Failure of steam line causes determined by NDT testing in power and heating plants

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ABSTRACT. This paper examines leakage and damages of steam and provides an overview of NDT testing in order to determine the cause of steam lines failure in power plants and heating plants. This approach may be applied to similar structures and its application in preventive maintenance would help extend the life of steam pipes.

KEYWORDS. Steam line; Failure; NDT testing.

INTRODUCTION

Steam lines and high pressure pipelines are vital parts of the thermal power plant system. In fact, they are the connection between the boiler and turbines in power plants or boilers in power stations and customers in heating plants. They are critical components in power plants and heating plants and have a significant impact on the reliability and availability of power plants and heating plants. Continuous exploitation in very hard working conditions can lead to relatively frequent system steamline failure. Damages on steam line elements may appear well before it is expected, and not just as a result of internal pressure and temperature, but also as a consequence of the loads that occur due to poor design and inadequate maintenance. Also, damage of steam line elements may appear because of numerous on-off switching of the boiler as well as misuse of start diagram. Failures of steam lines, other than direct material damage, could jeopardize the safety of personnel and equipment. Among the causes of these failures inadequate operation and maintenance takes a high rank. Leaking of steam lines caused by material creep is expected if number of hours spent in operation is higher than design number of hours. Fig. 1 shows part of steam line of heated vapor in block 1 on TPP "Kolubara A" - Veliki Crljeni (near Belgrade). The RA, RB and RC line thermal units 1 to 5 span lenghts of 200-300 m and capacities of 300-500 t/h. During its operation there were relatively frequent delays caused by defects of supporting structure [1, 2], and in extreme case even failure or steam line leakage, which is usually explained by gaps in technology development and mishandling.

Figure 1: Part of the steam line during NDT.

TECHNICAL DIAGNOSTICS

During the operation period, fatigue of steam line components may occur. Degradation of material properties and deformation of elements can be accelerated due to the exploitation and repair errors, that's why periodic or continuous diagnostic measurements, conducting periodic tests and data collection programs defined by [1, 2] are needed. In this way, processes that could lead to the creation of system damage are under systematic control, what is also the legal obligation imposed by the regulations, directives and harmonized standards [3 - 5].

Properly conducted technical diagnostics protects parts of the steam line from accident, and also ensures safer conditions for employees as well as rational techno-economic exploitation and maintenance.

Technical diagnostic of steam lines must be based on three basic principles:

- volume of tests and measurements shall be in accordance with the program of research [1] and an expert knowledge of steam line structure and working conditions;
- tests and measurements must be performed in accordance with special procedures, using appropriate equipment and qualified personnel;
- test results should be presented in such way that the conclusions include steam line operating conditions, the availability of the test team and staff with appropriate experience and knowledge in the field of design, construction, installation, operation, maintenance, reliability, fracture mechanics and others.

NDT TO DETERMINE CAUSE OF STEAM LINE FAILURE

For purpose of determining the causes of failure it is necessary to make steam line 100% visual inspection, magnetic, penetrant, ultrasonic, hardness and method of replica testing.

If necessary, other tests that would give us a reliable and useful results to determine causes of steam line failure could be done. Fig. 2 shows the possibility of evaluating some damage using NDT methods in the life of the steam line.

Visually optical control (VT)

VT is used to detect defects that are visible on the surface of the steam line from the outside or inside of the tube. It applies regardless the method to be applied after it, because it is possible to detect errors, such as in our case, and avoid the use of other, more costly methods of NDT. It is often used for the selection of critical areas of the facility for the application of other NDT testing methods.

At the same objects it may be performed multiple times (eg, before and after cleaning, or before and after the execution of corrosion protection, etc.).

Control of the inside of the tube (endoscopy) allows optical access to the interior of steam lines. It is performed using an endoscope, and as a result we get control of video or photograph controlled inner surface, Fig. 3.

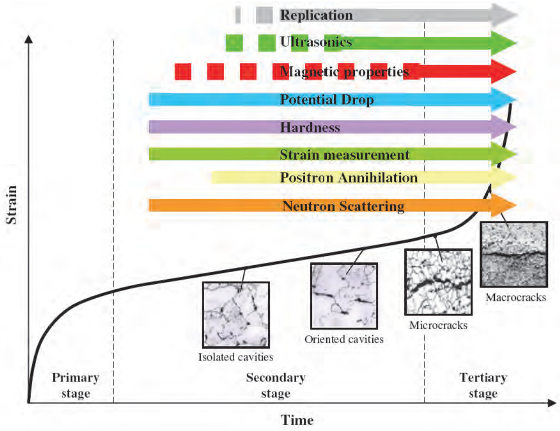

Figure 2: Application of NDT methods in detecting defects in the life of the steam line [6].

