INVESTIGATION OF CREEP PROPERTIES THROUGH SUB-SIZE SPECIMEN

Eva CHVOSTOVÁ, Pavel KONOPÍK

COMTES FHT a.s., Dobřany, Czech Republic, EU
echvostova@comtesfht.cz, pkonopik@comtesfht.cz

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Abstract

Residual lifetime estimation and early detection of possible risks of mechanical equipment failure and structures is a key question for reliable operation of industrial plants. Currently, this issue is particularly critical in power stations that are approaching their designed lifetime. Residual lifetime of operating device can be evaluated using standard tests, but these usually cannot be performed due to limited material amount that can be extracted from the components. It is possible to use in these cases a semi destructive sampling of materials and testing methods employing miniature specimens. This article deals with comparison of the creep results obtained with the use of on standard test bars and sub sized samples that are axially loaded. The experiment was performed on steam line steel CSN 15 128 after operation and G17CrMoV510. Emphasis was put to practical use of the test results and therefore residual life was assessed with the use of standard and new mini specimens. The results obtained for standard and mini samples exhibit very good agreement without necessity of any correlation.

Keywords: Creep test, sub sized samples, material CSN 15 128, G17CrMoV510

1. INTRODUCTION

Residual life estimation is an important factor for early detection of potential risks of mechanical failures and structures especially for power plants and petrochemical plants that are approaching their designed end of life. The remaining service life can be evaluated using standard tests, but also by using semi-destructive techniques using mini samples. Currently there are available methods, where a small test sample is subjected to the same loading mode, as is the case of standard samples. For example the micro-tensile test [1], the miniature fracture toughness test [2,3], the miniature fatigue test and mini-Charpy test for DBTT determination. These methods maintain minimal material demands without requiring previously established correlations or at least they use a much more reliable type of correlation (without necessity to measure wide range materials). The above mentioned miniaturized testing techniques have been verified. These testing methods using miniaturized specimens maintaining testing loading mode are being developed and successfully applied and this paper shows results of miniaturized standard specimens testing in the field of creep tests [4,5].

2. EXPERIMENTAL MATERIAL

Steels ČSN 15 128 [6] and G17CrMoV510 were selected for the experiment. These materials are commonly used in power plants. In the first case the samples were extracted from steam line steel CSN 15 128 after period of service operation ca. 180 000 hours and had following parameters: internal gas pressure in pipe 18 MPa, operation temperature of 543 °C and the pipeline dimensions: diameter 324 mm, wall thickness 48 mm. All test specimens were taken in tangential direction. Chemical composition of the steel investigated is shown in **Table 1**. In the second case, it was a low-alloyed Cr-Mo-V steel for castings, cast in sand molds with the designation G17CrMoV510 and supplied according to the specification ŠN 42 2745. Its chemical composition is in **Table 2**.

Table 1 Chemical composition of the experimental material ČSN 15 128

	C	Mn	Si	Cr	Mo	V	Al	S.	P
Real chem. composition [%]	0.14	0.52	0.36	0.69	0.48	0.27	0.019	0.017	0.019
ČSN 41 5128 [%]	0.10 0.18	0.45 0.70	0.15 0.40	0.5 0.75	0.40 0.60	0.22 0.35	max 0.025	max 0.040	max 0.040

Table 2 Chemical composition of the experimental material G17CrMoV510

	C	Mn	Si	Cr	Mo	V	Ni	Al	S.	P
Real chem. composition [%]	0.18	0.73	0.40	1.33	0.95	0.28	0.06	0.049	0.013	0.017
ŠN 42 2747 [%]	0.15 0.20	0.50 0.80	0.30 0.50	1.2 1.5	0.90 1.10	0.20 0.30	max 0.60	max 0.004	max 0.030	max 0.030

