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INFLUENCE OF TEMPERATURE AND TOTAL STRAIN ON THE FATIGUE DAMAGE OF CAST STEEL

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Abstract

The paper presents test results of the course of fatigue damage of the GX12CrMoVNbN9 in conditions of the constant-amplitude loadings. As the parameter of fatigue damage there was assumed the change of mechanical properties which was determined in various stages of fatigue life. Three stages with a different rate of growth of the fatigue damage parameter were distinguished in the course of fatigue damage. It was stated that the critical value for the fatigue damage parameter depends on the level of loading and temperature.

***Keywords**: cyclic properties, fatigue life, fatigue damage, martensitic cast steel*

1. Introduction

Description of the course of fatigue damage cumulation and decrease of the mechanical properties of structural materials caused by the cyclic loading makes an essential engineering problem for many years [1, 2]. Studies on fatigue damages development were always connected to the searching for applicable measure of the fatigue damage. Various methods were used (direct and indirect): optical, changes of the electric or magnetic field, temperature, acoustic emission, mechanical properties, etc. [3, 4, 5, 6]. Mentioned methods are not for all-purposes and they are chosen dependently of the character of the fatigue damage development.

In this paper the change of the material reaction to the cyclic loadings was assumed as the fatigue damage parameter. This paper attempts to verify the methods for measuring fatigue damage parameter under low cycle fatigue (LCF) conditions.

LCF tests can be carried out under controlled loading or strain. Under controlled loading testing machine keeps the amplitude of the loading constant (σ_a=const). During the tests changes in the total strain (ε_{ac}) or plastic strain (ε_{ap}) may occur. It may be caused due to the fatigue damage. During the tests under controlled strain the amplitude of total strain (ε_{ac}=const) or plastic strain (ε_{ap}=const) is kept constant which afterwards may result in changes of the amplitude of the loading (σ_a).

In Fig. 1 there is presented a scheme of possible changes of control parameters of the testing machine and measured parameters for the mentioned tests.

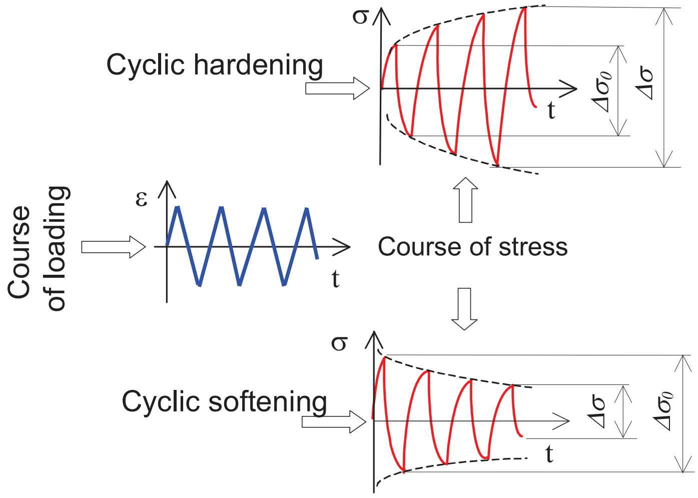


Fig. 1. Controlled parameters of testing machine and measured values

During LCF tests softening or hardening of material often takes places, followed by so called stabilization. Changes of the analysed hysteresis loop parameters after the stabilization can be ascribed to the progressive process of the fatigue damage.

Damage parameter can be defined in various ways [7, 8, 9]. In case of loading control (σ_a=const) the damage parameter D_σ may be described as follows:

$$D_\sigma = 1 - \frac{\Delta\varepsilon_0}{\Delta\varepsilon} \qquad (1)$$

where: $\Delta\varepsilon_0$ – the range of total strain during the stabilization period

$\Delta\varepsilon$ – the range of total strain during the damage period

Whereas for the tests with the total strain control (ε_{ac}=const) the damage parameter D_σ may be described as follows:

$$D_\varepsilon = 1 - \frac{\Delta\sigma_0}{\Delta\sigma} \qquad (2)$$

where: $\Delta\sigma_0$ – the range of stress during the stabilization period,

$\Delta\sigma$ – the range of stress for the damage period,

The aim of this work is the analysis of the influence of the temperature and level of total strain on the critical value of the damage parameter and its course during loadings.

2. Description of tests

Specimens for the tests were made of GX12CrMoVNbN9-1 martensitic cast steel. The shape and dimensions of the specimens were in agreement with the standard [12] PN-84/H-04334. Chemical composition of the cast steel is collected in table 1.

