APPLICATION OF THE ENERGY PARAMETER FOR FATIGUE LIFE ESTIMATION UNDER UNIAXIAL RANDOM LOADING WITH THE MEAN VALUE

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ABSTRACT

The paper contains a comparison of the results of calculation and experiment for the alloy steel 10HNAP. Specimens made of this steel were subjected to uniaxial constant-amplitude and random loadings with both zero and non-zero mean values of loading. For determination of the steel fatigue life, the energy parameter including the mean value of loading was proposed. Under random loading, cycles were counted with the rain flow algorithm, and damage was accumulated with the Palmgren-Miner hypothesis. For the registered stress histories, elastic-plastic strains were calculated with the kinematic hardening model proposed by Mróz-Garud.

1 INTRODUCTION

There are stress, strain and energy models which can be used for analysis of fatigue test results including the influence of the mean loading value. At present, the energy models [3, 4] are often used to describe multiaxial fatigue. However, in this model the influence of the mean value on fatigue is not examined in detail. The aim of this paper is to elaborate on the energy model including the influence of the loading mean value and its verification in fatigue tests of 10HNAP steel. The influence of the mean value for 10HNAP steel was analysed previously according to the stress models formulated by Goodman, Gerber [2] and Dang - Van [1, 2].

2 THE TESTED MATERIAL AND SPECIMEN SHAPE

Plane specimens of 10HNAP steel [5] were tested on a fatigue test stand SHM 250. This stand enables tests to be performed under controlled force, displacement or strain of cyclic or random loadings. Chemical composition of the tested alloy steel is following: C=0.115%, Mn=0.71%, Si=0.41%, P=0.082%, S=0.028%, Cr=0.81%, Cu=0.30%, Ni=0.50% in wt. and Fe=balance. Static properties are following: E=215GPa, σ_{YS}=414MPa, σ_{TS}=556MPa, ν=0.29, El_{10}=31%, RA,=35% and cyclic properties are following: $\sigma`_f$=1136MPa, b=-0.105, $\varepsilon`_f$=0.114, c=-0.420, n'=0.156, K'=853MPa. Under cyclic loading, the tests were performed for five different stress amplitudes and three levels of the mean loading, 75MPa, 150MPa and 225MPa. Under random loading, the tests were done for seven different values of root mean square of stress, σ_{RMS} and mean values, σ_m (zero, compressing and tensile). Observation time for random loading was $T_0 = 649$ s, and sampling time was $\Delta t = 2.641\cdot10^{-3}$s, i.e. 245760 instantaneous samples.

3 THE ENERGY MODEL

The energy parameter in time domain can be calculated from

$$W(t) = 0.5\sigma(t)(\varepsilon(t)-\varepsilon_m)\,\mathrm{sgn}[\sigma(t),(\varepsilon(t)-\varepsilon_m)] \tag{1}$$

similarly to the model presented in [3, 4], where ε_m is strain mean value.

Function sgn[$\sigma(t)$, $\varepsilon(t)$- ε_m] distinguishs the positive and negative work of a cycle, i.e. energy of tension (positive) and compression (negative). Application of the function sgn in calculations causes the history of the strain energy density parameter at time to change in a symmetric way, while cyclic stresses and strains change in relation to the mean values. Fig. 1 and 2 show the constant-amplitude and random histories $\sigma(t)$ with the mean value σ_m=75 MPa and the corresponing history of strain $\varepsilon(t)$ as well as history of the strain energy density parameter with time with and without the function sgn. From the graphs it appears that application of the function sgn reduced the mean value of W_m.

The fatigue life of the tested material for the low- and high-cycle regime can be calculated from

$$W_a = \frac{\sigma'^2_f}{2E}(2N_f)^{2b} + 0.5\varepsilon'_f\sigma'_f(2N_f)^{b+c}, \tag{2}$$

where W_a is the amplitude of the strain energy density parameter.

