Investigation of a steam pipeline leaking in a nuclear powerplant

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The article deals with the real defect, a crack that occurred on a part of the steam pipeline of the separator and the steam superheater of the turbo-generator in the V2 nuclear power plant (NPP) in Jaslovské Bohunice. The damage was caused by the mechanism of erosion-corrosion, which led to a reduction of the pipe wall with the critical thickness. The main cause of the failure was identified to be the usage of unsuitable steel, instead of the required steel EN 10028-2, during the reconstruction of the pipeline.

INTRODUCTION

The corrosion and erosion stability of operating components is one of the most important presumptions for the long-term and safe operation of all nuclear facilities, and this also applies to steam pipelines. The article presents the results of the material properties evaluation and the chemical composition of the damaged part of the steam pipeline, where the leak was detected. The damaged pipe was originally a part of the T-piece marked as 56T (Figure 1, yellow arrows show steam flow in the pipes).

Fig. 1. Leaking on steam-pipe – red ellipse

According to the documentation, the parameters of the pipeline at the leak location shall be:

material:	EN 10028-2
dimension:	Ø 219×6,3 mm
length:	1400 mm
pressure:	1,487 Mpa
temperature:	197,9 °C
dryness:	0,9153 %
mass flow:	5,34 kg/s (for one separator)

Part of the evaluation of the pipe´s damage was to verify the quality of the pipe´s material with the conditions specified in the regulation and to determine the cause of the leak.

Macroscopic analyses

During the photographic documentation of the pipeline damaged parts in the delivered state (2 pcs of the pipeline), its initial macroscopic analyses was also fulfilled from the outer and inner side of the pipes. The outer surface of the pipes appeared to be fine and undamaged. However, the area of the leak was squeezed and

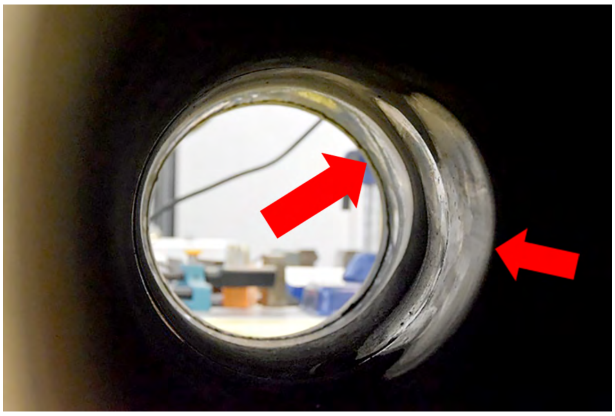

Fig. 2. Polished surfaces inside the pipe

deformed, which may have been caused by multiple moving of pipe samples before those were delivered to the laboratory.

Inside the pipes, the presence of visually polished surfaces were found on both analysed samples, as well as large areas with deposits. The polished surfaces are clearly visible in Figure 2. According to the distribution of the shiny surface, it can be concluded that these are the surfaces that were most affected by the steam stream after its dividing by passing through the component 56T. It was found that the greatest decrease in the thickness of the pipe´s material wall occurred precisely in the area where polished surfaces occurred.

Macroscopic analyses – sample M2.1

The delivered pipe pieces were cut into smaller samples, for the analyses. This was also the case with the M2.1 sample shown in Figure 3. This sample was also analysed in a detail using a stereomicroscope during which the following was found:

- the measured length of the leak is approximately 41.8 mm;

Fig. 3. Sample M2.1

- the material of the sample showed no signs of damage from the outer side;
- the pipe material was partly polished, and partly with traces of damage that appears with erosion corrosion from the inner side (Figure 3);
- the greatest loss of material occurred in this area.

The erosion-corrosion occurs in a fast-flow media environment. It is often caused by a disruption of the passive or other protective layers, which should protect the metal surface against active dissolution during moderate flow.

As it is shown in Figure 3, particles remained trapped in some of the pits, which can escalate the disruption of the oxidation layer. Some could remain trapped there even after the pipeline was shut down, and subsequently a small layer of iron oxide formed around them (orange coloured areas).

Chemical analyses

To verify the chemical composition of individual parts of the pipeline, three samples labelled M1, M2 and M3 were prepared. M1 is the mark of the sample from the material coming from the T-piece, behind which the damaged piece of pipe of size 1400 mm was welded. M2 is the mark for the part of the pipeline with damage (1400 mm length bounded by welds). M3 is the pipe material located behind the damaged part of the pipeline. The results of all three samples' chemical analyses are presented in Table 1.