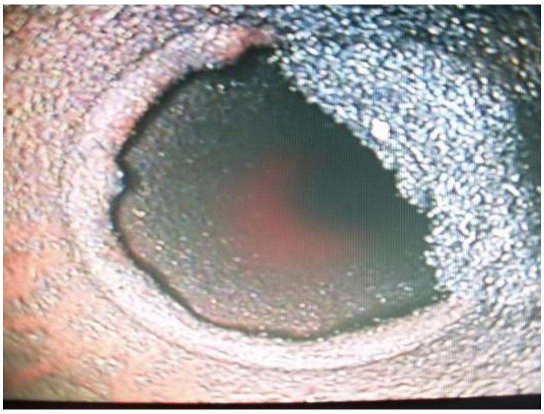

Figure 3: Photo of interior surfaces steamline.

Magnetic particle testing (MT)

The method is based on emphasizing the stray magnetic flux caused by the presence of surface or subsurface defects like cracks, notches, inclusions and other types of sharp or planar defects. Advantage of the method is that it requires a moderate cost, and if done correctly, you get a very good sensitivity for the detection of surface defects. The disadvantages of this method is that it could only be appllied to ferromagnetic materials as well as the potential need for degaussing after completing the testing. The method is commonly used for the detection of cracks and other defects in weld joints, castings and forgings.

Ultrasonic testing (UT)

The method is based on detecting changes in acoustic resistance due to the presence of cracks, voids, inclusions, and general physical separation in the material. The advantage of the method is that is also applicable to the thicker material, it is excellent for detecting and locating cracks and other defects, and it is suitable for automation. The biggest disadvantages are the need for a medium on the surface to be tested (or complete immersion of testing item in contact medium), as well as the request that surface on which the probe is moving is relatively smooth (ie cleaning needs, grinding the metallic shine). The most common application is to detect and precisely determine the position of defects in plate, welded joints (and butt and fillet) steel castings and forgings (if their geometric configuration allows). Application of this method for testing materials with high attenuation of ultrasound energy (for example, high alloyed austenitic steels, cast bronze ...) is difficult and can be done only under special circumstances.

Hardness testing (HT)

For evaluation of properly applied heat treatment after welding, hardness testing of the base metal, HAZ and weld materials are performed. At the same time, hardness and hardness differences must be within the limits of applied materials. In Tab. 1. the recommended values of hardness [7] of materials that are commonly used to produce steam line are shown.

Materials	Hardness [HV]		
	Base materials[2]	Weld joint	Heat Affected Zone (HAZ)
1.5415 15 Mo3	140-190	≤260	320
1.7335 13CrMo44	135-185	≤270	320
1.7380 10CrMo910	140-190	≤280	320
1.7715 14MoV63	145-190	≤280	320
1.7745 15CrMoV510	140-215	≤280	320
1.4922 X20CrMoV12-1	215-265	≤300	350[1]

[1] Hardness value of 350 HV must not be exceeded in the HAZ

[2] For cold-rolled sections such as tube bends in the base material greater hardness for HV 60 are allowed.

HB ≅ 0.95HV; $\sigma_M \cong 1/3$HB

Table 1

Method of replica testing (REP)

Metallographic examination, Fig. 4, the surface layer of material of pipe bends, weld joints and pipes on the old steam pipe RA 10 block A1, is conducted by the method of nondestructive testing of materials, using metallographic replica, according to [8].

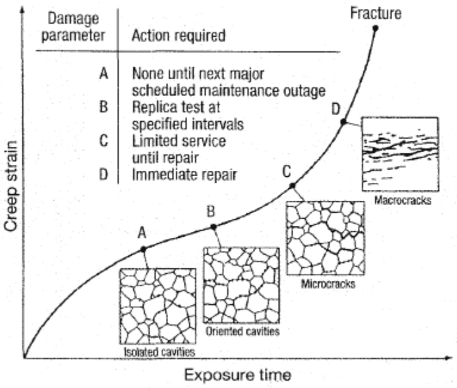

Figure 4: Overview of possible damage to the established method of replica [9].