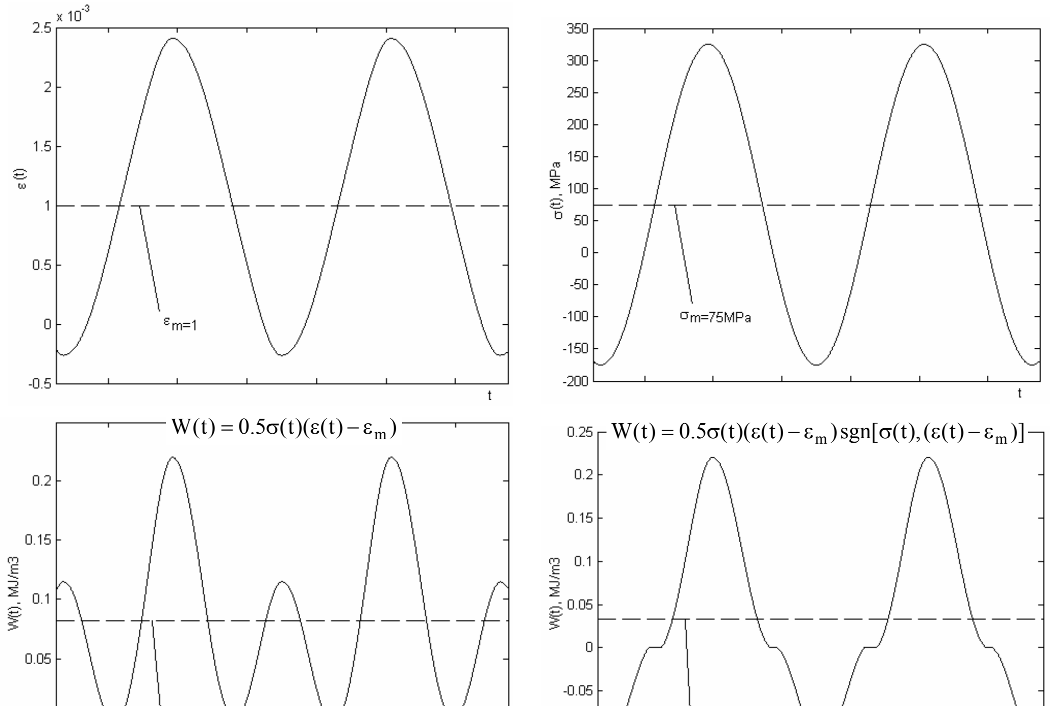

Fig. 1. History of the energy parameter at time W(t) for constant-amplitude loading.

4 APPLICATION OF THE MRÓZ-GARUD MODEL

This paper uses the incremental kinematic model of material hardening formulated by Mróz-Garud [6]. This model is based on the Mróz idea [7] introducing the plastic modulus field. According to this idea for the one-dimensional case, the non-linear curve of cyclic strain (σ - ε) is replaced by a sequence of linear segments. Each linear segment has its own modulus of plasticity (C_0, C_1, C_2, . . ., C_{m-1}). The points on the new linearized curve of cyclic strain where moduli of plasticity change, determine fields in the nine-dimensional space of stresses with constant moduli of plasticity (fields of moduli of plasticity). The surfaces f_1, f_2, . . ., $f_{m.}$ with constant moduli of plasticity are reduced to spherical surfaces in the case of selection of a proper scale and application of the Huber-Mises-Hencky condition of plasticity (H-M-H). The Mróz-Garud model assumes that the material is homogeneous, isotropic, and influence of the loading rate can be neglected. Moreover, the model does not include thermal phenomena and assumes constancy of the Young's and Poisson's modul.

