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The Reasons of Steam Pipeline Elbow Rupture

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Abstract

In the paper the reasons for steam pipeline's elbow material rupture, made of steel 13CrMo4-5 (15HM) that is being used in the energetics. Based on the mechanical properties in the ambient temperature (R_m, $R_{p0,2}$ and elongation A_5) and in the increased temperature ($R_{p0,2}^t$) it was found, that the pipeline elbow's material sampled from the ruptured area has lower $R_{p0,2}$ i $R_{p0,2}^t$ by around 2% than it is a requirement for 13CrMo4-5 steel in it's base state. The damage appeared as a result of complex stress state, that substantially exceeded the admissible tensions, what was the consequence of considerable structure degradation level. As a result of the microstructure tests on HITACHI S4200 microscope, the considerable development of the creeping process associates were found. Also the advances progress of the microstructure degradation was observed, which is substantial decomposition of bainite and multiple, with varied secretion size, and in most cases forming the micro cracks chains. With the use of lateral micro sections the creeping voids were observed, that creates at some places the shrinkage porosities clusters and micro pores.

Keywords: Materials used in the power industry, The degradation of microstructure, Steel 13CrMo4-5, Mechanical properties

1. Introduction

The issues, that regards the evaluation of the durability of the technical condition and the flawless exploitation of the steam pipelines are the most important tasks of the diagnostic services. The durability, and the ability to evaluate it is one of the main criteria of the planning method, scope optimization and schedule of the repairs not only for the pipelines, but also all materials used for important elements in the energetics [1-4]. After defined period of exploitation of the pipelines, the structural changes, combined with structure degradation processes, reveal themselves, their classification is being shown in Table 1.
These processes, combined mainly with bainite and perlite decomposition, are quite dangerous phenomenon, that leads to breakdowns, which financial and safety consequences are hard to anticipate. So it must be sought, to identify the potential places of already existing cracks occurrence and the areas of increased breakdown risk before exploitation admission for another period of time [5-8].

2. Scope and purpose of research

The goal of this dissertation is to determine the reasons of the damage (crack) of the steam pipeline's elbow made of alloyed steel 13CrMo4-5 after 300 000 hours.
In order to achieve the assumed goal, the scope of work included:

- technical documentation analysis,
- mechanical properties testing (R_m, $R_{p0,2}$ and elongation A_5) in ambient and increased temperature (A_5^t and $R_{p0,2}^t$),
- microstructure survey,
- summary and exploitation recommendations.

Table 1.
Classification of microstructure degradation processes in steam pipeline material

<table>
<tr><th>Damage processes</th><th>Structure changes</th><th>Secretion processes</th><th>Structure class</th><th>Depletion level</th></tr>
<tr><td rowspan="5">0 / A</td><td rowspan="2">0</td><td rowspan="3">0</td><td rowspan="2">0</td><td>0.1</td></tr>
<tr><td>0.2</td></tr>
<tr><td>I</td><td>1</td><td>0.3</td></tr>
<tr><td rowspan="3">I / II</td><td>a</td><td>2</td><td>0.4</td></tr>
<tr><td rowspan="3">a / b</td><td>3</td><td>0.5</td></tr>
<tr><td rowspan="2">B</td><td>4</td><td>0.6</td></tr>
<tr><td rowspan="4">II</td><td>5</td><td>0.7</td></tr>
<tr><td>C</td><td rowspan="3">b</td><td>6</td><td>0.8</td></tr>
<tr><td rowspan="2">D</td><td rowspan="2">7</td><td>0.9</td></tr>
<tr><td>1.0</td></tr>
</table>

A – single pores; B – oriented pores; C – micro cracks; D – macro cracks. 0 – no structural changes; I – partial decomposition of the bainite/perlite areas; II – total decomposition + carbides; a – coagulation, carbides growth in bainite; carbides on the grain edges; b – decomposition and balling of carbides, carbides net.

3. Research method

The static tensile test (tensile strength R_m, yield strength $R_{p0,2}$ and elongation A_5) of the steam boiler pipeline's elbow in the temperature of 20°C, conducted as per the standard PN-EN-10002-1+AC1 on Instron 3382 machine, using the transfer factor of 20:1 and fixed tensile speed of 5 mm/min. The tests for tensile samples in temperature of 500°C ($R_{p0,2}^t$), were done as per the standard PN-EN-10002-5, on Amsler 200 machine, in the load of the 40 kN. Twelve tests of each was conducted, and two extreme were rejected.

