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STUDIES ON THE FATIGUE CHARACTERISTICS AND FATIGUE CURVES OF HIGH NITROGEN STRUCTURAL STEEL IN LOW CYCLE AREA OF LOADING

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ABSTRACT

The influence of the nitrogen as an alloying element in high nitrogen structural steel 30Cr2Ni2MoN2V on its behaviour during cyclic loading in the low cycle area has been investigated. The methods for parameters investigation of the low cycle fatigue have been studied. The fatigue characteristics in the low cycle area of loading have been investigated on Servo hydraulic test machine. The presence of nitrogen as an alloying element has no significant influence on the cyclic behaviour. It is obtained that the high nitrogen steel is more suitable for threaded connection elements intended for water-cooled atomic reactor bodies of type WWAR.

Keywords: high nitrogen structural steel, nuclear power engineering, low cycle fatigue, rigid fatigue loading.

INTRODUCTION

At present in the nuclear power engineering as a material for water-cooled atomic reactor bodies of type WWAR is used nitrogen free steel 38CrNi3MoV (similar to 4337+V, AISI). In some technical characteristics this steel does not meet the requirements in the nuclear power engineering. (R_{02}<780 MPa at test temperature of 350 °C). In the Institute of metal science "Acad. A. Balevsky" at Bulgarian academy of sciences is developed high nitrogen structural steel 30Cr2Ni2MoN2V with high strengthen and plastic properties [1]. The carried out investigations and the obtained experimental results prove that steel 30Cr2Ni2MoN2V has properties exceeding the technical requirements in the nuclear power engineering (R_{02}>900 MPa). Because of the specific operation conditions in the nuclear power engineering is of interest the behaviour of the nitrogen steel in the low cycle area of loading.

According to the methods for parameters investigation of the low cycle fatigue process a determinative factor for the damages in the low cycle area of loading is the cyclic plastic deformation arising on some critical place of the construction. The stress - deformation curves, called hysteresis curves obtained at constant amplitude of stress ($\Delta\sigma = const$) defined a soft mode of loading and at constant amplitude of deformations ($\Delta\varepsilon = const$) – a hard mode of loading. For determination of the materials parameters in the low cycle loading a mode of constant amplitude of the deformations ($\Delta\varepsilon = const$) is preferred, as the low cycle fatigue phenomenon depends basically on the value of these deformations. In this case the dependence of the stress on the cycles number of the change loading (rigid fatigue loading) $2N_f$ ($2N_f=10^N$, where $2N_f$ is cycles number till destruction) gives an information about the elastic - plastic behaviour of the material in the period before the appearance of a fatigue crack [2].

The time for increasing of the formed fatigue crack has also importance for the crack durability of the material. The basic purpose is to determine the number of cycles as the crack grows to the size, after that comes the final destruction and to plot the fatigue curves ε_a -2N$_f$ ($\varepsilon_a = \varepsilon_e + \varepsilon_p$), where: ε_a - total deformation; $\varepsilon_e = \frac{\Delta\varepsilon_e}{2}$ - elastic deformation; $\Delta\varepsilon_e$ - amplitude of elastic deformation; $\varepsilon_p = \frac{\Delta\varepsilon_p}{2}$ - plastic deformation; $\Delta\varepsilon_p$ - amplitude of plastic deformation for the real detail. By analogy with the curve $da/d\mathrm{N} - \Delta k$ Douling [3] introduces the dependence $da/d\mathrm{N} - \Delta J$ for the strongly developed plastic deformation. The collected experimental data show that the dependence is a right line in log-log plot expressed by the following equation:

$$\frac{da}{d\mathrm{N}} = C_2(\Delta J)^{m_2}, \quad (1)$$

where: $\frac{da}{dN}$ - growth rate of fatigue cracks; ΔJ - cyclic J-integral; C_2 and m_2 are empirical constants.

For the fatigue curves can be used the equations for plastic and elastic deformation (Manson – Coffin and Buskin equations) [3].

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon'_f(2\mathrm{N}_f)^c \quad , [\%] \quad (2)$$

$$\frac{\Delta\varepsilon_e}{2} = \frac{\sigma'_f}{E}(2\mathrm{N}_f)^b \quad , [\%] \quad (3)$$

where: ε'_f - cyclic toughness coefficient; c - fatigue toughness exponent; σ'_f - fatigue strength coefficient; b - fatigue strength exponent; E - elastic modulus.

In the experiments the Douling's method of approach for determination of the empirical coefficients in equations (2) and (3) is used. To plot the fatigue curves are tested 12 up to 15 samples from a given material. The experiments are carried out under conditions of a symmetric cycle of total deformation at room temperature. The hysteresis curves are recorded periodically by digital oscilloscope and then reproduced by X-Y recorder. The test machine registers automatically also the cycle number till the sample destruction. From the obtained stabilized hysteresis curves the amplitudes of the elastic - $\Delta\varepsilon_e$ and the plastic deformation - $\Delta\varepsilon_p$ are determined and the dependencies of the elastic and the plastic component of deformation on the number of cycles till destruction are plotted.

