

REMAINING LIFETIME ASSESSMENT OF THE BOILER TUBE

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Abstract

Assessment of remaining lifetime represents a very complicated problem, which needs the knowledge of degradation processes in the material of a component, and also the service conditions of the components, e.g. way of loading and the influence of the surrounding environment. There is a common interest to operate the produced components as effectively as possible and thus as long as possible without reducing their safety and reliability, what could cause economic and human losses. This is a problem of safe operation and its prolongation in justifiable cases.

As a result of new modern and more resistant materials development, the general interest is to be able to evaluate the extent and rate of degradation processes at various service conditions, mainly to prevent the components from brittle fracture. The goal even in the stage of a component design is to guarantee their long-time operation. At present, the assessment of component material microstructure is one of the methods that makes it possible to evaluate its remaining lifetime.

It is thus important to be able to evaluate the extent of material mechanical properties degradation as a result of various service factors and the elaboration of methods for its assessment.

Nowadays, the evaluation of component material microstructure represents one of the possible methods for remaining lifetime assessment.

Keywords: Creep tests, degradation, boiler tube

1. INTRODUCTION

The article deals with the evaluation of the remaining lifetime on the basis of microstructure evaluation of selected materials in the power producing industry. At first, the microstructure investigation of selected component, where the customer's demand was to assess the remaining lifetime by means of traditional creep tests. On the basis of performed creep tests the remaining lifetime was determined by usual procedure. After finishing the creep tests the microstructure was investigated again. The evaluation of the creep tests and comparison of the microstructure before and after the tests is in detail summarized in this article.

2. CREEP TESTS

The main principle of a creep test is heating of a testing pole to the pre-defined temperature and loading of the testing pole by tension force in a direction of the longitudinal axis of the pole. The following standards are valid for creep tests at higher



Figure 1 Creep stands

temperatures: ČSN EN 10 291- 6/2001, DIN 50 118 and ASTM E 139. The tests are performed on special testing devices that are called „stands“ (Figure 1).

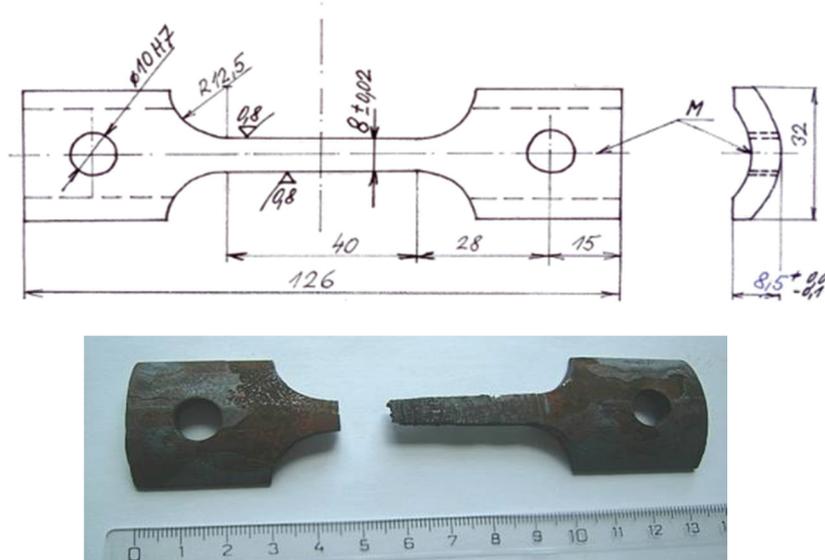


Figure 2 Sample for creep testing

The samples were made from boiler tubes (steel SA 216-T22) with standard dimensions (Figure 2). Evaluation of creep test results - especially stress rupture strength R_mT and creep strength RT - are based on a large number of tests. It can be determined for the following periods of time: 103 h, 5 x 103 h or 105 h (it means that the time duration of a test is more than 10 years). While verifying properties of a new kind of steel up to 30 testing poles need to be evaluated. Total time duration of those tests is approximately (1-3) x 105 h, however, time duration of some testing poles must be more than 104 h.