Tab. 1. Chemical composition [%]

C	Mn	Si	P	S	Cr	Mo	V	Nb	N
0.12	0.47	0.31	0.014	0.004	8.22	0.90	0.12	0.07	0.04

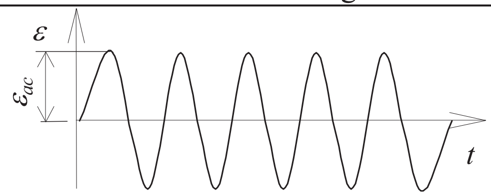
At first static tensile tests were carried out in order to determine levels of total strain for the fatigue tests. There were used specimens for the fatigue tests. The specimens underwent increasing loading with the rate of machine piston displacement speed of 0.05 mm/s. Specimen's elongation was measured by a 12.5 mm gauge length axial extensometer with measuring range of 3.75 mm which was fixed to the specimen. The static tensile tests were carried out under temperatures of 20, 400, 600°C. Strength properties are collected in table 2.

Tab. 2. Strength parameters of cast steel for the three temperatures

Parameter	Temperature, °C		
	20	400	600
Re, MPa	503	418	303
Rm, MPa	663	535	338
$El._{12.5}$, %	36.3	38	63.5
A, %	63.4	71	87.3
E, MPa	206870	180234	150120

After analysing static tensile tests five levels of total strain ε_{ac} were accepted in low cycle tests according to table. 3.

Tab. 3. Parameters of loading programs

Course of loading	Parameters
	ε_{ac1}=0,25% ε_{ac2}=0,3% ε_{ac3}=0, 35% ε_{ac4}=0,5% ε_{ac5}=0,6% *f=0,2 Hz*

Tests consisted in cyclically loading specimens until the specimens break. Procedure of measuring strain employed for LCF tests was the same as for static tensile test. Test temperature of 20°C and frequency of *0.2 Hz* were employed. Accepted sampling frequency of force signal and strain signal allowed to describe loading cycles with set of 200 points. As the end criterion of the fatigue test, the deformation of hysteresis loop (during semi cycle of compression) is accepted. During the tests momentary values of loading force and strain for selected loading cycles were recorded.

3. Test results and discussion

Recorded momentary values of the loading force and strain for loading cycles allowed to plot the hysteresis loop in stress σ - strain ε coordinate system. Stresses in the specimen under tensile loading were calculated by dividing momentary value of loading force by cross-sectional area before the specimen was loaded. Exemplary hysteresis loops for the two levels of total strain (ε_{ac}=0,25 % and ε_{ac}=0,6%) obtained for the two levels of temperature (T=20°C and T=600°C) were shown in Fig 2 and 3.

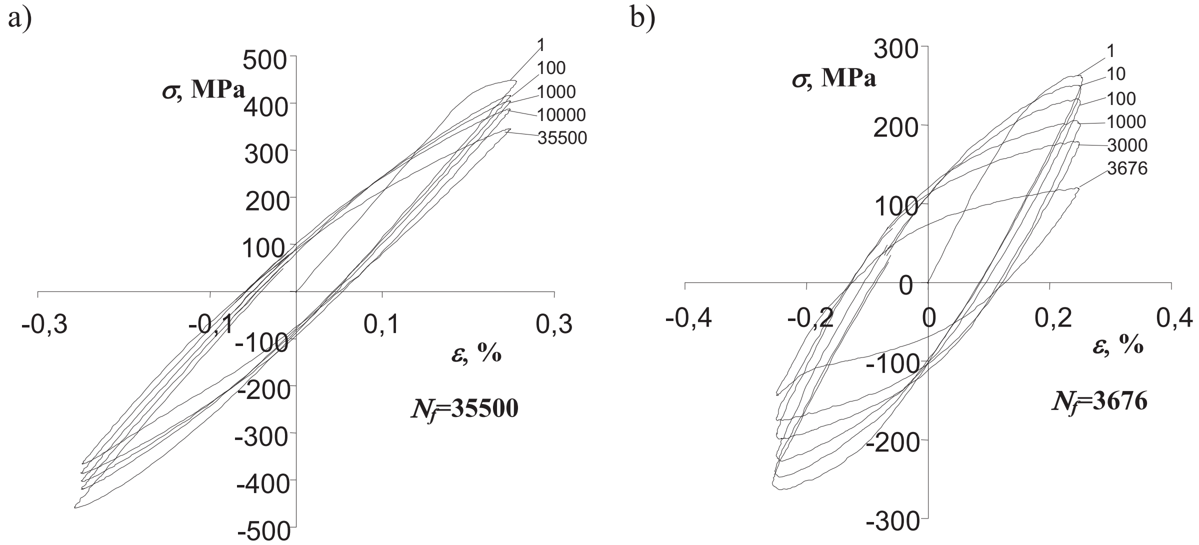


Fig. 2. Hysteresis loops for the level of total strain of ε_{ac}=0,25%: a) T=20 ºC, b) T=600 ºC