The purpose of the present work is the investigation of the fatigue characteristics and fatigues curves of high nitrogen structural steel and its nitrogen free analogue in the low cycle area of loading.

EXPERIMENTAL

30Cr2Ni2MoN2V and 38CrNi3MoV steels intended for production of threaded connection elements in atomic reactors, where the cycles loading are important operating problem, are investigated. For both steels have no data on their behaviour in cycle loading. This determines the necessity of investigations for future application. The investigations are carried out on metal from two steel ingots – high nitrogen and nitrogen free, produced on industrial units: the induction furnace working on a method casting under pressure – IF-05 and installation for electroslag remelting under pressure – ESRP-2. In the research Servo hydraulic test machine MTS-810.12 is used. The experiments are carried out at constant value of the deformation amplitude set by an extensometer attached to the sample and to the system for reverse connection to the test machine. The operation frequency of the tests is 1 Hz.

For the specific tasks of the experiment an apparatus is developed consisting in the following components: power source of direct current of 0-50 A range and voltage 10 V; electro conductive sample holder; digital voltmeter to register the potential difference.

RESULTS AND DISCUSSION

The investigations are carried out according to the methods for determination of fatigue strength at set service life 10^4 of the cycle and the fatigue curves under conditions of low cycles fatigue [4]. The obtained fatigue curves on the basis of 10^4 cycles for the elastic and the plastic component of the deformation for both investigated materials are presented in Fig. 1. As a re-

Table 1. Value of empirical coefficients.

Steel	$\lg\varepsilon'_f$	$\lg\frac{\sigma'_f}{E}$	b	c
38CrNi3MoV	1,07	0,9	-0,026	-0,044
30CrNi2MoN2V	1,03	0,94	-0,027	-0,040

sult of the carried out experiments data are obtained for the empirical coefficients in equation (2) and (3), presented in Table 1. The increasing nitrogen concentration in steel 30Cr2Ni2MoN2V does not change considerably the behaviour parameters of the material in the low cycle area of loading (Table 1, Fig. 1). It is observed trend of decreasing of the fatigue toughness coefficient - ε'_f and increasing of the fatigue toughness exponent. In all probability this is a consequence of the brittleness action of the nitrogen. The plastic deformation during the cyclic loading in the low cycle loading is irreversible due to which the plastic properties of the material are changing.

A dependence of a stress on the cycle's numbers at constant total deformation of a cycle is obtained ($\varepsilon_a = 1{,}8\ \%$) (Fig. 2). For both investigated steels is apparent a constant cyclic softening, which proceeds intensively till the final sample destruction. The increased concentration of nitrogen as alloying element in steel

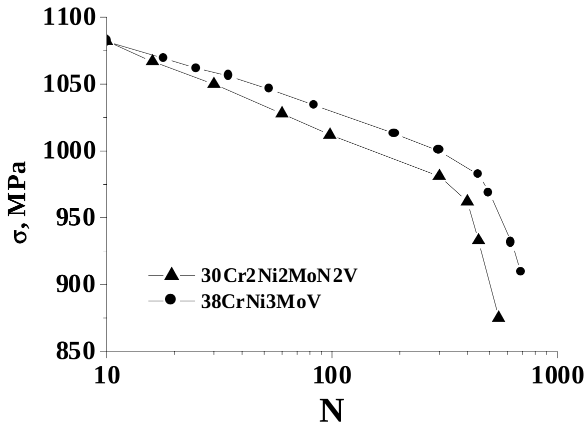

Fig. 2. Dependence of a stress on cycles number of loading change at ε_a =1,8 %.

