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INFLUENCE OF TEMPERATURE ON MATERIAL DATA DETERMINED ON THE BASE OF LOW CYCLE FATIGUE TESTS

Stanisław Mroziński, Radosław Skocki, Zbigniew Lis

University of Technology and Life Sciences in Bydgoszcz
ul. Prof. Kaliskiego 7 85-789 Bydgoszcz, Poland
phone: +48 52 340 82 12, fax: +48 52 340 82 71
e-mail: stmpkm@utp.edu.pl

Abstract

The work deals with the method of fatigue life calculations with application of material characteristics determined during low cycle fatigue tests [7]. Analysis of obtained results enables to state that values of parameters n' and K' change and depend on fatigue life period n/N as well as temperature. Values of parameters n' and K' determined in half of fatigue life (n/N=0,5) are nor mean values for the whole range of fatigue life. The comparative analysis of obtained results indicates the scale of simplification by assumption, as results of elaboration, of values of parameters n' and K' from the one period of fatigue life n/N=0,5.

Keywords: fatigue life, cyclic properties

1. Introduction

In the fatigue life calculation method that bases on the local strain and stress analysis [7] there are used material data determined during fatigue life tests in the range of low cycle fatigue life. The method of tests as well as elaboration of test results are covered by the standard [1]. In accordance with guidelines included in the mentioned document low cycle properties of metals are defined on the base of constant amplitude tests on several (minimum 5) levels of controlled stress or strain [1]. At each level of strain or stress there are processed at least three fatigue life tests. During tests there are recorded, for chosen cycles of loading, temporary values of loading force and strain of a specimen. Recorded values of force and strain enable, after the end of tests, to perform the analysis of basic parameters of a hysteresis loop and define their correlations.

One of two characteristics defined on the base of performed tests is the cyclic stain curve describing a dependence between the plastic strain amplitude ε_{ap} and the stress amplitude σ_a. During the elaboration of test results it is assumed that between these parameters, from the stabilization period, appear the power relationship. In double logarithmic coordinates it is described by the Morrow equation [3] that is:

$$\lg \sigma_a = \lg K' + n' \lg \varepsilon_{ap} \tag{1}$$

where: K' - the curve exponent,
n' - the gradient of the curve (the strain hardening coefficient)

Parameters n' and K' of the equation (1) are basic material data used during fatigue life calculations. The presented method of elaboration of test results does not arouse doubts in case of cyclically stable materials. Doubts do appear in case of materials characterized by changes of cyclic properties that do not show stabilization period.

On the base of the analysis of works on low cycle test on metals [2] it can be stated that the period of stabilization may appear in short term or does not appear at all [4]. For such materials necessary parameters of the hysteresis loop (σ_a and ε_{ap}) are assumed from the period responding to half of fatigue life n/N=0,5, where: N- fatigue life on the defined loading level to the failure appearance while, n=0,5N. The processing during determination of hysteresis loop parameters in the case of the lack of stabilization period is shown in Fig. 1. In the figure there are schematically shown exemplary curves of changes of one of parameters (σ_a) appearing in the equation (1) on five levels of total strain ε_{ac} during tests of alloy steel [4].

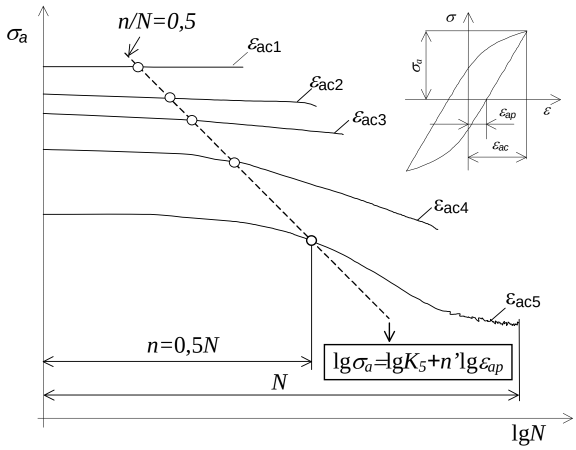


Fig. 1. Processing during elaboration of test results with the classic method (material with the lack of stabilization period) [4]

From the course of curves (σ_a) it results that tested steel undergoes essential softening. Points marked on individual stress curves mean half of fatigue life (0,5n/N) on each level of total strain ε_{ac}. Values of parameters n' and K' obtained as a result of approximation of hysteresis loops parameters (σ_a, ε_{ap}) with the equation (1) describe only temporary cyclic properties of material for the fatigue life period n/N=0,5. During fatigue life calculations they undergo an informal transposition (approximation) on the whole range of fatigue life. Such an attitude during determination of material data can be one of reasons of diversification of tests and calculation results observed for many metals and their alloys [4]. The problem especially refers to determination of material data of metals in increased temperatures.