In order to detect the microstructure of materials, adequate preparation is made of tested surfaces, and that included cleaning and a range of fine sanding operations. After the final polishing and cleaning, the test surfaces were eroded with appropriate reagent, ie. 4% nital.

DETERMINING DAMAGES

Structures of the steam line is exposed to the low cycle fatigue loads. This load caused a fatigue damage of pipes and leakage of steam lines on observed object, Fig. 5, which was confirmed by visual inspection.

After that, NDT methods are used for testing the steam pipeline section and supporting structure before and after damage. Fig. 6 and 7 show the measurement of control and testing methods, NDT, and in Tab. 2 and 3 the results of measurements of diameter and wall thickness of the damaged part of the steam line are listed.

Figure 5: Determination of damage by visual inspection.

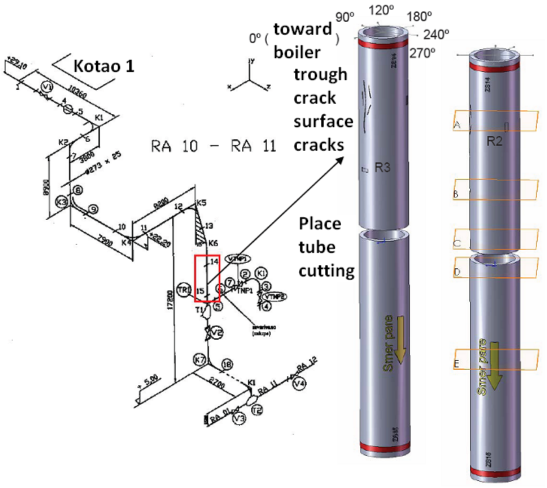

Figure 6: Scheme of measurement tests (dimensional inspection of the damaged steam line part).

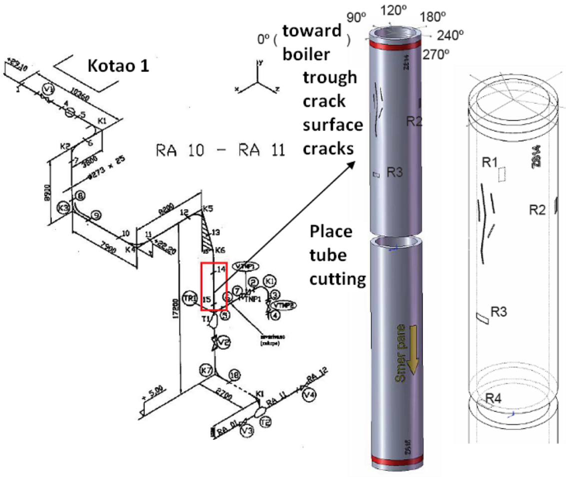

Figure 7: Scheme of measuring and making replicas of the damaged steam line part RA-10.

Part of the tube	Diameters (mm)				
Plane measurements	*A*	*B*	*C*	*D*	*E*
Axis measurements 0°-180°	288.9	276.8	285.0	285.9	283.1
Axis measurements 90°-270°	282.4	284.0	285.1	284.3	283.4

Table 2

Part of the tube		Wall thickness (mm)					
Plane measurements		*A*	*B*	*C*	*D*	*E*	*Remark*
Designation of measuring point	*0°*	21.2	20.1 (R3)	22.4	22.4	22.9	23.2 (A-R1)
	90°	24.3	24.7	25.6	25.8	25.5	24.7 (A-R2)
	180°	27.0	27.3	27.0	27.9	27.1	/
	270°	24.2	23.3	23.1	23.9	23.7	/
R - place where replicas are taken							

Table 3

Assessment of the microstructure of the materials that are used for tube bends and welded joints and creep damage level are made according to the recommendations for the assessment of the microstructure [10].

The degree of quality degradation of the microstructure of the old pipe was determined according to the recommendations of the European Commission for assess the remaining life of the microstructure [11].

Fig. 8 and 9 show the typical microstructure of the surface layer of the old pipe taken from a replica in accordance with the drawing in Fig. 7.