Table 1 Results of creep tests - steel SA 213 - T22

Locality	Temperature T [°C]	Stress [MPa]	Time to rupture [h]	Parameter Larson - Miller [PLM]
Superheater 1	580	75	1965	19873
		80	890	19579
		100	185	18997
		120	50	18512
		140	7	17784
Superheater 2	580	75	1841	19849
		80	681	19480
		100	148	18915
		120	51	18520
		140	9	17877
Superheater 3	580	75	1507	19774
		80	792	19536
		100	206.5	19038
		120	50	18512
		140	15	18066

2.1. Time extrapolation of creep test results

Time extrapolation of results is performed during creep tests. One of the most frequently used methods of interpolation is a method that makes use of Larson-Miller parameter. This extrapolation is based on Arrhenian relation therefore it is possible to mutually substitute influence of temperature and time during the process. The following relation is valid for the Larson-Miller parameter P (eq. (1)).

$$P = T_1 \cdot (C + \log t_1) = T_2 \cdot (C + \log t_2) \quad (1)$$

It means that effect of temperature T1 during test time t1 is equivalent to the effect of temperature T2 during test time t2. Process at a temperature T1 and a very long time t1 can be substituted by a process much shorter but at a higher temperature [1]. Another possibility is a combination of increase or decrease of stress at the same temperature. **Table 1** and **Figure 3** summarize results of creep tests that were performed on the material SA 213-T22 [2] with parameters from eqs. (2), (3).

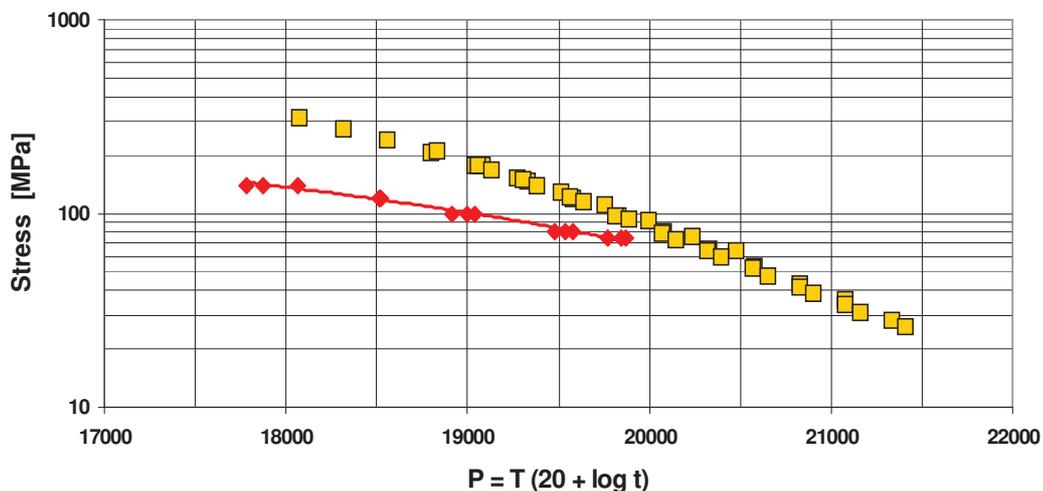


Figure 3 Results of creep tests, steel SA 213 - T22

Superheater: $P_{LM} = 19990$

$$P_{LM} = T \cdot (20 + \log \tau_{rboiler}) \quad (2)$$

Residual lifetime of the boiler steam piping for temperature 539°C is:

$$\tau_{rboiler} = 10^{\left(\frac{P}{T} - 20\right)} = 10^{\left(\frac{19990}{539 + 273,15} - 20\right)} \cong 41085 [h] \quad (3)$$

3. MICROSTRUCTURE ANALYSIS

There are several methods to examine the quality and condition of materials and joints at the stage of new pressure equipment manufacturing as well as during the operational lifetime of any industrial pressure equipment [3].

Reliability of power plant components depends also on preventing material defects which is closely linked to the estimation of the residual lifetime of power equipment. Verification of microstructural status can significantly contribute to this purpose. This verification can be done in two ways - using nondestructive investigation of microstructure or traditionally by sampling. The aim is to find out real status of power plant parts and essentially contribute to the estimation of residual lifetime in power plant parts.

