DEGRADATION EVALUATION USING MINIATURIZED TENSILE SAMPLES

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Abstract

Many power plant operators are currently struggling with the problem of expiring the design life of components. The question often arises whether to continue the operation of the equipment or if it is already necessary to shut down/overhaul it. The knowledge of mechanical properties is therefore crucial. Semi-destructive sampling, subsequent production of mini tensile test specimens (M-TT) followed by mechanical testing can then provide the necessary information. The agreement between the results obtained using miniaturized and standard bodies has already been proven by many authors. The aim of this paper is to demonstrate that the use of M-TT is possible even in the case of severely degraded materials. The experiment was performed on SUPER 304H austenitic steel in the ground state and in the degraded state

Keywords: Miniaturization, tensile test, degradation, SUPER 304H, elevated temperature

1. INTRODUCTION

Nowadays, energy industry tends to increase productivity, flexibility, and thus, complexity of power plants. In addition, the operating equipment have to meet the safety requirements. The power plant operators need to be aware of the current plant condition. Therefore, a regular monitoring of the state of equipment utilized in terms of mechanical properties is crucial. However, the problem is often the need to shut down the component for sample extraction for experiments. Therefore, semi-destructive sampling of a small amount of material is usually successfully used to evaluate the current condition of a component. This amount of material can be then used for miniaturized mechanical tests to assess the degree of degradation. However, the transferability of the obtained results to standard bodies is not always unambiguous.

To comprehend the knowledge about this phenomena, our institute is involved in a project (FW01010368), in which individual types of miniaturized specimens such as tensile tests specimen (M-TT), Charpy test specimen (KLST), Compact tension specimen for fracture toughness tests (MCT), and the specimen for measurement of the dynamic modulus are applied. All the results obtained using above mentioned miniaturized specimens are compared to standard-sized samples and evaluated in terms of their ability to detect material degradation. The agreement between M-TT and standard specimens has already been proven by many authors [1-4].

The aim of this paper is to show that the application of M-TT is possible even in the case of severely degraded materials. The experiment was performed on SUPER 304H austenitic steel in the ground and degraded state. This material it is a typical representative of materials used in the energy industry.

1. MATERIAL SPECIFICATION

Most of the performed experiments were done at the material SUPER 304H because of its great availability. The specification of steel is listed in [5]. The material was supplied by Sumitomo Metals. Steel SUPER 304H was delivered in the form of the seamless tubes with outer diameter 38 mm, wall thickness 6.3 mm and a tube length of 5700 mm [5]. The heat treatment performed by producer (Sumitomo) was solution annealing under the following conditions: 1150 °C/2 min holding/cold water quenching [5].

The heat number of supplied steel is F124139. Its chemical composition is summarized in **Table 1**. The supplied steel is designed in accordance with prescribed values by the standard ASME Case 2328-1. The mechanical properties of the material in delivered condition are listed in [5].

Table 1 Chemical composition of supplied steel SUPER 304H (in wt%) [5]

	C	Si	Mn	P	S	Cu	Cr	Ni	Nb	B	N	Al
Min. (ASME Case 2328-1)	0.07	-	-	-	-	2.50	17.0	7.5	0.30	0.001	0.05	0.003
Max. (ASME Case 2328-1)	0.13	0.30	1.00	0.04	0.01	3.50	19.0	10.5	0.60	0.010	0.12	0.030
Heat No. F124139	0.08	0.25	0.81	0.003	-	3.07	18.3	9.0	0.49	0.004	0.11	0.005

2. AGEING

A laboratory isothermal aging on air was used to reach the degraded state of the austenitic steel SUPER 304H. The processing temperature was selected as 675 °C, which is slightly higher in comparison with operation parameters of USC power plant. The increase of temperature is motivated by the degradation processes acceleration. The time of isothermal ageing was up to 27 000 hours.

The experimental material in three various states was used for testing, i.e. the base material without any thermal exposition (*degradation state 0*) and two exposed states: after 12 000 (*degradation state I.)* and 27 000 hours (*degradation state II.)*. Those exposition states may simulate the operation degradation with related precipitation processes. In fact, the second exposition time (*degradation state II.*) correspond with nearly end of power plant lifetime according Larson-Miller parameter (LMP) construction.

3. METALLOGRAPHY

The base material (**Figure 1**) can be described as fully austenitic with twins and a presence of niobium carbonitrides. After thermal exposition, sigma phase precipitated at triple grain boundaries points and at the grain boundaries (**Figure 2**). Sigma phase is composed of brittle intermetallic particles which affect the mechanical properties.