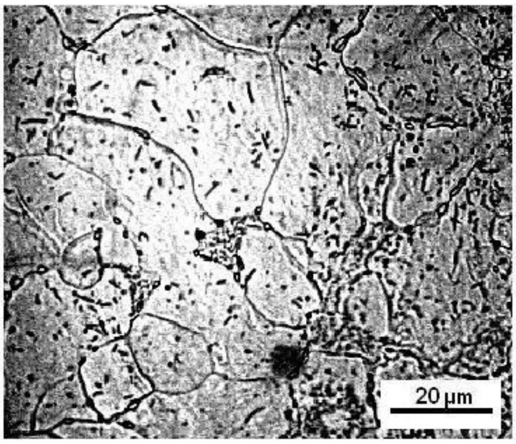

Figure 8: Replica RA10-R1. Assessment of the microstructure [11]: Level B / Level C: Initial spheroidization and carbide precipitation per grain boundary in places with the presence of globular pearlite. 4% nital.

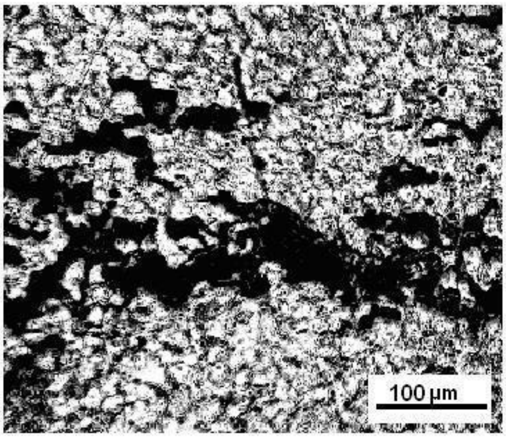

Figure 9: Replica RA10-R3. Macro cracks. Assessment of the microstructure [10]: 5; Assessment of the microstructure [11]: Level B / Level C: Initial spheroidization and carbide precipitation per grain boundary in places with the presence of globular pearlite. 4% nital.

In microstructure of tested replica taken from the surface of the material of the old pipe, a certain degree of quality degradation was observed wich is caused by initial spheroidization and carbide precipitation per grain boundary in places with the presence of globular pearlite- the level of quality degradation of microstructure B / C, according to [11]. Products of corrosion and corrosion damage in spots are present in the microstructure of tested replica.

ANALYSIS OF DAMAGE

The damaged parts of steam line were analyzed, to determine the cause of the problem, which is a process that requires a systematic approach. Test results of NDT methods contribute to the knowledge of damage formation and allow us to determine the cause of steam line failure. Based on the research of failure and causes of failure of certain components of steam line using method FMEA and reliability parameters obtained from the analysis of the data collected in real operating conditions, a system of continuous diagnosis could be established.

Stress analysis [12,13,14], damage and fractures [15,16] of welded joints of steam line elements provide important directives for the development of design methods and construction elements of the steam line to improve the properties of existing materials and their processing technologies. Also, by analyzing fractures, the development of new technical solutions and methods of testing is enabled [17] in the prototype stage. It is necessary to take into account the risk analysis and structural integrity [18,19], as a new approach to the assessment of structural integrity.

THE DATABASE INFORMATION

Load data, the characteristics of the base material and its welded joints, technology development, technical and physical characteristics reported fractures data and preventive measures provided for damage and destruction are obtained from the databases. Database of implemented testing [2] and research [20] on the appropriate structures allows us to analyze the behavior of supporting elements of steam line in order to determine changes in mechanical properties of materials. Load data, as well as the characteristics of the base material and its welded joints, technology development, technical and physical characteristics of the recorded fracture and destruction are inserted into the appropriate database. Reliable assessment of the integrity of the observed elements, could be made only after creation of adequate database and the basis for the development of computer programs [21]. Supporting software packages would allow more efficient use of the database, the analysis of some influencing factors, and the search of alternative solutions in all phases of design and development of construction.

CONCLUSION

Only by examining the construction of steam line operating conditions it is possible to assess their condition completely. During examination period the necessary data are obtained to determine the quality and structural integrity assessment and evaluation of the impact of the elements on the capacity and is given the necessary data to establish the joint work of devices and structure of steam line.

The results presented in this paper and conducted research projects allow us to analyze the behavior of supporting elements of steam line in order to determine changes in mechanical properties of materials.

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