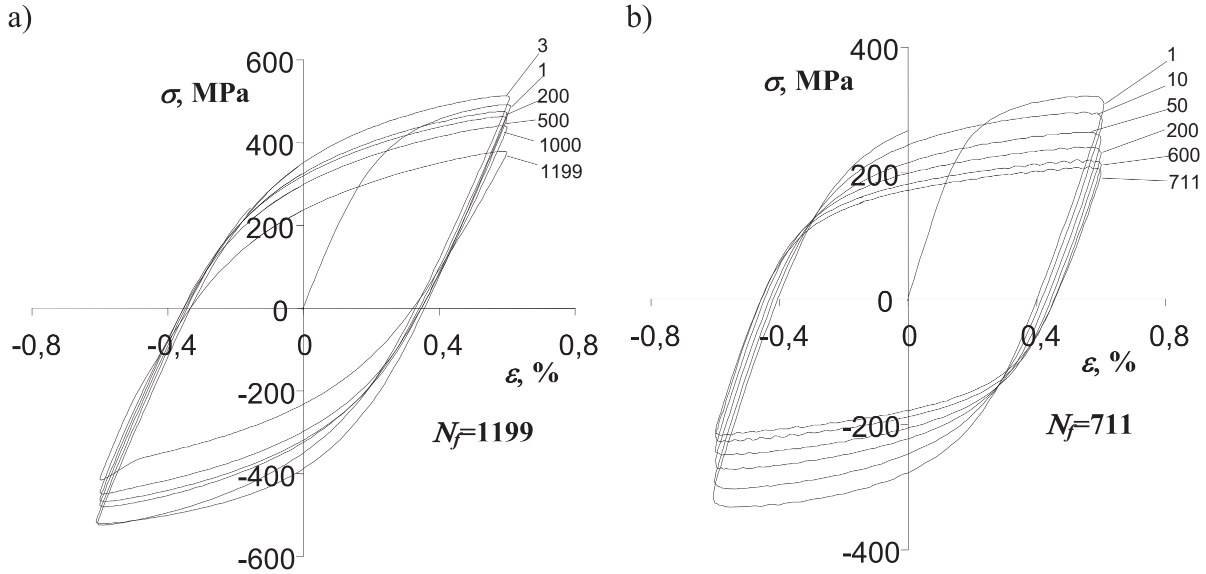


Fig. 3. Hysteresis loops for the level of total strain of ε_{ac}=0,6%: a) T=20 ºC, b) T=600 ºC

On the basis of analysis of hysteresis loop shape it can be stated that tested material cyclically softens. With increasing of the number of cycles the range of stress decreases $\Delta\sigma$ and the range of plastic strain $\Delta\varepsilon_{ap}$ increases. The above changes were observed at room temperature and at elevated temperatures. In order to illustrate the changes of the mentioned parameters there were shown exemplary courses of changes of the range of stress $\Delta\sigma$ in the function of number of loading cycles obtained for the two temperatures (Fig. 4).