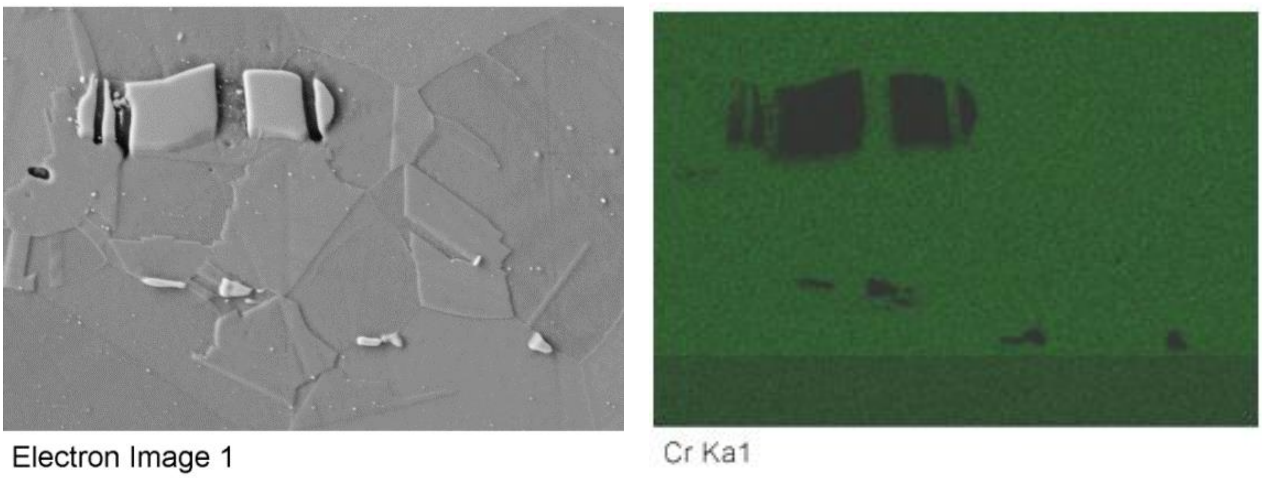


Figure 1 Microstructure of base material [6]

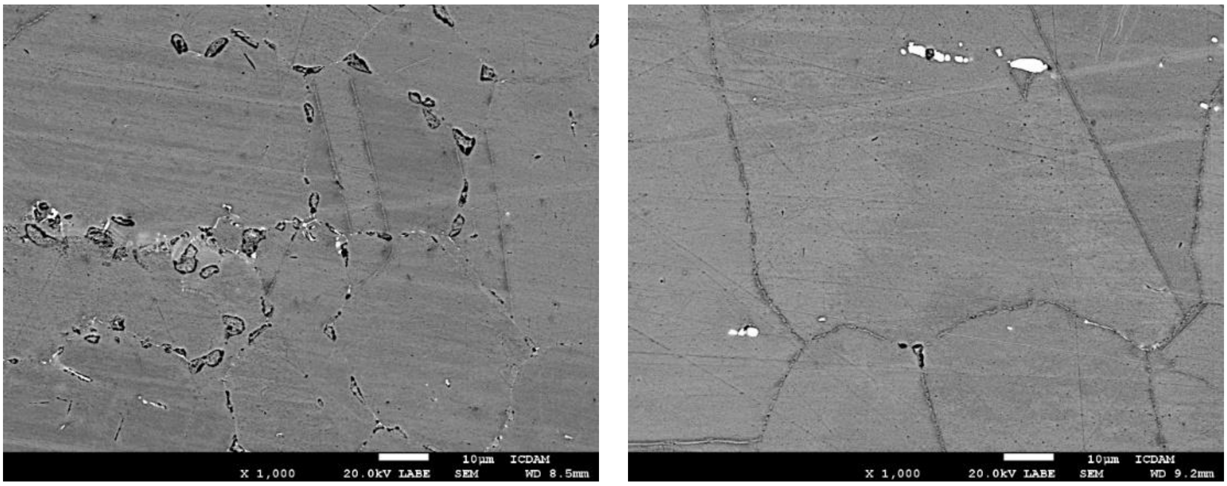


Figure 2 Microstructure of aged material [6]

2. EXPERIMENT – TENSILE TEST

The geometries of the standard (St) and miniaturized (M-TT) specimens are presented in **Figure 3**. The M-TT specimens were extracted using an electrical discharge machining (EDM) by several-passes of the wire to get the high-quality surface. The standard specimens were produced by CNC machines and tested according to the standard CSN EN ISO 6892-1 [7] on an electro-mechanic testing machine. The strain was monitored by means of contact extensometer Epsilon with L_0 = 25 mm. The M-TT specimens were tested according to the internal methodology RD 2/30, which is accredited and follows the standard CSN EN ISO 6892-1/ASTM E8 [8]. The M-TT tests were carried out on a universal testing machine TiraTest with a linear drive and the load capacity of 10 kN. The testing machine was equipped with the mechanical grips suitable for testing miniaturized specimens. The testing setup can be seen in **Figure 4.** Due to small specimen size, a single camera with the MERCURY RT (real-time tracking) system were set up. The deformation was tracked by means of optical extensometer based on Digital Image Correlation technique (DIC)[9]. Prior to testing, a stochastic pattern was applied on the specimens' surface with ratio of 50% white and 50% black colour to allow the deformation tracking by the optical system. All tests were performed under quasi-static conditions (strain rate – 0.00025 s-1).

