with the tube's circumference. This kind of surface morphology is typical of rapid crack propagation in steel without significal deformation. A cross-section of the tube was cut and prepared for

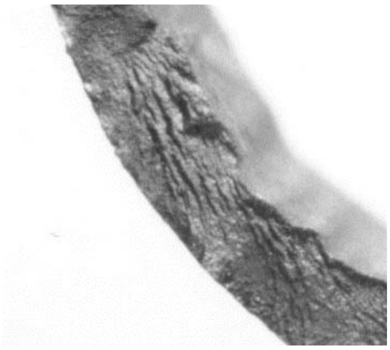

Figure 5: Ridges on the fracture surface
Slika 5: Brazde na površini preloma

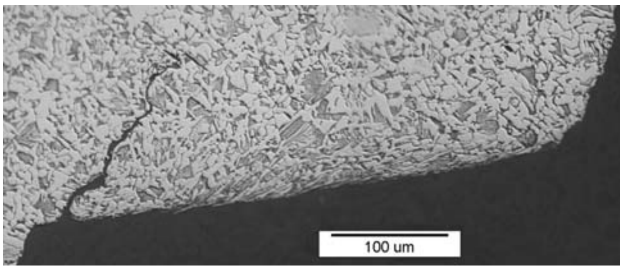

Figure 6: Crack on the fracture surface
Slika 6: Razpoka na površini preloma

metallographic examination. The crack in **Figure 6** shows transcrystal propagation typical for fatigue.

3.2 Chemical analysis

The chemical analysis of the tube material was made with an ICP optical emission spectrometer[7]. This chemical composition is listed in **Table 1**.

Table 1: Chemical composition of the tube in mass fractions, *w*/%
Tabela 1: Kemijska sestava cevi v masnih deležih, *w*/%

C	Mn	Si	P	S	Cr	Ni	Mo	Al
0.21	0.74	0.17	0.003	0.017	0.04	0.01	0.02	0.012

A comparison of the values in **Table 1** with the reference data[8] shows that the chemical composition of the tube corresponds to the steel grade ASTM A 106 Gr. B, which is widely used for the manufacturing of tubes.

3.3 Hardness measurement

A sample of the fillet weld was prepared for hardness *HV* 0.3 measurements. The results are shown in **Table 2**. The hardness indentations were 0.1 mm apart, starting in the base metal, continuing across the heat-affected zone (HAZ) and on into the weld deposit metal.

Table 2: Hardness *HV* 0.3 across the fillet weld
Tabela 2: Rezultati meritev trdot *HV* 0,3

base metal													
1.	138	2.	142	3.	141	4.	141	5.	139	6.	141		
heat-affected zone													
7.	153	8.	145	9.	145	10.	152	11.	154	12.	156	13.	163
14.	162	15.	175	16.	165	17.	174	18.	165	19.	159	20.	162
21.	178	22.	176	23.	175	24.	171	25.	177	26.	178	27.	177
28.	173	29.	194	30.	199	31.	192	32.	199	33.	196	34.	199
35.	203	36.	201										
weld deposit metal													
37.	214	38.	211	39.	210	40.	212	41.	214	42.	218	43.	217
44.	213	45.	210	46.	215	47.	211						

The average base metal hardness is *HV* 140.3; and it is within the standard values for A 106 Gr. B steel. The highest values measured were not in the HAZ, as would be expected, but in the weld deposit metal. The average value was *HV* 213, which should be considered as being relatively high.

3.4 Metallographic examination of the fillet weld

The fillet weld between the tube and the flange, with the base metal and the HAZ, is shown in **Figure 7**.

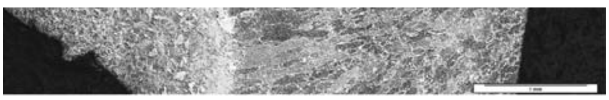

Figure 7: Fillet weld with heat-affected zone
Slika 7: Kotni zvar s toplotno vplivanim področjem

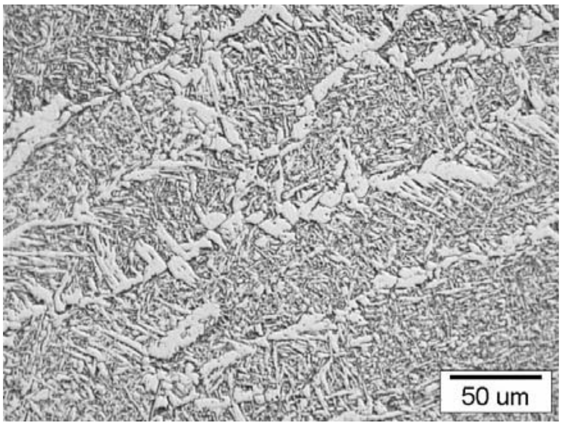

Figure 8: Microstructure of the fillet-weld deposit material
Slika 8: Mikrostruktura deponiranega materiala zvara

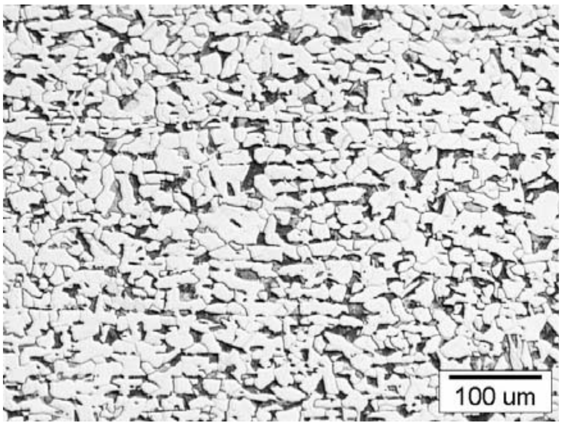

Figure 9: Microstructure of the tube's base metal
Slika 9: Mikrostruktura osnovnega materiala cevi

There is clear evidence of columnar crystals in the weld deposit metal. The microstructure consists of bainite with a small amount of ferrite in the grain boundaries after the transformation (**Figure 8**). The grains of austenite in the HAZ near the fusion line grew in size because of the overheating.

At the cooling cooling the austenite transformed into pearlite, bainite and a ferrite net. The microstructure of the base metal (**Figure 9**) consist of uniform grains of ferrite and pearlite. The wide HAZ indicates a very large input of heat during the welding.

4 CONCLUSION

After our examinations we can conclude that the fracture occurred in an area where plasticity and toughness were diminished with the overheating during the welding. The fracture took place in two stages. In the first stage a fatigue crack started to grow from one point on the outer tube surface. The propagation of this fatigue crack was much faster in the circumferential direction than in the radial direction. During the second stage the crack propagated even faster, this time without any plastic deformation. The fracture surface was damaged, and so it is impossible to determine how many steps it took for the fatigue crack to start and how many steps it took for the final fracture to take place. Based on available data we can conclude that the main cause of the fracture was a local increase in the bending stresses on the outer tube surface because of uncontrolled, possibly resonant, vibrations of the wet-steam pipeline during the start up or the shut down of the system.

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