The samples M1 and M3 comply with the EN 10028-2 standard in terms of chemical composition as can be seen from the results. However, the M2 sample did not comply, which means that it is not the same material, but probably EN 10028 steel.

It is a stainless, constructional, heat-resistant, carbon steel, with a guaranteed yield strength at higher temperatures, which is suitable for components of thermal

Tab. 1. Chemical analyses results

Standard or sample	Element									
	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al
EN 10028-2	0.10 ÷ 0.18	0.40 ÷ 0.70	0.15 ÷ 0.35	max. 0.040	max. 0.040	0.70 ÷ 1.30	–	0.40 ÷ 0.60	–	–	–
Sample M1	0.15 ±0.01	0.56 ±0.02	0.24 ±0.02	0.011 ±0.002	0.014 ±0.003	0.94 ±0.01	0.37 ±0.01	0.42 ±0.02	0.008 ±0.001	0.041 ±0.003	0.009 ±0.002
Sample M2	0.10 ±0.01	0.33 ±0.01	0.21 ±0.02	0.014 ±0.002	0.016 ±0.003	0.051 ±0.003	0.020 ±0.002	<0.01	0.005 ±0.001	0.09 ±0.01	0.007 ±0.002
Sample M3	0.15 ±0.01	0.58 ±0.02	0.25 ±0.02	0.014 ±0.002	0.017 ±0.003	0.95 ±0.01	0.38 ±0.01	0.43 ±0.02	0.009 ±0.001	0.042 ±0.003	0.008 ±0.002
EN 10028	0.07 ÷ 0.15	0.35 ÷ 0.60	0.17 ÷ 0.35	max. 0.040	max. 0.040	max. 0.25	max. 0.25	–	–	max. 0.25	–

energy equipment, pressure vessels, chemical equipment, or pipelines. However, due to the lower Cr content, compared to steels of class 15, it has a lower resistance to erosion corrosion.

Metallography

In Figure 4 is shown the cut plan for the sample marked M2.3. The A cut was chosen at the border between the polished surface and the captured deposits. It is an area where the loss of the base material of the pipe was not so significant. This passing is very well visible in Figure 4. In the polished state, it is nice to see that the deposits have two layers in Figure 5. The first layer is probably formed with its own oxides from that area. It´s because the layer is thin, homogeneous and of equable thickness. The second layer, which is significantly inhomogeneous and has a variable thickness, was probably gradually deposited on top of the original layer of oxides. In the case of the inhomogeneous layer of deposits, it can be said that these are released material oxides from the polished areas of that pipe together with other particles brought from other parts of the pipeline. This is supported by the findings in the C cut (Figure 6).

Fig. 4. Sample M2.3 with markings of cuts for metallographic analyses

This is the place the most affected by the loss of material on sample M2.3. As can be seen, erosion corrosion occurred in this exact spot. No layer of protective or other oxides is visible here. The deformation of the outer grains of the inner surface is visible. This deformation was caused by the impacts of particles or droplets contained in the steam.

The last metallographic evaluation of sample M2.3 was performed in the area of the D cut. It is a part of the sample, located right after checkpoint 56T. The border between the C and D cuts was located approximately in the middle of the weld. Beyond the boundary of this weld (in the direction of steam flow), a rapid change in material loss is visible (Figure 4). In contrast, before the weld, there is a material with minimal change in its thickness. This part of the pipeline was chosen precisely to compare possible changes in the structure of the material. As can be seen from the figures, in Figure 7 the microstructure is significantly finer, together with a higher pearlite content, when compared to the microstructure captured in Figure 6 (or Figure 5).

However, it is fair to say that the surface in Figure 7 is like Figure 6 without visible protective oxides. and quite distinctly fractured. Similarly, deformations of surface grains are not absent after the impact of small particles/droplets contained in the steam. Nevertheless, a significantly increased resistance of the used material was observed with this sample. This implies that D cut contains a more suitable material for a specific use, and it corresponds to the regulation and standard EN 10028-2.