The micro sections were prepared as per the standard procedure, with grinding, polishing and pickling with solvents appropriate for a given material. Initial evaluation of the structure was conducted with the use of Hitachi S4200 microscope. Micro sections were done of the cross-section of the pipes in the area, where the internal damage occurred and without observed cracks. The replica of the structure was prepared with the use of triafole film with acetone, sputtered with carbon or gold. The observation of the microstructure was conducted with the use of scanning electron microscope, with magnifications 500 to 2000.

4. Research results

The chemical content of 13CrMo4-5 steel is being shown in the Table 2.

Table 2.
Chemical content of the construction alloyed 13CrMo4-5 steel (%wt)

Chemical content of 13CrMo4-5 steel									
C	Mn	Si	P	S	Cu	Cr	Ni	Mo	Al
0,15	0,56	0,21	0,036	0,033	0,21	0,89	0,28	0,49	0,02

The photo of the steam pipeline elbow and the crack is being shown on the Figure 1.

The sampling areas for the mechanical properties testing (in the crack area and outside) has been shown on the Figure 2.

a)

b)

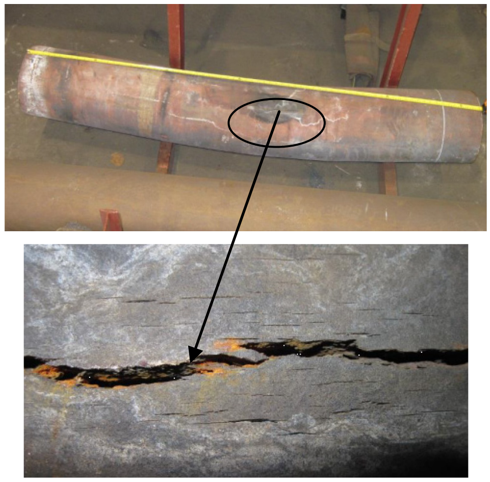

Fig. 1. Pipeline elbow subjected to testing: a) overview; b) the elbow's crack area

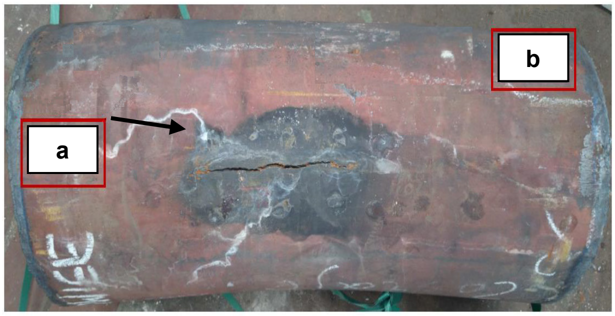

Fig. 2. (a, b) The areas from which samples were taken for mechanical properties testing: a) damaged area, b) not damaged area

The result of mechanical properties for 15HM steel in the areas damaged and not damaged (in the temperature of 20°C) is being shown in the Tables 3 and 4.

Table 3.
Mechanical properties of 13CrMo4-5 steel in the ambient temperature (20°C) close to the crack (a)

Item	Mechanical properties		
	R_m, MPa	$R_{p0,2}$, MPa	A_5, %
1	466	286	26
2	476	288	26
3	465	286	25
4	469	291	25
5	470	282	26
6	467	282	27
7	470	289	25
8	471	288	26
9	474	290	26
10	472	288	27
Mean	**470**	**287**	**26**

Table 4.
Mechanical properties of 13CrMo4-5 steel in the ambient temperature (20°C) in the area that was not damaged (b)

Item	Mechanical properties		
	R_m, MPa	$R_{p0,2}$, MPa	A_5, %
1	497	312	29
2	501	316	27
3	500	320	28
4	497	316	28
5	495	311	28
6	500	313	28
7	499	315	27
8	501	317	28
9	496	314	29
10	496	315	29
Mean	**498**	**315**	**28**

The results for the same mechanical properties in the damaged area and without crack in the increased temperature (500°C) are shown in Tables 5 and 6.

Table 5.
Mechanical properties of 13CrMo4-5 steel in the increased temperature (500°C) close to the crack (a)

Item	Mechanical properties	
	$R_{p0,2}^{500C}$, MPa	A_5^{500C}, %
1	193	32
2	196	31
3	197	30
4	192	33
5	190	32
6	189	32
7	192	33
8	192	33
9	190	32
10	189	32
Mean	**192**	**32**

Table 6.
Mechanical properties of 13CrMo4-5 steel in the increased temperature (500°C) in the area that was not damaged (b)

Item	Mechanical properties	
	$R_{p0,2}^{500C}$, MPa	A_5^{500C}, %
1	230	30
2	228	29
3	229	28
4	232	29
5	228	29
6	227	30
7	228	29
8	230	29
9	226	30
10	232	30
Mean	**229**	**29**

Out of the data shown in the Tables 3-6 comes, that the 13CrMo4-5 steel material sampled from the place where crack occurs has lower yield strength $R_{p0,2}$ and $R_{p0,2}^{500C}$ of about 2% from the requirement for the same steel in it's base state as per the standard PN-74/H-74252. The material sampled from the area without any internal damages complies with the requirement of mentioned above standard.