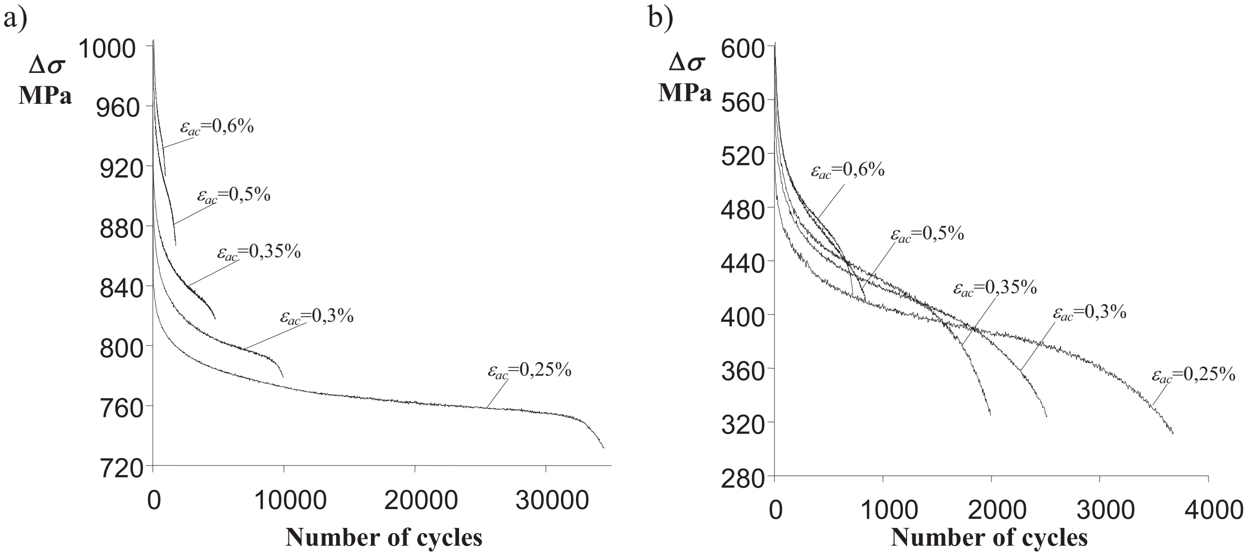


Fig. 4. Changes of stress $\Delta\sigma$ in the function of loading cycles: a) T=20ºC, b) T=600ºC

On the basis of the performed curves it can be stated that during LCF tests there was lack of the stabilization period. In the courses of $\Delta\sigma$ three distinctive stages can be drawn with various intensity of softening. These stages were widely described in the work [10, 11].
Values of the range of stress $\Delta\sigma$ from different period of fatigue life were employed to calculate the damage parameter $D_{\sigma.}$ Due to lack of the stabilization period, the value of $\Delta\sigma_o$ determined in equation (2) was assumed from the first loading cycle.
Exemplary results of changes of the damage parameters D_σ in the function of cycles obtained for the five levels of total strain at temperature of 20 and 600 ºC were shown in Fig. 5.

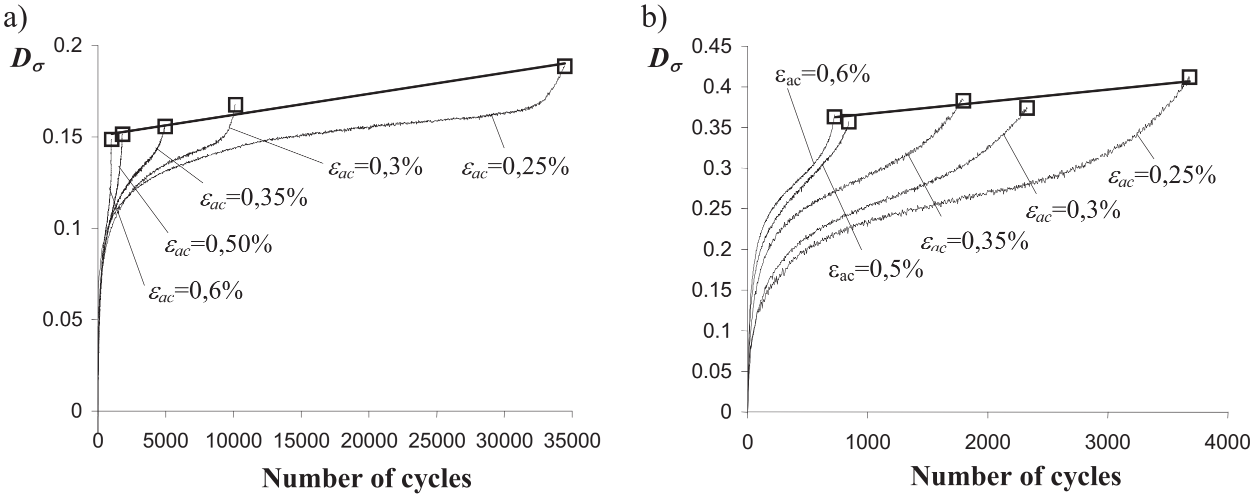


Fig. 5. Changes of damage parameter D_σ in the function of number of cycles: a) T=20ºC, b) T=600ºC

After comparative analysis of curves of damage parameter D_σ it can be stated that their course depends on the level of total strain. On the diagrams of this parameter three characteristic stages can be distinguished. The stage of quick growth of the damage parameter (stage A), steady growth (stage B) and once again quick growth (stage C). These stages occurred for all levels of total strain. The largest rate of growth of D_σ occurred in the stage A. The rate of growth of D_σ in this stage is influenced by the level of total strain ε_{ac} and temperature of the tests. In order to evaluate the influence of the temperature on the changes of the D_σ parameter in Fig. 6 there was shown exemplary courses of this parameter for the three levels of total strain and three temperatures (20, 400, 600 °C).