The hardening coefficients were evaluated according to the standard ČSN EN ISO 10275 [10] in a deformation range 2 %-Ag. All test results are summarized in **Table 2**. A comparison of the resulting flow plastic curves is shown in **Figure 5**. The resulted hardening coefficients are presented in **Figure 6** and **Figure 7**.

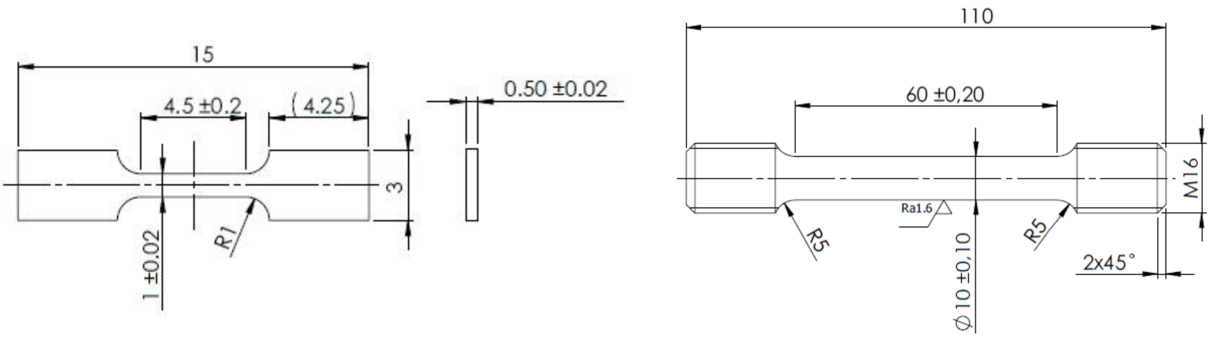
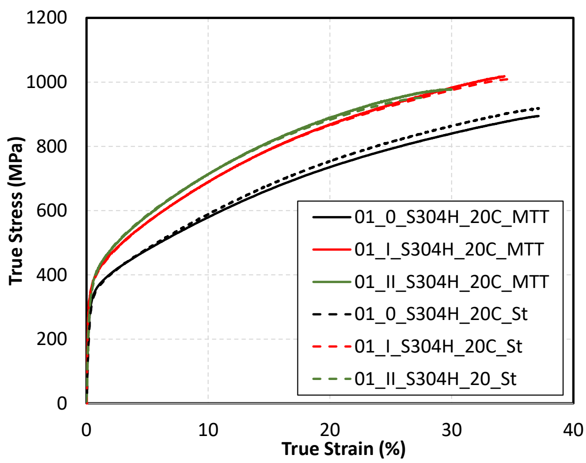


Figure 3 Geometry of the specimens, LEFT – M-TT; RIGHT – Standard

Figure 4 Quasi-static mini-tensile test setup

Table 2 Resulting hardening coefficients for individual geometries and degradation states

Geometry	Temperature °C	$n_{2\text{-}Ag}$ -	n_St.dev -	$C_{2\text{-}Ag}$ MPa	C_St.dev MPa	Degradation state
M-TT	20	0.30	0.002	1182.4	11.2	0
	20	0.29	0.005	1390.9	3.7	I.
	20	0.28	0.003	1412.7	25.9	II.
	600	0.34	0.007	955.5	9.1	0
	600	0.20	0.007	689.7	4.1	II.
	600	0.21	0.006	674.2	4.9	I.
Standard	20	0.31	0.004	1242.1	4.8	0
	20	0.29	0.001	1374.6	9.3	I.
	20	0.27	0.005	1353.9	17.9	II.
	600	0.32	0.004	968.0	13.5	0
	600	0,19	0,003	669,0	5,6	I.
	600	0,17	0,005	658,9	9,7	II.