3. MATERIAL SAMPLING AND SUB-SIZE SPECIMENS

For the case of sub-size specimens testing, a special procedure was applied to the experimental material extraction, simulating a real process of the material extraction from in service components. All sub-size specimens were subsequently machined out of such an extracted material. The size of specimens was adjusted to fit into the available volume of the experimental material that is possible to extract in semi-destructive manner. Creep tests were carried out on these test-pieces. A portable Electric Discharge Sampling Equipment (EDSE) [4] features easy handling, low-pressure coolant circuit (minimize spatter), quick electrode release and replace and a possibility to design own geometry and last but not least high sampling efficiency. Due to this fact the device is suitable for an in situ sampling out of in-service components, see **Figure 1**. The influence of electro-erosive machining on the work piece is demonstrated in the **Figure 2.** The depth of the affected layer appeared to be slightly less than 10 µm thick.

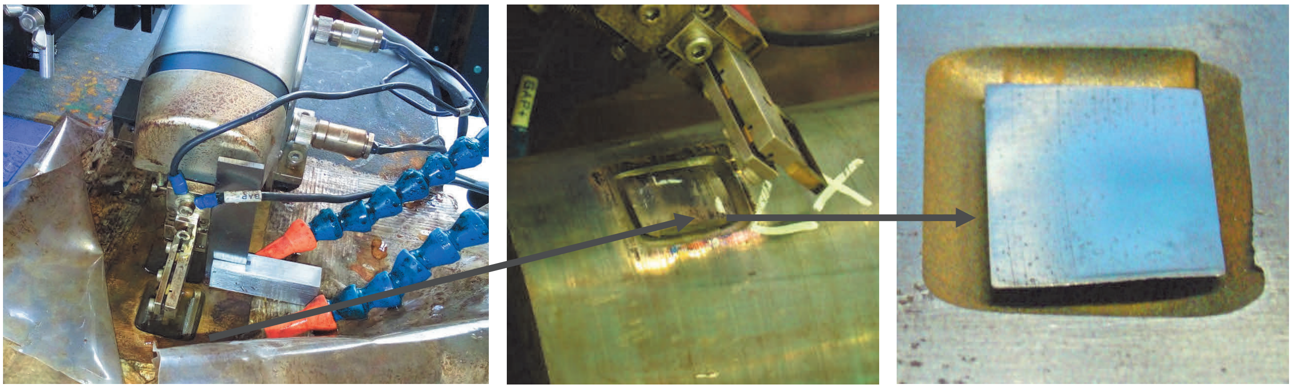


Figure 1 The set-up of EDSE;
whole device set up on the left and extracted piece detail on the middle and right

Sub-size specimens' dimensions and geometries were developed on the basis of available extracted piece of the experimental material. The material volume is limited and thus specimens' size and its distribution within the extracted material was carefully plan in order to utilize maximum of the material available for test-pieces. Specimens outline and cutting scheme within the extracted piece of material can be seen in **Figure 3.** The specimen geometry comes from modified dog bone shape and was used for material ČSN 15 128. For G17CrMoV510 material, test specimens with a diameter of two mm were used. Both dimensions are based on the shape of the sample with dimensions of 20 mm x 20 mm x 4 mm that can be extracted from real in service components by semi-destructive device EDSE (the Electric Discharge Sampling Equipment).