The main aim of the work is the analysis of influence of temperature as well as the level of failure of cast steel on material data determined during low cycle fatigue tests.

2. Description of experimental tests

Experimental tests were performed with the usage of specimens made of martensitic cast steel GX12CrMoVNb9-1 (GP91). The shape of specimen and its dimensions are shown in Fig. 2.

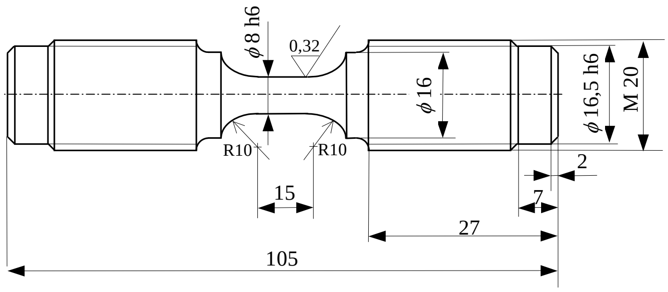


Fig. 2. Specimen for test

Tests were performed on five levels of strain ε_{ac} (0,25; 0,3; 0,35; 0,5; 0,6 %). The total strain amplitude was the controlled parameter during tests (ε_{ac}=const). During fatigue life tests for chosen cycles there were recorded temporary values of loading force as well as strain of specimen. As a criterion of test of the fatigue life test end on all levels of strain ε_{ac} there was assumed a deformation of the hysteresis loop in the half-cycle of tension.

3. Test results and their analysis

Values of loading force and strain recorded for chosen cycles were elaborated in order to determine the course of changes of basic parameters of the hysteresis loop that are $\varepsilon_{\mathrm{ap}}$ *and* σ_{a}. Temporary stress in specimen σ was determined by division the value of temporary loading force by the specimen cross-sectional area. Using maximum $\sigma_{\max}$ and minimum $\sigma_{\min}$ values of stress there was determined the amplitude value σ_{a}. Similar approach was applied while determining the value of the total strain amplitude $\varepsilon_{\mathrm{ap}}$.

As it was expected increased temperature caused decrease of fatigue life. Influence of temperature on fatigue life depends on the strain level. It is small in the area of the largest levels of strain and increases as strain decreases. In Fig. 3 there are shown exemplary curves of two parameters of the hysteresis loop ($\varepsilon_{\mathrm{ap}}$ and σ_{a}) in the function of number of loading cycles.

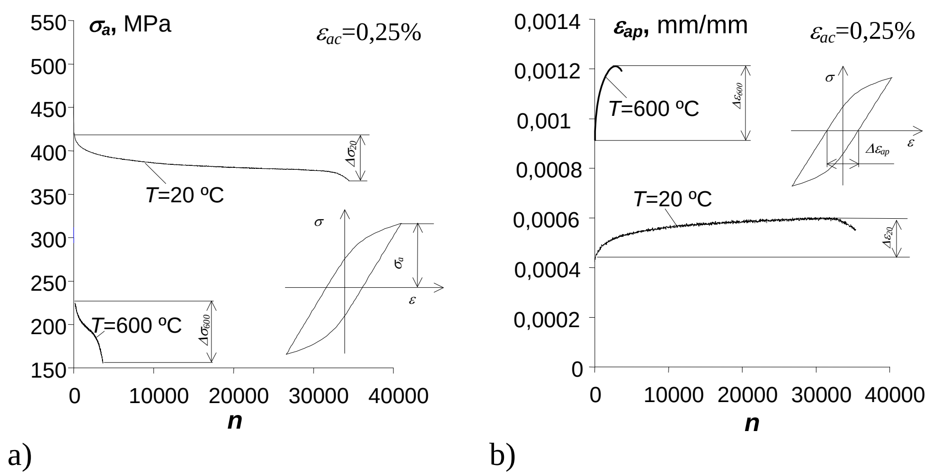
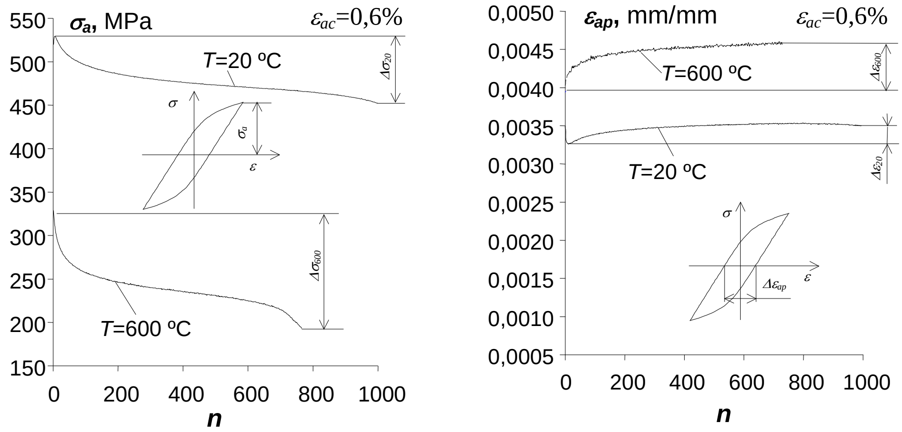