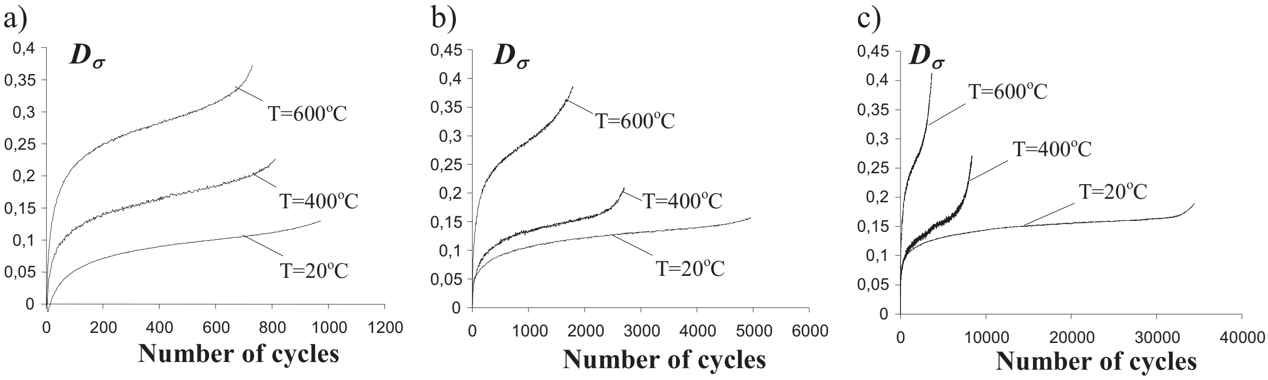


Fig. 6. Influence of the temperature on the damage parameter D_σ : a) ε_{ac}=0,25%, b) ε_{ac}=0,35%, c) ε_{ac}=0,6%

According to the diagrams in Fig 5 and 6 it can be stated that the value of the D_σ parameter at the moment when damage of specimen occurs is not constant. The value is influenced by the level of total strain and temperature of the tests. In Fig. 7. there were presented diagrams which illustrate the influence of the level of total strain and temperature on the critical value of the damage parameter D_σ.

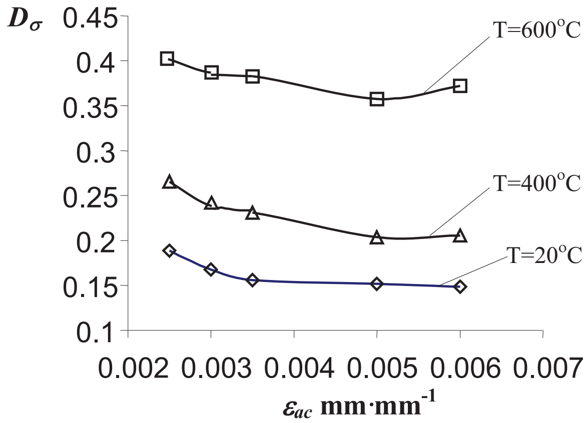


Fig.7. Influence of total strain and temperature on critical value of damage parameter D_σ

On the basis of performed curves it can be stated that the critical value of the damage parameter decreases with the increase of total strain ε_{ac}. Decrease in the damage parameter with the increase of the total strain is not large and equals from 11% for the temperature of T=20°C to about 14% at the temperature of T=600°C. The temperature of tests is very important. The lowest values of the D_σ parameter occurs at the room temperature (T=20°C). The highest values occurs at the temperature of T=600°C. The critical value of the D_σ at the temperature of T=600°C is almost 2 times higher than its values at the temperature of T=20°C.

4. Conclusions

Tested material softens during LCF with no significant stabilization period. Lack of this period makes difficult an analysis of the D_σ damage parameter during LCF test as its value covers the changes of properties caused by the softening of material and also course of the damage. In order to formulate applicable conclusions it is necessary to perform tests with using another parameters of hysteresis loop which would be insensitive on changes of cyclic properties e.g. plastic strain energy ΔW_{pl}. It was shown in the work [10, 11].

The course of D_σ damage parameter is influenced by the level of total strain and temperature of test. On the basis of analysis of diagrams with damage parameter in the function of loading cycles three characteristic stages can be determined with various rate of growth of the damage parameter. Critical value of this parameter when the material breaks is not a constant value and it depends on the test temperature and slightly on the level of total strain.

Minor influence of the level of total strain on the critical value of the damage parameter confirms the reports in the literature, where this parameter is considered to be in use in scientific research or in engineering to control the level of damage of technical object. A drawback of the method of measuring the level of damage is a destructive character of the tests which hast to be performed in order to obtain the information about momentary values of the damage parameter.

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