DAMAGE ASSESSMENT DURING CREEP AND FATIGUE OF POWER PLANT STEELS USING DESTRUCTIVE AND NONDESTRUCTIVE TECHNIQUES

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ABSTRACT – Development of damage due to creep at elevated temperatures and fatigue at room temperature was assessed for power engineering steels using destructive and non-destructive methods. The experimental programme contained also microscopic observations to find feedback between macro- and microscopic parameters.

INTRODUCTION: The results of parallel destructive and non-destructive tests give us an opportunity to determine parameters enabling better predictions of damage development in materials due to their possible correlations. Development of creep and fatigue damage was investigated in this research using destructive and non-destructive methods in steels commonly applied in power plants (A336 Gr5, 40HNMA, 13HMF and P91). In order to assess damage during such type processes the tests for each kind of steel were interrupted for a range of the selected time periods (creep) and number of cycles (fatigue). As destructive methods the standard tension tests were carried out after every kind of prestraining. Subsequently, an evolution of the selected tension parameters was taken into account for damage identification. The ultrasonic and magnetic techniques were used as the non-destructive methods for damage evaluation. In the final step of the experimental programme microscopic observations were performed. In the case of ultrasonic method the acoustic birefringence coefficient was used to identify a damage degree in the steels tested. In the case of magnetic technique the classical Barkhausen effect (HBE) and magnetoacoustic emission (MAE) were measured.

PROCEDURES, RESULTS AND DISCUSSION: As destructive methods the standard tension tests were carried out after prestraining of materials and non-destructive investigations. Subsequently, an evolution of the selected tensile parameters was taken into account for damage identification. In order to assess a damage development during creep, fatigue or plastic deformation the tests on steels were interrupted for a range of selected strain magnitudes (creep and plastic flow) or number of cycles (fatigue). The representative results of tensile tests for the 13HMF steel after fatigue and creep are presented in Fig.1a and Fig.1b, respectively. Taking into account the results presented in Fig. 1a it is easy to note that this material in terms of typical stress parameters is almost insensitive to fatigue prestraining, i.e. the yield point and ultimate tensile stress variations are rather small. An opposite effect can be observed for the same material prestrained under creep conditions. In this case the prior deformation leads to the hardening effect. Details of investigations on the 40HNMA and P91 steels were described earlier by Kowalewski et al. [2008, 2009]. The results for creep prestrained 40HNMA steel exhibited significant effect of softening. For all steels in question the hardening effect was achieved in the case of prestraining induced by means of plastic deformation at room temperature.

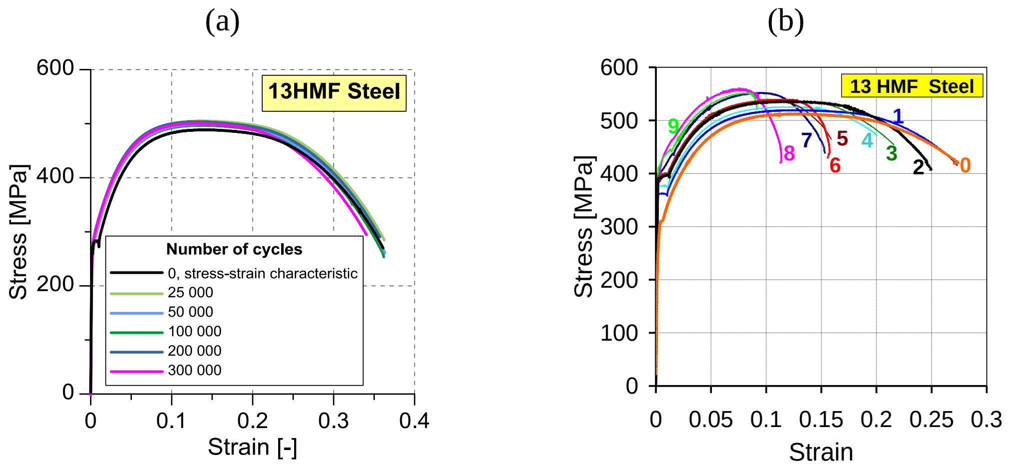

Fig. 1. Tensile characteristics after fatigue (a) and creep (b) prestraining for the 13HMF steel (numbers in the right diagram identify time to stop of creep test: 1 - 149h, 2 - 300h, 3 - 360h, 4 - 407h, 5 - 441h, 6 - 587h, 7 - 664h, 8 - 796h and 9 -1720h; 0 – as-received material).