The goal was to evaluate the microstructure of the inspected power plant components and to classify the material status according to the microstructure degradation standard scales, which were set up using real micrographs.

The samples before and after the creep tests were chosen for the evaluation. The samples were etched in the etching agent Nital. Microstructure analysis was carried out by an optical microscope Nikon Epiphot 300. Pictures of the fracture areas were taken by an electron microscope [4-6].

The analysis was primarily focused on type, shape and size of structure formations, volume and distribution of the phases present and character of imperfections. The purpose of the metallographic analysis and evaluation was to determine grade of the material degradation.

The microstructures of the investigated samples were evaluated according to two scales. The first one was the scale of the microstructure changes due to the long-term effect of high temperature which contains five (1-5) grades of damage and the second one was the scale for evaluation of the material degradation due to the cavitation damage which includes six (I-VI) grades [7].

3.1. Before creep test

The microstructure of the samples before the creep testing consisted of ferrite-pearlite with uniformly distributed carbides which were spheroidized (**Figure 4**). The structural elements were aligned in bands as a result of cold working (**Figure 5**, **Figure 6**) and there were also noticeable thin decarburized layers (circa 30 μm) in areas which were close to the inner and outer surfaces of the pipes (**Figure 7**). Classification of the microstructure before the creep testing is **3** (1-5) and **IV** (I-VI) according to the scales in [7].

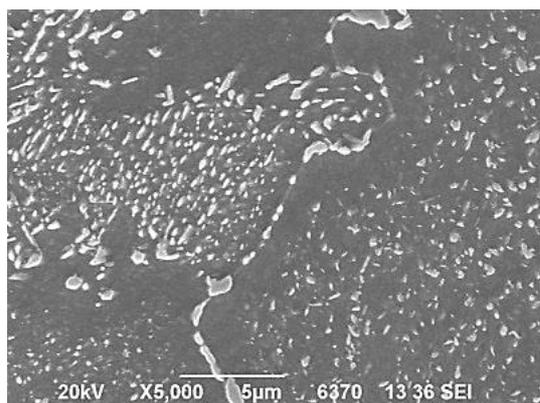


Figure 4 Microstructure before creep tests

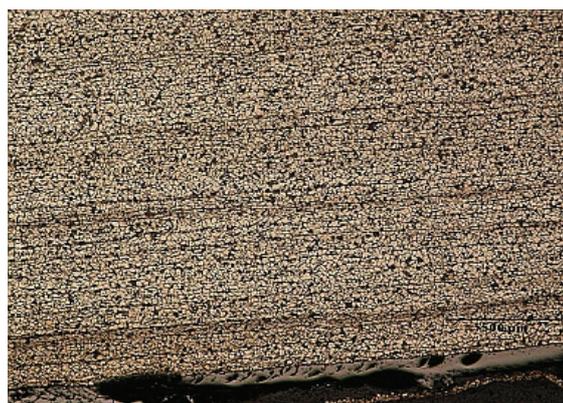


Figure 5 Structure lines before creep test



Figure 6 Ferrite - pearlite structure, inner surface, before creep test



Figure 7 Outer affected surface, before creep test

3.2. After creep test

The microstructure was observed also after the creep tests. The creep tests were carried out at the temperature of 580 $^{\circ}\text{C}$ and the strains from 75 MPa to 140 MPa. It is possible to observe a large number of cavities

especially close to the intergranular fracture (**Figures 9, 10, 11**); these cavities coagulate and form macro-cavities. The carbide particles are much coarser and are precipitated on the grain boundaries. The fracture area was analyzed by electron microscope but because of the heavy oxidation of the crack surfaces it was impossible to get any qualitative characteristics (**Figure 8**). Classification of the microstructure before the creep testing is **5** (1-5) and **VI** (I-VI) according to the scales in [7]. The material is at the end of its lifetime.