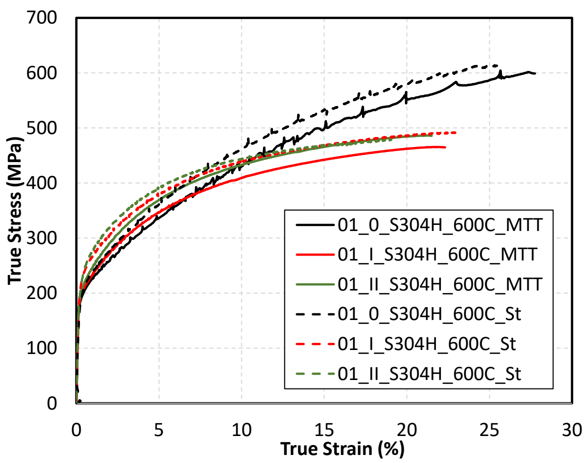


Figure 5 Comparison of the results obtained using miniaturized and standard tensile test specimens. Degradation state 0, I and II. Temperature LEFT – 20 °C; RIGHT – 600 °C

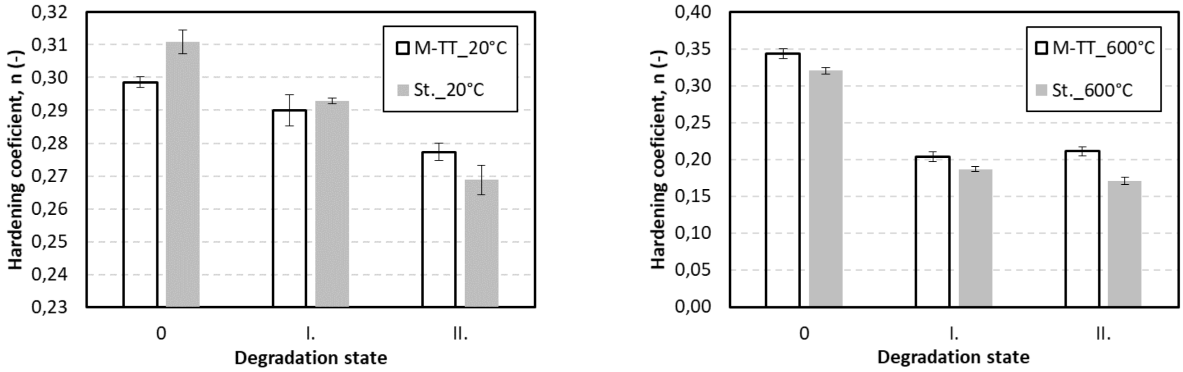


Figure 6 Comparison of the hardening exponent "n" for miniaturized and standard specimens, LEFT – at 20 °C; RIGHT – at 600 °C

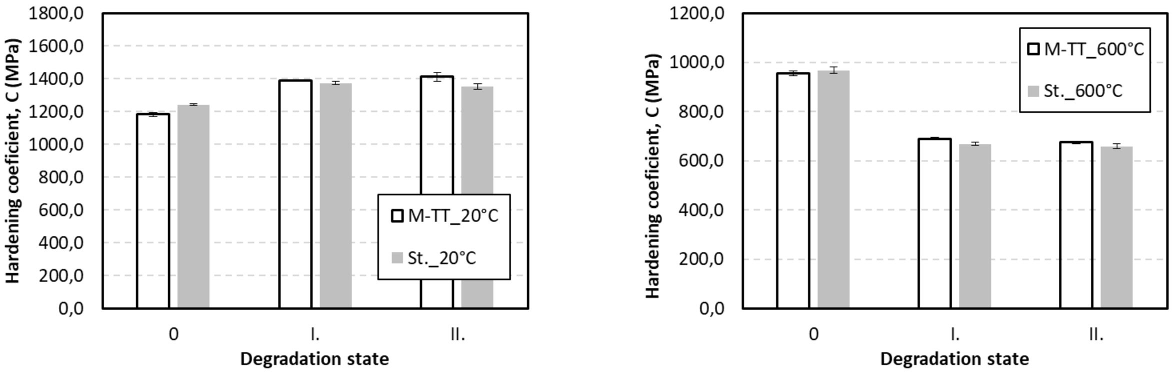


Figure 7 Comparison of the hardening coefficient "C" for miniaturized and standard specimens, LEFT – at 20 °C; RIGHT – at 600 °C

3. CONCLUSIONS

The results show good agreement of the values obtained using miniaturized and standard specimens. Furthermore, the MTT specimens are characterized by sensitivity to the material degradation. This is also shown by the fact that the Portevin-Le Chatelier effect (PLC) was visible on M-TT at the temperature of 600 °C on non-degraded material. In the case of degradation at stage I. and II., the PLC was not observed. The variance of the results was also approximately the same. Future tests will focus on performing of the same assessment on another ferritic-pearlitic material used in the energy industry.

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