Next stage of defining the reasons of the pipeline's elbow cracking were the structural research. The sampling places for representative samples for micro structure testing are shown on the Figure 3.

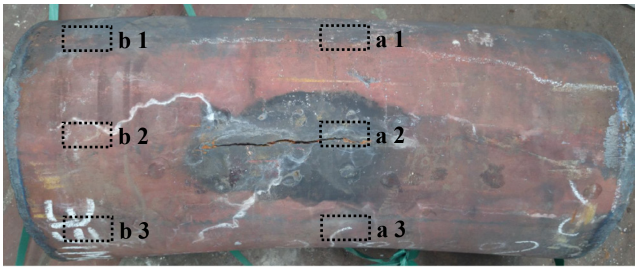

Fig. 3. The sampling places for representative samples for micro structure testing: a) damaged area, b) not damaged area

The replicas of the pipeline's elbow of the not damaged area (fig 3b) with different magnitudes are shown on the Figure 4, and those of the damaged area (Fig. 3a) on the Figure 5.

The SEM micro structures of the areas without damage and of those with damages are shown on the Figure 6.

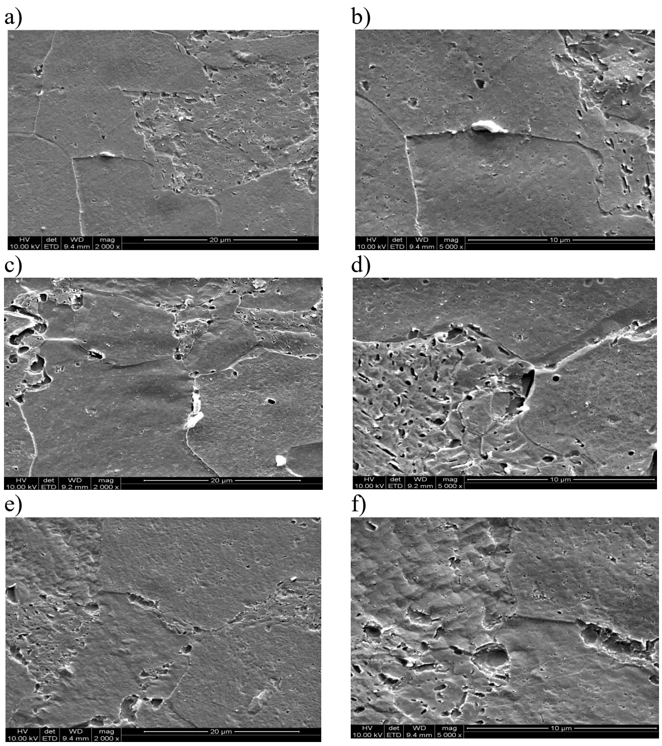

Fig. 4. The microstructure of the tested pipeline's elbow, from the area without the damage: a and b) area b1; c and d) area b2; e and f) area b3 with different magnitudes

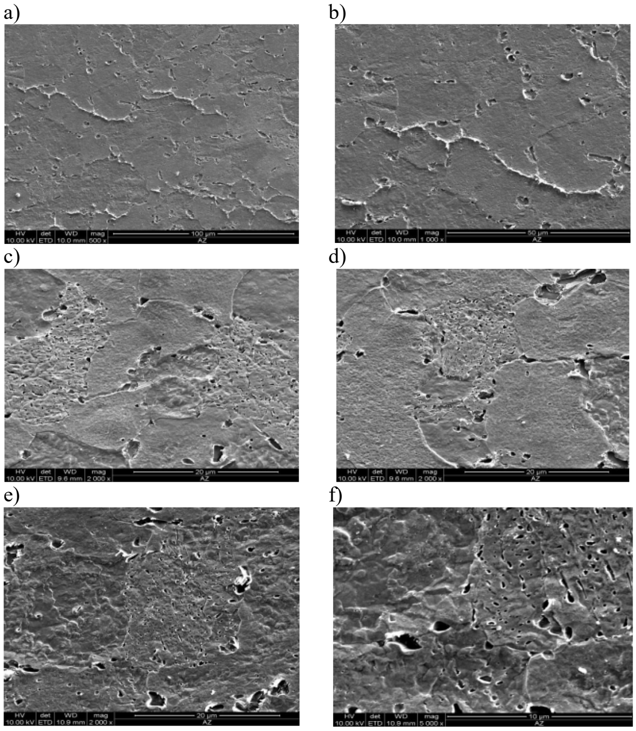

Fig. 5. The microstructure of the tested pipeline's elbow, from the area with the damage: a and b) area a1; c and d) area a2; e and f) area a3 with different magnitudes

