DAMAGE DEVELOPMENT IN STEELS SUBJECTED TO EXPLOITATION PROCESSES: ATTEMPT TO CORRELATE THE PARAMETERS OF DIFFERENT TESTING TECHNIQUES

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Summary 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 micro-scopic parameters. Three different power engineering steels were tested, i.e. 40HNMA, 13HMF and P91.

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 (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.

EXPERIMENTAL PROCEDURE AND TESTED MATERIALS

After prestraining of materials and non-destructive investigations the standard tension tests were carried out as destructive method. 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). Taking into account the results for the pre-fatigued 13HMF steel 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 [1, 2]. The results for creep prestrained 40HNMA steel exhibited significant effect of softening. For all steels in question the same effect was achieved in the case of prestraining induced by means of plastic deformation at room temperature, i.e. hardening.

THE RESULTS AND THEIR ANALYSIS

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. Having parameters of destructive and non-destructive methods of damage assessments their mutual relationships were considered in order to find their character. The representative results are presented in Fig.1 for the 13HMF steel. In the same way the results for P91 and 40HNMA steels were elaborated.

The results exhibited that magnetic techniques can be very sensitive to degradation development for the small strain levels (up to 2%), and almost insensitive above that value. The ultrasonic techniques gave 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 curve was determined for the material in the as-received state and after exploitation (80 000h), Fig.2a. As it is seen, these curves differ significantly, identifying the

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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.

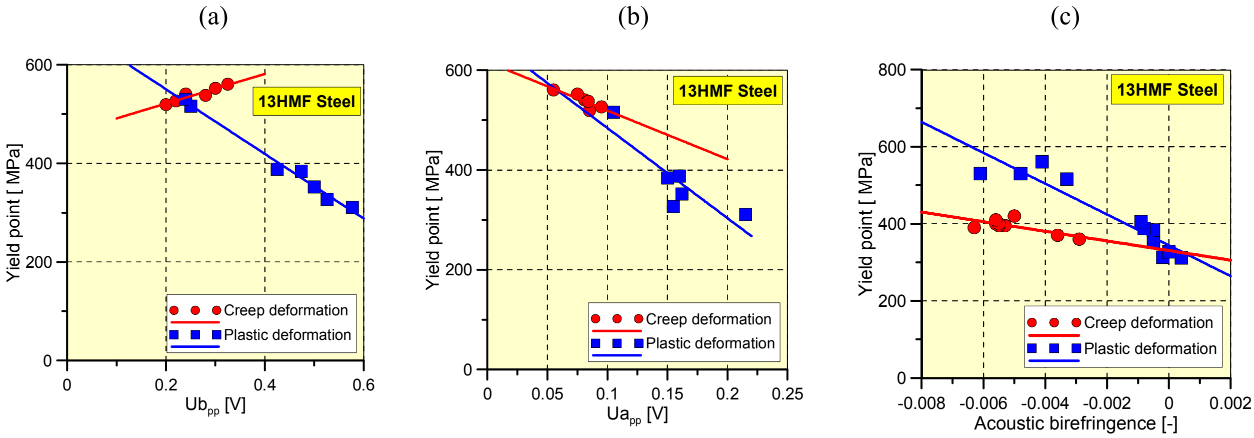

Fig. 1. Illustration of mutual relationships between the yield point and damage sensitive parameters of non-destructive investigations: (a) Ub_{pp} - measure of the HBE; (b) Ua_{pp} - measure of the MAE; (c) acoustic birefringence.

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 [3]. The first group is described by the ratcheting (a shift of the hysteresis loop as a result of the strain mean level increase), generated by local deformation around the voids, non-metallic inclusions and other defects in the microstructure, whereas the second one by cyclic plasticity (a gradual increase of the hysteresis loop width) 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.

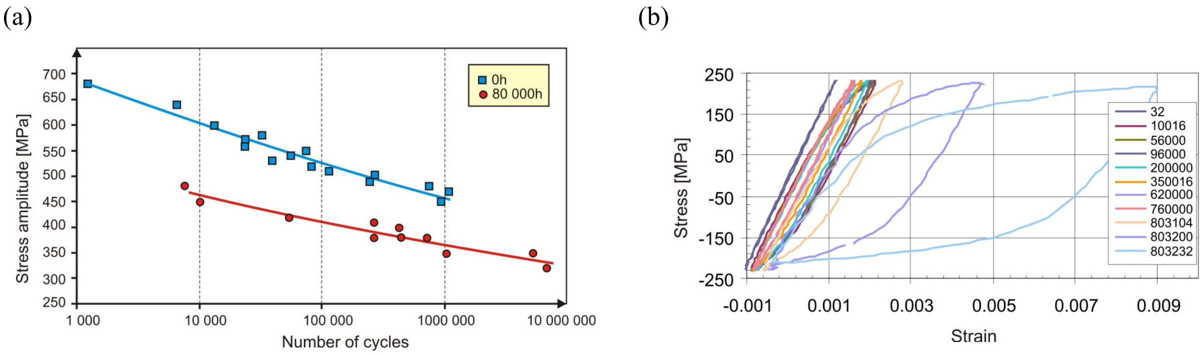

Fig. 2. Representative results of fatigue tests for the 13HMF steel: (a) the Wöhler characteristics for the material in the as-received state and after exploitation; (b) strain evolution during fatigue under stress amplitude of 230 MPa.

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 the power plant is to limit the number of installation stops, because its lifetime is the longest for continuous stable operation. Documentation of procedures developed for the creep contains graphs illustrating the correlation between the strength parameters of destructive tests and selected parameters of non-destructive methods.

References

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