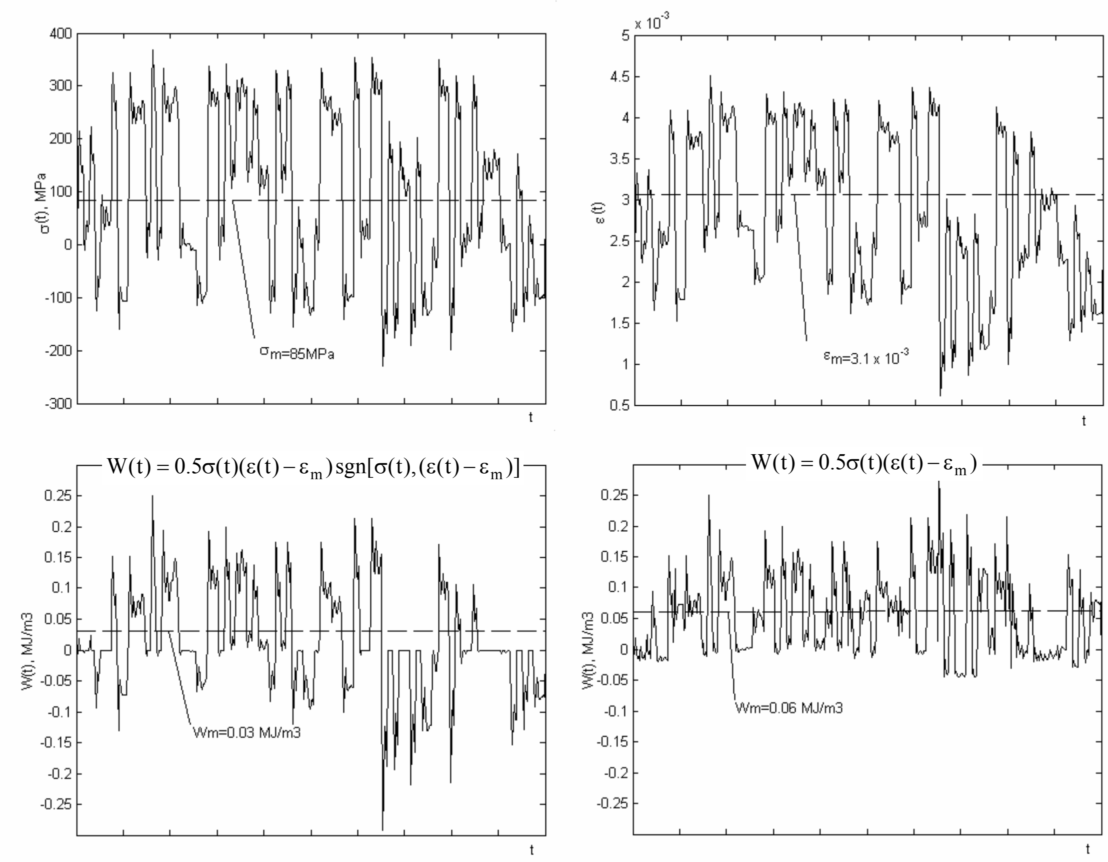

Fig. 2. History of the energy parameter at time W(t) for random loading.

5 VERIFICATION OF THE MODEL

5.1. Constant-amplitude loading

The transform amplitudes of the strain energy density parameter were calculated from

$$W_{aT} = \begin{cases} \dfrac{(\sigma_a + \sigma_m)\varepsilon_a}{2} & \text{for} \quad \sigma_m \geq 0 \\ \dfrac{\sigma_a \varepsilon_a}{2} & \text{for} \quad \sigma_m < 0 \end{cases} . \tag{3}$$

Under constant-amplitude loading for $\sigma_m \geq 0$, Eq.(3) is connected with the Smith-Watson-Topper parameter (SWT) [8] according to the following equation

$$W_{aT} = 0.5P_{SWT} = 0.5\sigma_{max}\varepsilon_a = 0.5(\sigma_a + \sigma_m)\varepsilon_a\,, \tag{4}$$

A graphical comparison of experimental and calculated lives is shown in Fig.3. The solid line represents a perfect conformity of results, the dashed lines represents a scatter band with coefficient of 3, i.e. $N_{fexp}/N_{fcal}=3$ (1/3), because constant-amplitude tests give such scatter [5].

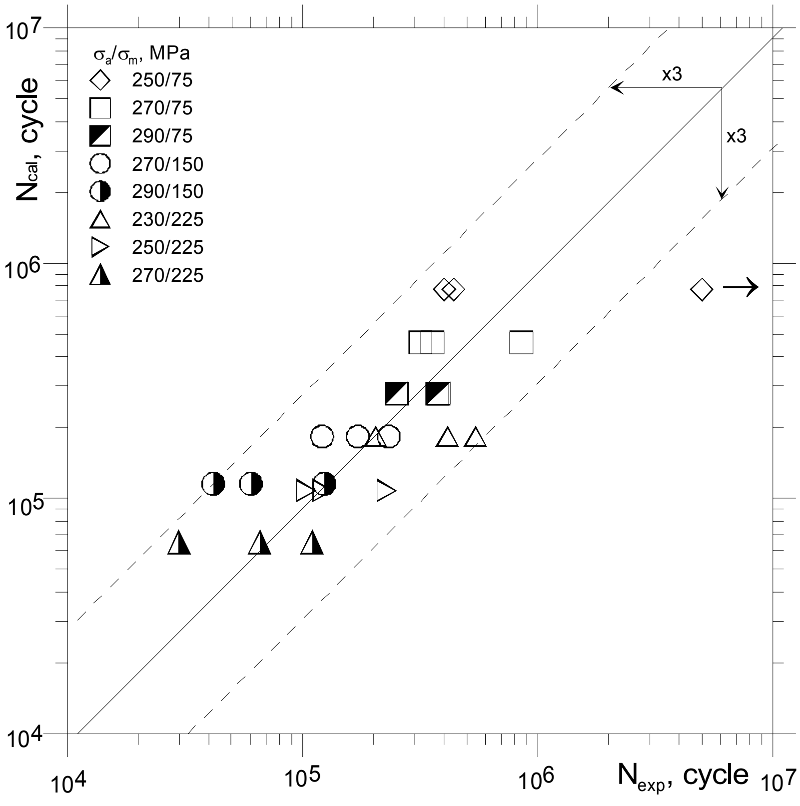

Fig.3. A comparison of the calculated and experimental lives for 10HNAP steel under constant-amplitude tension-compression