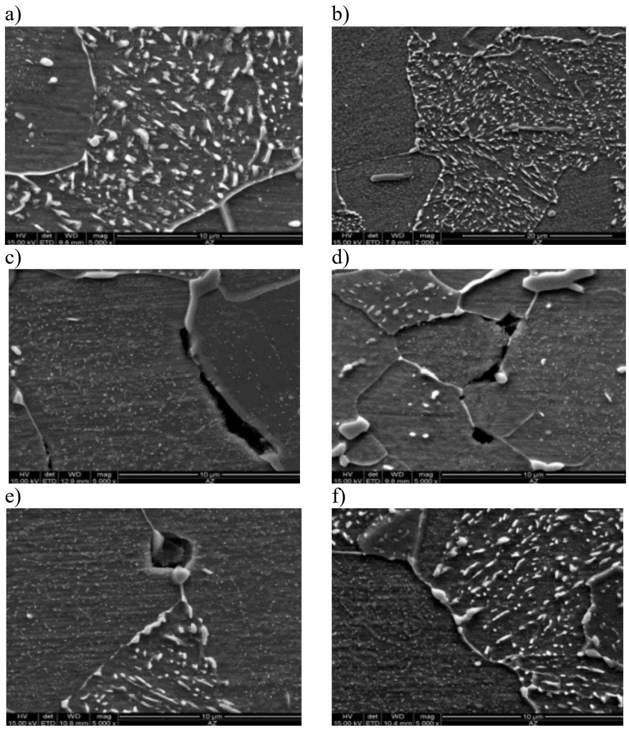

Fig. 6. The microstructure of the tested pipeline's elbow: a, c, e) of the area without the damage, b, d, f) of the area with the damage

5. Summary

In the paper the reasons for steam pipeline's elbow material rupture, made of steel 13CrMo4-5 after 300000 hours of operation in the overheated water steam conditions.

The conducted tests proved, that the pipeline's elbow rupture happened as a result of complex tension system, which substantially exceeds the admissible tensions. One of the degradation factors was the natural and at the same time – considerable structure damage level, notes both in the damaged area (areas: a1; a2; a3) and outside the damaged area (areas b1; b2; b3).

Out of the micro structure tests it comes, that in the not damaged areas the structure depletion is the same as in the base material, and the changes are on the level I (Table 1) what equals to partial decomposition of bainite/perlite areas. In the areas where the damage was observed, the structure depletion level is B/1, and the micro structure changes are on the level I/II, what equals to decomposition of bainite/perlite secretions, and carbide balling, with distinctive micro-cracks net.

On the basis of the conducted tests it may be stated, that the exploitation of the tested pipeline can be continued with maintaining certain exploitation regimes, with special consideration for pipeline's material temperature increase, which should not exceed 490^{o}C. In the balance exploitation time, the use of the pipeline should be limited to minimum.

References

[1] Dobosiewicz, J. (1999). *Investigations of thermal and mechanical energy*. Warsaw: Gamma.

[2] Dobosiewicz, J. (1984). Problems extend the life of the plant. *Power Engineering.* 7.

[3] Trzeszczyński, J. (2010). Assessment of and life prediction for the critical components of thermo-mechanical power equipment intended to be operated beyond 300 000 hours. *Power Engineering.* 2(Pro Novum), 806-812.

[4] Trzeszczyński J. (2008). Material Diagnostics on-line of thermal-mechanical power. *Power Engineering.* 1(Pro Novum), 279-283.

[5] PN-EN 10216-2 (2009).

[6] Trzeszczyński, J. (2008). Remote diagnostic systems for the evaluation of the technical condition of thermal-mechanical Power In Real time. *Power Engineering*. 836-839.

[7] Trzeszczyński, J. & Stanek, R. (2013). Management the maintenance of the technical condition of boilers on the basis of risk analysis. *Technical Supervision.* 269(6), 136-141.

[8] Trzeszczyński, J. & Stanek, R. (2013). Failure Frequency Analysis of a 200 MW Power unit critical elements as an Important Component of a Service Life Prediction Methodology. *Power Engineering.* 6, 505-508.