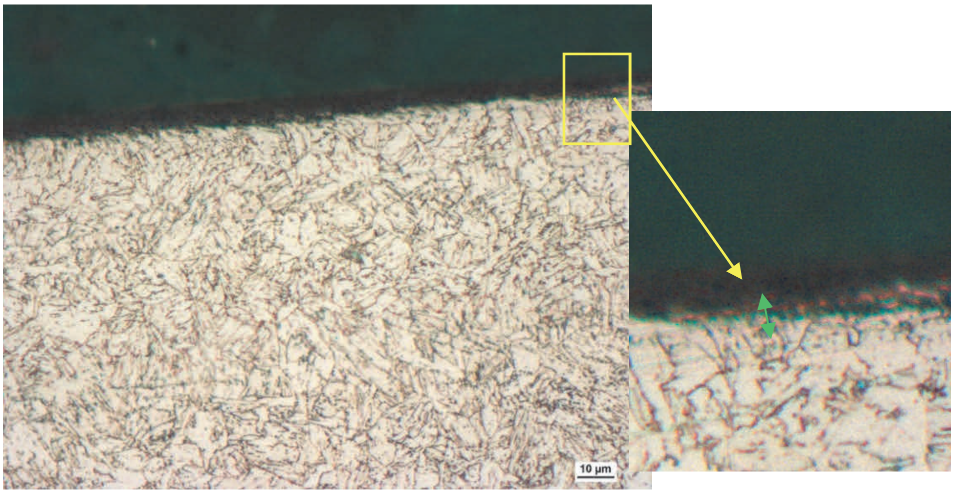
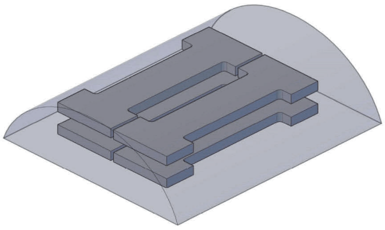
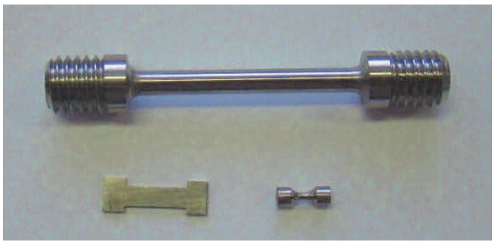


Figure 2 Influence of EDS machining on microstructure - affected depth is less than 10 µm



(a)



(b)

Figure 3 Specimens cutting scheme within EDSE extracted material
(a) and real samples used for creep testing (b)

4. CREEP TESTS

4.1. Performing creep tests

Creep tests on standard test bars were executed with the use of conventional creep machines fitted with furnace, strain and temperature measurement. In the case of miniaturized standard specimens testing, standard machines with modified grips were engaged. In order to ensure consistent contact force for all tests, the testing fixture is tightened by torque of 25 Nm using a torque wrench. Testing set up for testing of mini specimens is depicted in **Figure 4**.

Figure 4 Test arrangement creep - mini samples

The proposed fixture is intended only for time to fracture determination. Specimens of all considered geometries after creep tests are displayed in **Figure 5**.