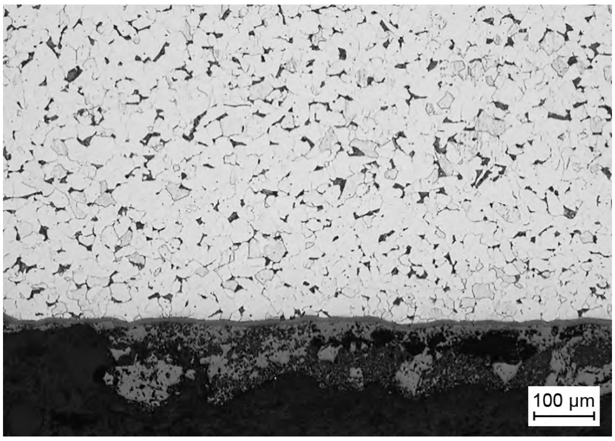

Fig. 5. A cut

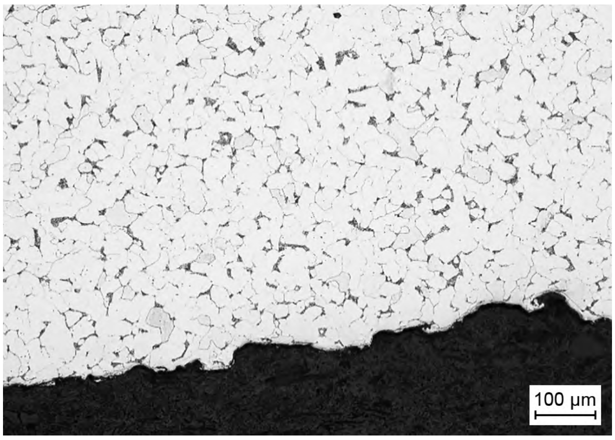

Fig. 6. C cut

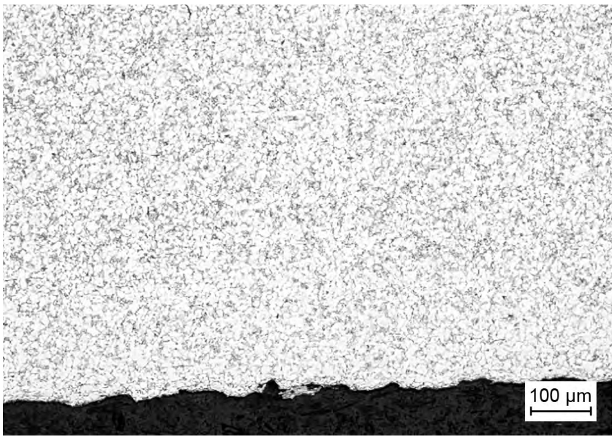

Fig. 7. D cut

DISCUSSION

Using the analyses individually for each sample, it was demonstrated that during the general repair of the pipeline the relevant part of the pipeline. behind component 56T was switched in terms of used material, EN 10028-2. Based on the instruction. the material EN 10028-2 should have been used. Since the analyses results it is probably the material EN 10028. This is indicated by the results of chemical, mechanical, and metallographic analyses.

The pipe leak itself occurs as a result of the erosion-corrosion mechanism on a relatively small area. On its surface was a constant mechanical removal of the formed oxide layer, and therefore a constant reaction between the inner surface of the pipeline and the water steam was running. Also, small particles of oxides from other areas of the pipeline were carried in steam. Those particles were subsequently hitting the exposed spot after their passing through the 56T component. This accelerated the corrosion of the pipe wall from the inner side.

CONCLUSIONS

Based on the above findings and obtained results, it can be stated that:

- during the reconstruction works on the pipeline route of the seventh sampling, change of material in the part of the pipeline behind checkpoint 56T was identified;
- EN 10028-2 material was not used, but lower class of material EN 10028, which is insufficient under required operating conditions;
- it can be said that there was no damage to the inner surface of the pipeline with the pipe parts made of EN 10028-2 steel;
- the main cause of the leak was the replacement of the standard material with a material with very low Cr content, which under these conditions caused a significant reduction in the resistance of the given part of the pipeline against erosion damage;
- during the accelerated thickness reduction of the pipe wall, the strength was exceeded in the analysed place and a leak appeared.

NPP operating personnel were advised to:

- consistently use the prescribed material during repairs;
- checked mainly the chemical composition of the material used in future repairs.