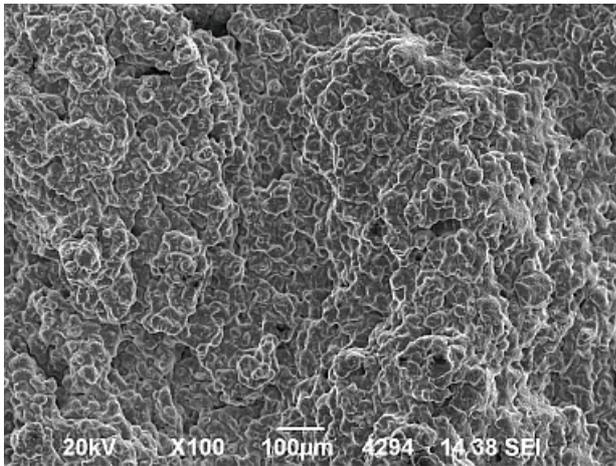


Figure 8 Fracture area after creep test

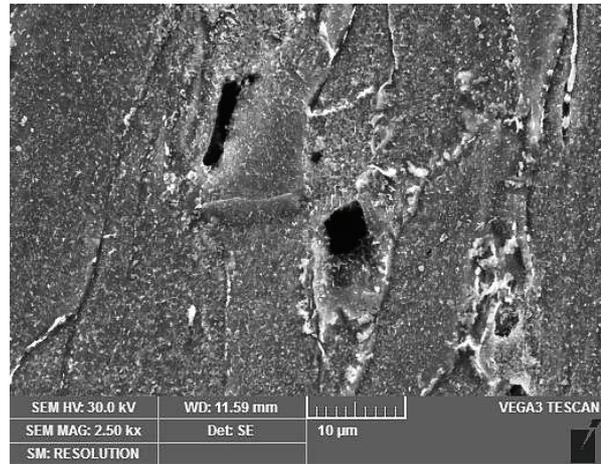


Figure 9 Cavities after creep test

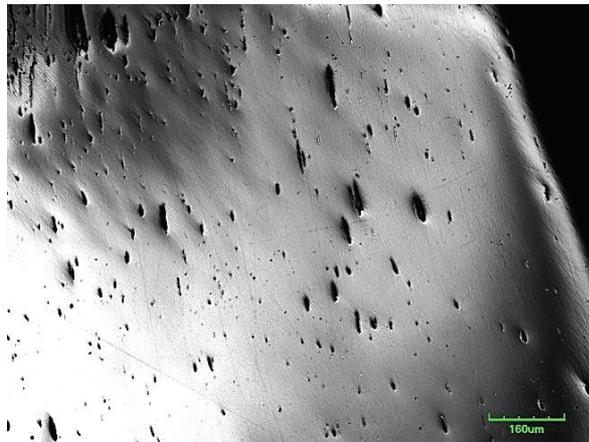


Figure 10 Cavities close to the fracture after creep test

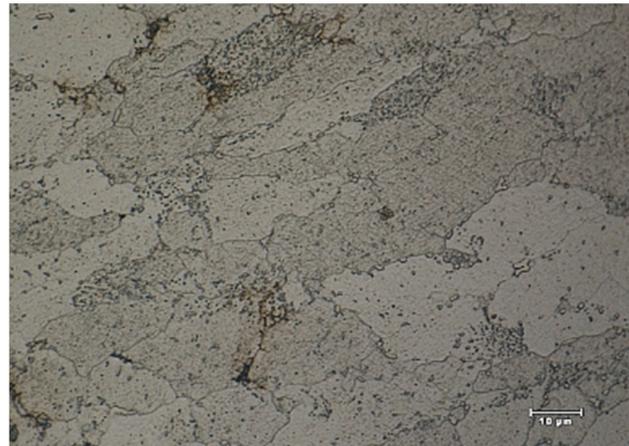


Figure 11 Cavities and grains after creep test

4. CONCLUSIONS

From the comparison of the results obtained by the traditional creep tests and by the microstructure examination of the steel SA 213 - T22 it implies that it is also possible to evaluate the residual lifetime of the power plant components on the basis of the microstructure investigation. However, it is necessary to set up a database of correlations between micrographs of the materials concerned and the results obtained by the creep tests of these materials. These results can be also correlated with the hardness measurements.

The results of the creep tests of the material tested presented in this paper indicate that the residual lifetime is approximately 5 years which is in an agreement with the microstructure status classified according to two microstructure degradation standard scales. This problem deserves a comprehensive approach because of a major economic benefits can be expected due to the possibility of non-destructive replica testing [4, 5, 6].

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