The ultrasonic and magnetic techniques were used as the non-destructive methods for damage evaluation. The results indicate that the acoustic birefringence, Ub_{pp} - measure of the HBE and Ua_{pp} - measure of the MAE are sensitive to the amount of prior deformation. Additionally, it was shown that all these parameters can be correlated with those determined on the basis of destructive tests. The results exhibited that magnetic techniques are very sensitive to degradation development for the small strain levels (up to 2%), and almost insensitive above that value. The ultrasonic techniques give a completely opposite assessment: very poor sensitivity for small deformations and good for deformations greater than 2%. Hence, it seems to be reasonable to use them together: in the first period of operation - magnetic methods, in the subsequent stages – ultrasonic ones.

In the case of material prestrained due to fatigue the destructive tests gave no clear assessment of material degradation, because the basic mechanical parameters (i.e. yield point and ultimate tensile stress) underwent increased. Therefore, in order to assess a degree of fatigue damage the alternative techniques were proposed. The Wöhler diagram was determined as the first step of fatigue tests on the 13HMF and P91 steels. It represents the number of cycles necessary to failure under given stress amplitude. In the case of 13HMF steel this diagram was determined for the material in the as-received state and after exploitation (80 000h), Fig.2a. As it is seen, these characteristics differ significantly, identifying the fatigue strength reduction due to the loading history applied. In addition, investigations were performed in which variations of the hysteresis loop width were evaluated under constant stress amplitude. These studies have shown that this type of procedure gives an opportunity to assess a supply of the safe operation period of the material, and there is no need for so many experiments, as this is required for the Wöhler diagram determination. Moreover, an identification of damage measures was carried out. The behaviour of metals under fatigue can be divided into two basic types of mechanisms in terms of the damage development, Kukla et al. [2011]. The first group is described by the ratcheting, generated by local deformation around the voids, non-metallic inclusions and other defects in the microstructure, whereas the second one by cyclic plasticity generated at the local level grains by dislocation motion and slip bands. In both cases, the strain changes measured for the entire sample volume are the sum of local deformations developing around defects in the form of non-metallic inclusions and voids (first group) or developing slips within individual grains (second group). Both fatigue damage measures are well presented in Fig. 2b.

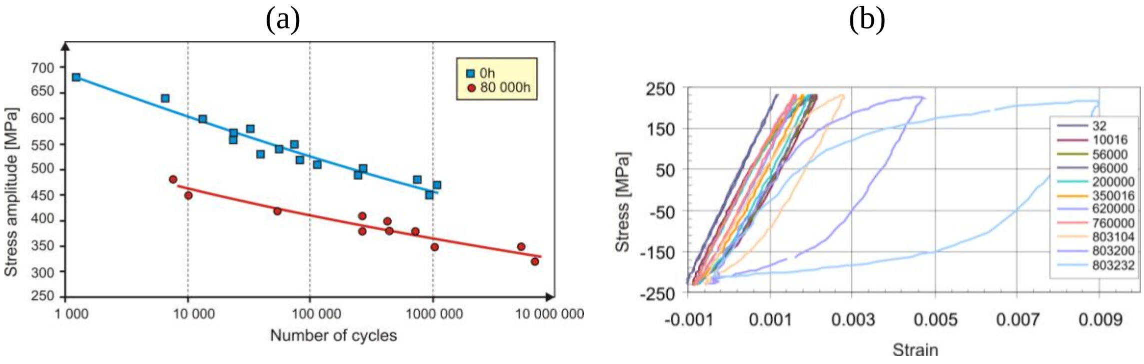

Fig. 2. Representative results of fatigue tests for the 13HMF steel: (a) comparison of the Wöhler characteristics for the material in the as-received state and after exploitation; (b) strain evolution during fatigue under stress amplitude of 230 MPa.

CONCLUSIONS: Analysis of the fatigue damage of power plant steels indicates that its greatest development can be attributed to the initial stage of operation. Consequently, a recommendation to power plants is to limit the number of stops of working installation, since only its continuous stable operation ensures the longest lifetime. Procedures developed for creep damage contain the graphs illustrating correlation between the strength parameters of destructive tests and parameters of non-destructive methods.

ACKNOWLEDGEMENT: The support from the National Centre for Research and Development (Poland) under grant NR 15-0049-04/2008 is greatly appreciated.

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