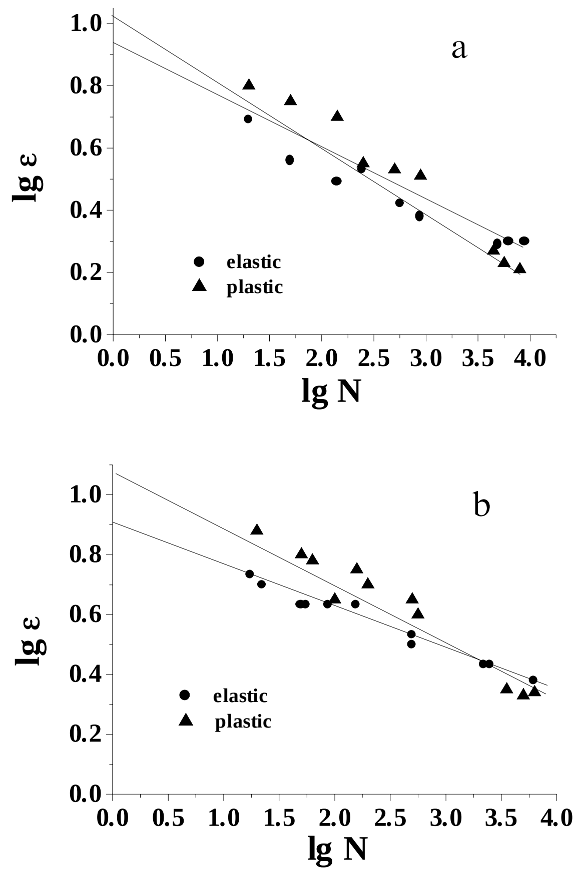

Fig. 1. Fatigue curves for elastic and plastic components for 30Cr2Ni2MoN2V (a) and 38CrNi3MoV (b) steels.

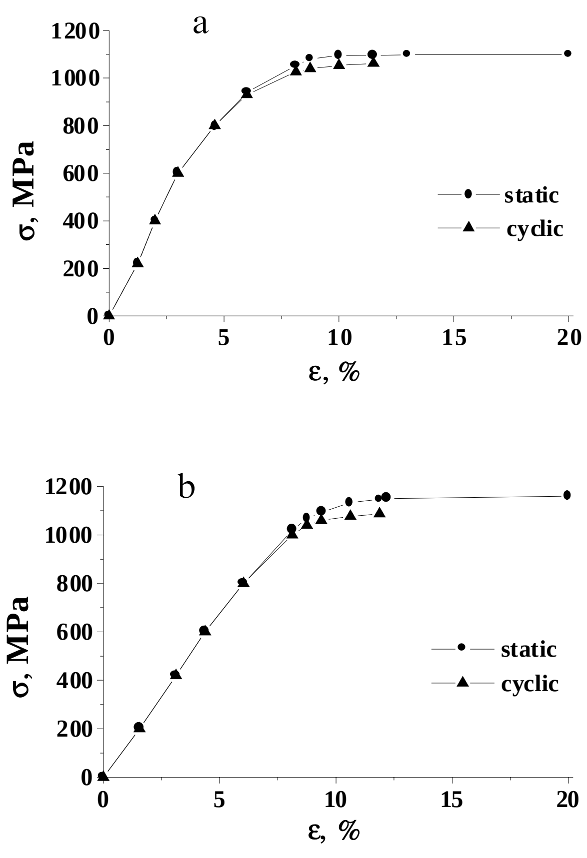

Fig. 3. Static and cyclic $\sigma - \varepsilon$ curves of the investigated steels: a) 30Cr2Ni2MoN2V; b) 38CrNi3MoV

30Cr2Ni2MoN2V does not give essential influence on its behaviour in this research.

Fig. 3 presents a comparison between the static and the cyclic $\sigma - \varepsilon$ curves. It gives quantitative valuation about the influence of the cyclic loading on the mechanical properties of the investigated steels. The location of the cyclic under the static curves proves that the both steels are cyclically softening. It is no considerable difference in the behaviour of the both materials. The higher nitrogen concentration in steel 30Cr2Ni2MoN2V does not change essentially the steel behaviour in the cyclic loading. It is obtained that the high nitrogen steel is more suitable for threaded connection elements intended for water-cooled atomic reactor bodies of type WWAR. Relatively low cycles number to transition from low cycles fatigue to high cycle fatigue ($1{,}7x10^3$) shows that the both steels are no particularly suitable for details under loading in the low cycle area. Because of the high elastic limit of the both materials they are more applicable for work in the high cycle area of loading.

CONCLUSIONS

The investigation methods of the parameters of the low cycle fatigue process are studied. The fatigue characteristics in the low cycle area of loading are investigated on Servo hydraulic test machine. The fatigue curves for the elastic and the plastic components of the deformation for steels 30Cr2Ni2MoN2V and 38CrNi3MoV are obtained. For both investigated steels a dependence of the stress on the cycle's number at constant total deformation of cycle is obtained. For both materials a constant cyclic softening is apparent, which proceeds intensively before the final sample destruction. A comparison between the static and the cyclic $\sigma - \varepsilon$ curves for the tested steels is made. The location of the cyclic under the static curves proves that the both steels are cyclically softening. High nitrogen structural steel 30Cr2Ni2MoN2V and its nitrogen free analogue have practically identical parameters in the low cycle fatigue tests. It is obtained that the high nitrogen steel is more suitable for threaded connection elements intended for water-cooled atomic reactor bodies of type WWAR. Relatively low cycles number to the transition from the low cycles fatigue to the high cycle fatigue ($1{,}7x10^3$) shows that the both steels are no particularly suitable for details under loading in the low cycle area. Because of the high elastic limit of the both materials they are more applicable for work in the high cycle area of loading.

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