5.1. Random loading

The algorithm for determination of the fatigue life of 10HNAP steel according to the presented model can be shown as:

- measurement of stresses σ(t),
- numerical determination of strains ε(t) corresponding to the given stresses according to the incremental kinematic model of material hardening formulated by Mróz-Garud,
- determination of the energy parameter history according to Eq. (1),
- determination of amplitudes, W_a and mean values, W_m of cycles and half-cycles with the rain flow algorithm [9],

- determination of the transform amplitude of the strain energy density parameter from the previously determined amplitudes and mean values according to

$$W_{aT}=\begin{cases} W_a+W_m & \text{for} \quad W_m\geq 0 \\ W_a & \text{for} \quad W_m<0 \end{cases}, \tag{5}$$

- determination of a damage degree according to the Palmgren-Miner hypothesis [10, 11],

$$S(T_0)=\sum_{i=1}^{k}\frac{1}{N_{fi}}, \tag{6}$$

where N_{fi} is determined from Eq. (2) for the calculated W_a,

- fatigue life determination according to the following relationship

$$T_{cal}=\frac{T_0}{S(T_0)}, \tag{7}$$

where T_0 is observation time.
Figure 4 shows comparison of the calculated and experimental lives for random loading with the zero and non-zero mean value of loading [12]. The solid line represents a perfect conformity of results, and the dashed lines represents a scatter band with coefficient of 3, i.e. T_{exp}/T_{cal}=3 (1/3).

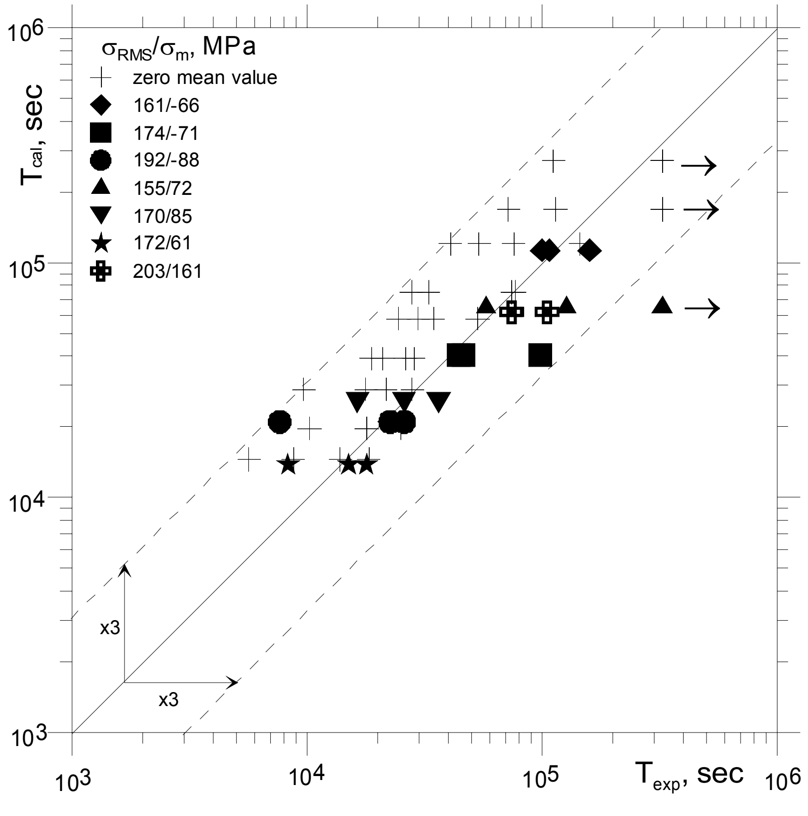

Fig.4. A comparison of the calculated and experimental results for 10HNAP steel under random tension-compression

5 CONCLUSIONS

From the verification of the energy model for specimens made of 10HNAP steel we can draw the following conclusions.

1. Satisfactory correlation of results between calculated and experimental fatigue lives was obtained under constant-amplitude and random tension-compression with zero and non-zero mean values.
2. Almost all the results for the considered loadings are within the scatter band with the coefficient of 3.
3. For random loading from calculation using the rain flow algorithm, acceptable fatigue life results were obtained. Negative mean value of cycles were neglected.
4. The presented parameter of strain energy density includes the influence of the mean loading and for constant-amplitude loading it reduces to the known Smith-Watson-Topper model P_{SWT}.

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