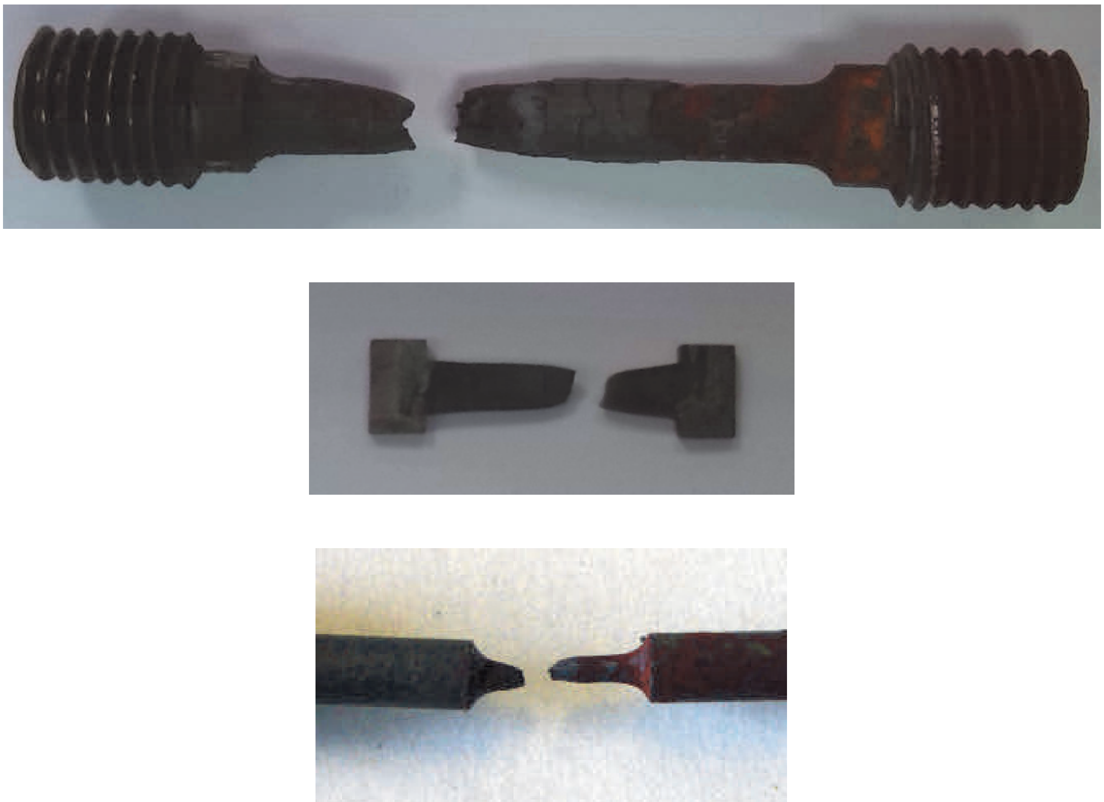


Figure 5 The test specimens after testing creep

The creep tests were carried out according to ČSN EN ISO 204 [5], the results of creep tests are evaluated in the form of time to fracture. Tests were performed on 18 standard creep specimens and 8 mini specimens for material ČSN 15 128. Tests were carried out in temperature range from 500 to 600 °C. The longest time to fracture was 7,699 hours in the case of standard specimens. In the case of miniaturized specimens times to fracture were up to several hundreds of hours in the current study. For material G17CrMoV510, tests were performed on 7 mini specimens for temperature range from 525 to 650 °C. The longest time to fracture was 1,853 hours.

4.2. Results of creep tests

Standard and new mini-specimens were evaluated with the use of standard formulas such as e.g. stress calculation. Comparison of results for all specimens was done with the use of Larson - Miller parameter defined as $\boldsymbol{P_{LM} = T\,(20 + \log \tau)}$, where T is temperature in K, and τ is time in hours. The results for material ČSN15 128 are summarized in **Figure 6**. There are shown reference creep properties for the material investigated as specified by materials standard in virgin state [4] and results obtained with full sized specimens and mini specimens. The values obtained clearly show material properties degradation due to service on difference between standard reference curve according to CSN 415128 and shift of presently measured values towards shorter times to fracture. Comparison of full sized and mini specimens yields excellent agreement within data scatter. This is very promising result as no correlation was applied here and thus this finding confirms of direct comparability of results obtained on specimens of different sizes [7]. Obtained results from sub-size creep tests for material G17CrMoV510 are shown in **Figure 7**. The results obtained with the use specimen with diameter 2 mm yield very similar results that are very positive result.