Fig. 3. Changes of parameters of the hysteresis loop on the level ε_{ac}=0,25%: a) σ_a, b) ε_{ap}



a) b)

Fig. 4. Changes of parameters of the hysteresis loop on the level ε_{ac}=0,6: a) σ_a, b) ε_{ap}

On the base of obtained curves it can be stated that there is no clear stabilization period of cyclic properties on any of loading levels. As the n number of loading cycles increases parameters of the hysteresis loop change. The stress amplitude σ_a (fig. 3a and 4a) decreases and at the same time the plastic strain amplitude increases ε_{ap} (fig. 3b, 4b). The pattern of changes of mentioned parameters attests to cyclic softening of the cast steel. In figures 3 and 4 ranges of courses of parameters recorded in the fatigue test were marked. On the base of the analysis of determined curves it can be stated that the range of changes of $\Delta\sigma$ and $\Delta\varepsilon$ parameters increases with the number of loading cycles and the strain level. Moreover the course of changes of parameters increases as temperature increases. He problem of softening of the cast steel in increased temperature was discussed in details in works [5, 6].

The method proposed in the work [4] was used to evaluate influence of temperature and fatigue failure level. Its pith is in usage of parameters of the hysteresis loop from different periods of relative fatigue life *n/N* during approximation of hysteresis loop parameters ($\varepsilon_{\mathrm{ap}}$, and σ_{a}) with straight lines described by the equation (1).

The above was schematically shown in Fig. 5. During elaboration of test results on each of loading levels there were separated 10 periods of relative fatigue life *n/N* . Periods were defined with the usage of parallel lines L_1-L_{10}. Lines stand for fatigue life periods where values of strain ε_{ap} were assumed. Analogically σ_a stresses were determined in the same periods of fatigue life.

