THERMOMECHANICAL FATIGUE OF P91 STEEL

P. Sulich[1], W. Egner[1], S. Mroziński[2] and H. Egner[1]
[1] Institute of Applied Mechanics, Cracow University of Technology, Kraków, Poland
[2] Faculty of Mechanical Engineering, University of Science and Technology, Bydgoszcz, Poland

1. Introduction

Thermomechanical low cycle fatigue accompanied by the elastic – plastic strains is one of the dominant failure modes in high temperature structural components, such as electric power boilers, boiler pipes, engine elements etc. The aim of this paper is the analysis of thermomechanical low-cycle fatigue behavior of P91 steel, widely used in power industry applications. First the material is tested experimentally in several test temperatures, then the material behavior is described by the constitutive model, implemented into a numerical procedure. Next the material characteristics are identified in different test temperatures. Finally the numerical simulations of fatigue tests are performed and compared with the experimental results. To reduce the number of material parameters for identification, the Armstrong and Frederick - type constitutive model [1] extended with temperature rate effects [2] was here applied.

2. Experimental equipment and material investigated

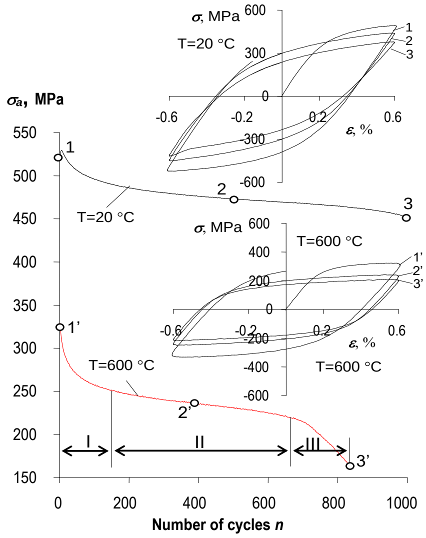
Tested specimens were cut out of a boiler pipe of diameter 200 mm and wall thickness 20 mm. Low-cycle fatigue tests were strain controlled, with constant total strain amplitude ($\varepsilon_{ac} = \text{const}$, frequency of loading 0,2 Hz) and constant temperature in each test (Fig. 1a). Also, the non-isothermal fatigue test was performed, according to the temperature program shown in Fig. 1b. Experiments were performed on testing machine Instron 8502, equipped with heating chamber.

3. Material behaviour

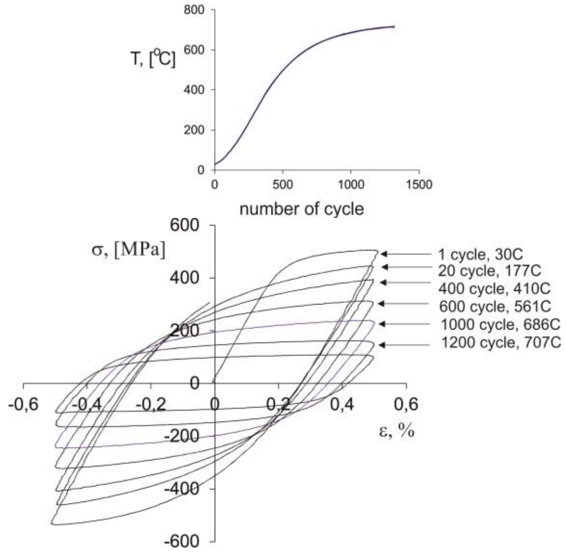
Tested steel exhibits cyclic softening, regardless of the testing temperature (half-stress amplitude decreases with increasing cumulated plastic strain). This softening could be divided into three phases, which are: the rapid softening phase during the initial few hundred cycles, followed by a slow quasi-linear softening phase, and finally again fast softening till rupture (see Fig. 1a). The first phase is generally explained by the rapid change of dislocation density inherited from the quench treatment, the second is related to the formation of dislocation sub-structure and carbide coarsening under the action of time, temperature and cyclic load, while the third phase is a consequence of micro-damage development in the material that ultimately causes failure of the tested sample.

4. Results

Figure 2 presents the comparison between the test results and their simulations by the Armstrong and Frederick - type constitutive model implemented into a numerical procedure. As shown in Fig. 2a, the model simulates with a good accuracy the chosen hysteresis loops. Figure 2b illustrates the influence of temperature rate in kinetic equations of backstress and dragstress (cf. [3]). If the temperature rate is not explicitly regarded in these equations, the hysteresis loops tend to shift along the stress axis (case (2)). This erroneous behaviour becomes correct when temperature rate is consequently accounted in constitutive model (case (1)).

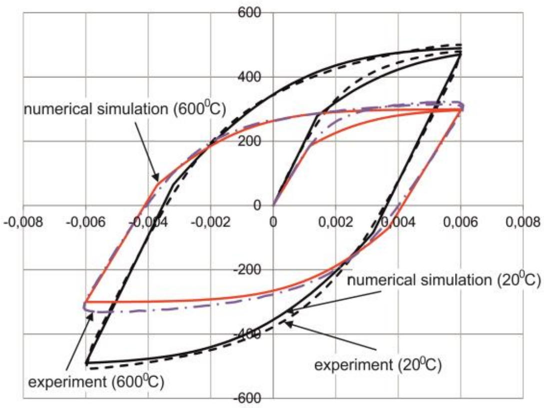


(a)

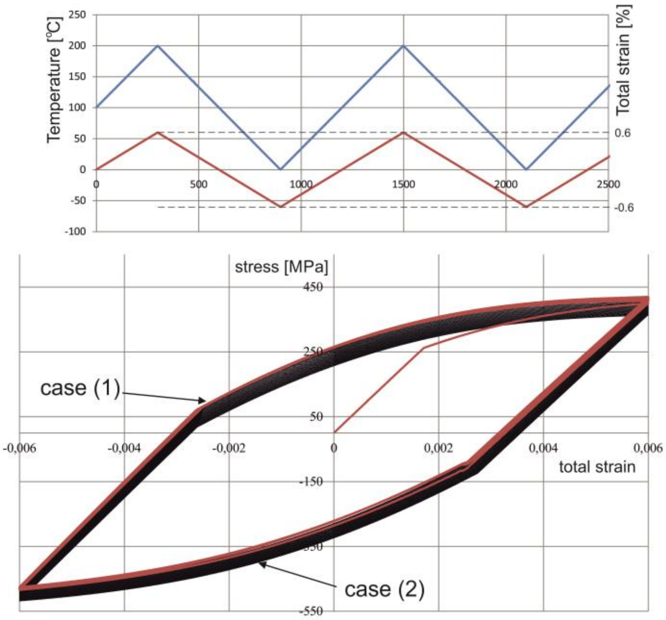


(b)

Figure 1. (a) Cyclic softening with constant strain range (isothermal);
(b) Non-isothermal fatigue test.



(a)



(b)

Figure 2. (a) Comparison between experimental and calculated responses with a strain rate of 10^{-2} at temperatures of 20^0C and 600^0C; (b) Simulation of thermomechanical fatigue.

5. References

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