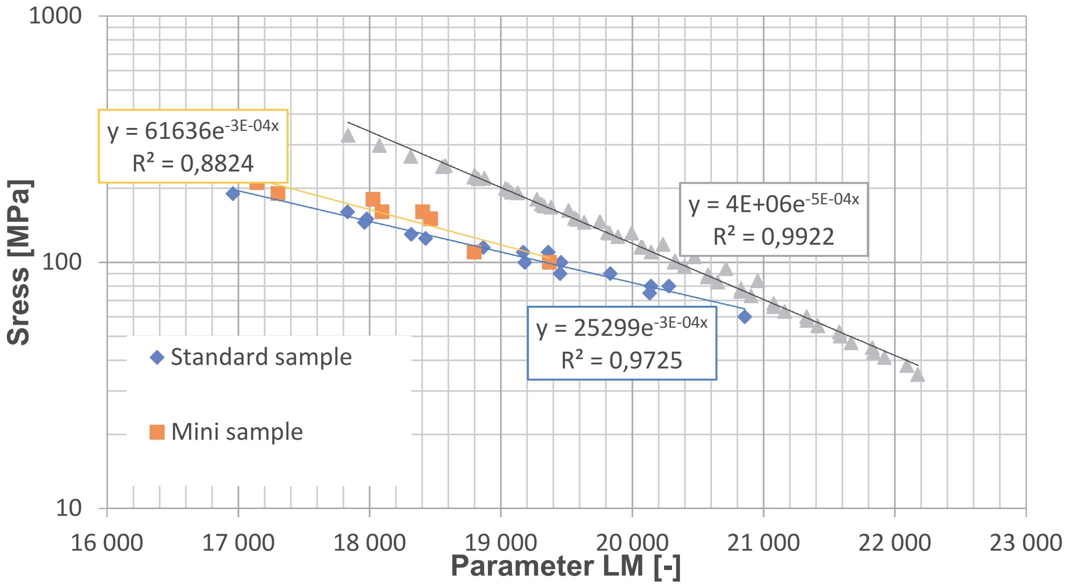


Figure 6 Comparison of creep results for material 15 128 after service

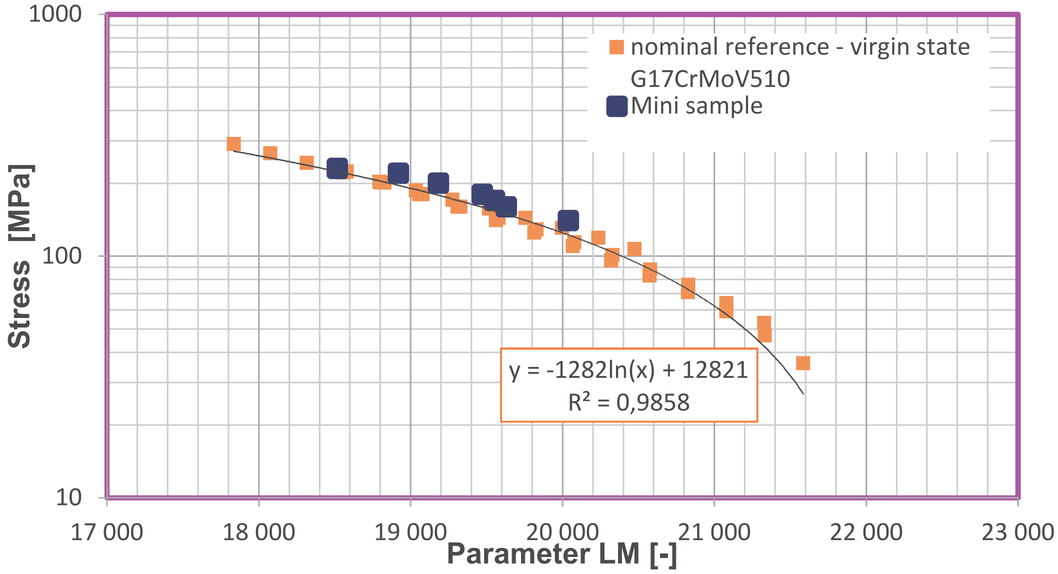


Figure 7 Comparison of creep results for material G17CrMoV510

5. CONCLUSION

The paper deals with possibilities of actual creep properties determination with the use of miniaturized experimental specimens. Standard creep specimen results are compared with results obtained from mini-creep specimens. The standard sized specimens provide reliable results, however it is usually impossible to machine them out of real in-service components. Therefore miniaturized creep specimens were proposed keeping the same loading mode as standard creep tests while material demand for specimens machining can be covered by volume that can be extracted from serviced component. The dimensions of creep mini-samples proposed here are based on material volume that can be extracted by available EDSE sampling device.

Results were summarized for comparison in the form of Larson-Miller plot. Results of mini creep specimens exhibited very good agreement with standard creep test results. This is very positive finding. The results confirm possibility of direct comparability of results attained for specimens of different sizes in loaded in the same mode. More data a longer time to fracture and strain measurements with the miniaturized specimens have to be accumulated for more general conclusions and recommendations.

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