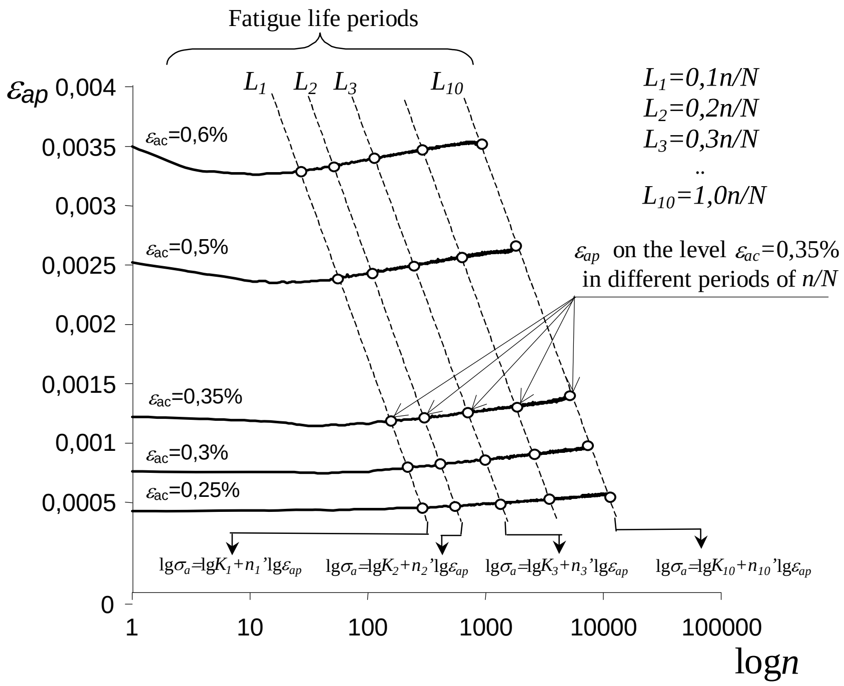


Fig. 5. Changes of plastic strain of the cast steel in temperature 600°C, the method of elaboration of test results

Values of coefficient *n'* and exponent *K'* of the equation (1) obtained in different fatigue life periods were analyzed in the function of relative fatigue life *n/N*. Curves of changes of *n'* and *K'* are shown in Fig. 6. In order to illustrate the simplification performed during elaboration of test results in the figure there were also marked values of mentioned parameters for the one period of fatigue life (*n/N*=0,5).

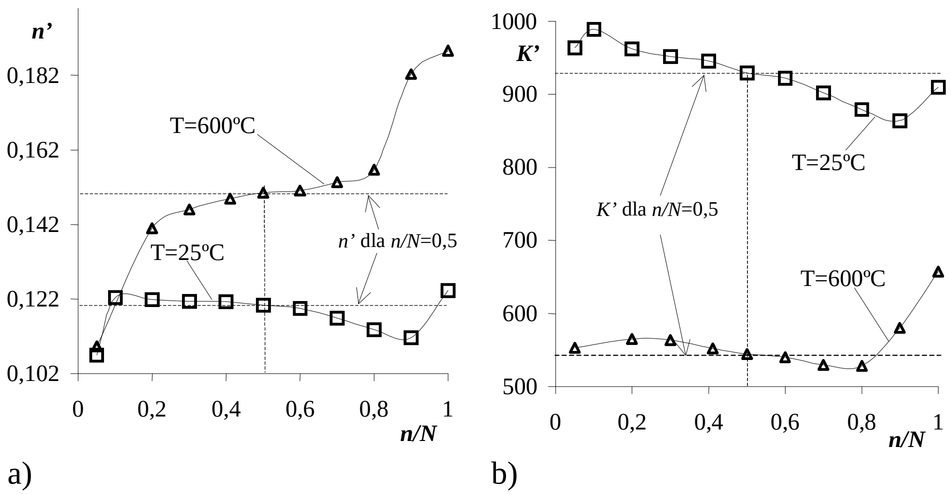


Fig. 6. Elaboration results of low cycle tests of the cast steel obtained in two temperatures: a) value of the exponent *K'*, b) value of the coefficient *n'*

As it was expected values of parameters *n'* and *K'* change and depend on the fatigue life period *n/N*. Bigger changes of material data are a consequence of the bigger range of changes of parameters of the hysteresis loop in the function of the number of loading cycles in increased temperature. The comparative analysis of material data *n'* and *K'* in both temperatures indicates the scale of the performed simplification by assuming, as elaboration results , values of parameters *n'* and *K'* from the one period of fatigue life *n/N*=0,5.

4. Summary

Martensitic cast steel during low cycle loading in ambient temperature and in temperature 600 °C undergoes cyclic softening without clear stabilization period. Temperature and total strain level influence on the value of appearing softening.

Material data (*n’* and *K’*) used in fatigue life calculations essentially depend on fatigue life in which they were determined. Bigger range of changes of loop parameters in temperature 600 °C causes that the range of material data changes in increased temperature is also bigger than in ambient temperature.

Material data of martensitic cast steel (*n’* and *K’*), obtained as a result of elaboration of fatigue life tests with the method given in the standard [1], describe only temporary cyclic properties. Values of data determined in half of fatigue life (*n/N*=0,5) are not mean values for the whole range of fatigue life.

Material data (*n’* and *K’*) obtained in different fatigue life periods enable a design engineer to estimate the range of possible changes of cyclic properties. In case of essential machine elements it is possible to perform calculations that verify extreme values of those parameters.

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