THE ENERGY APPROACH IN THE CALCULATION OF LIVES FOR HIGH CYCLE FATIGUE

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In the paper an energy based method of fatigue life calculation under non-proportional random bending with torsion loading is presented and experimentally verified. The method identifies strain energy density parameter in the critical fracture plane through integration of the chosen fragments of power history according to the distinguished ranges of stresses. Round specimens made of steel 10HNAP (S355J2G1W) included in the standard PN-EN 10155 of 1997 were tested. The material is a low-alloy of higher resistance to atmospheric corrosion structural steel. The tests performed in the high cycle fatigue regime (HCF) under variable-amplitude and pseudo-random combined bending and torsion loading, were held at Opole University of Technology [1]. The tests were carried out under narrow-band loading with the dominating frequency 20 Hz and 28.8 Hz the coefficient of irregularity I = 1 and 0.99. The equivalent instantaneous power, $p_{eq}(t)$, understood as a scalar product of instantaneous values of suitable components of the stress tensor $\sigma_{ij}(t)$ and the strain rate tensor $\dot{\varepsilon}_{ij}(t)$, is calculated according to the following relation [2]

$$p_{eq}(t) = \sigma_{ij}(t) \bullet \dot{\varepsilon}_{ij}(t) \tag{1}$$

where i, j = 1, 2, 3.
Eq. (1) is integrated in the time interval $t_{k+1} - t_k$ for each distinguished stress range $\sigma_{ij}(t_{k+1})$ - $\sigma_{ij}(t_k)$, and increment of the strain energy density is calculated

$$\Delta E_{eq[(k+1)-k]} = \int_{t_k}^{t_{k+1}} p_{eq}(t)dt = \int_{t_k}^{t_{k+1}} \sigma_{ij}(t)\dot{\varepsilon}_{ij}(t)dt \tag{2}$$

The procedure of calculation of strain energy density for one stress range includes observation of changes of stress history and integration of suitable fragments of instantaneous power histories (Fig. 1). Energy changes, determined in the moments corresponding to the distinguished ranges in the stress history, correspond to work of external forces on suitable displacements. They are identified with elastic energy temporarily accumulated in the material. In the assumed algorithm of calculations there is a possibility of precise distinction of work under both compression and tension [2].

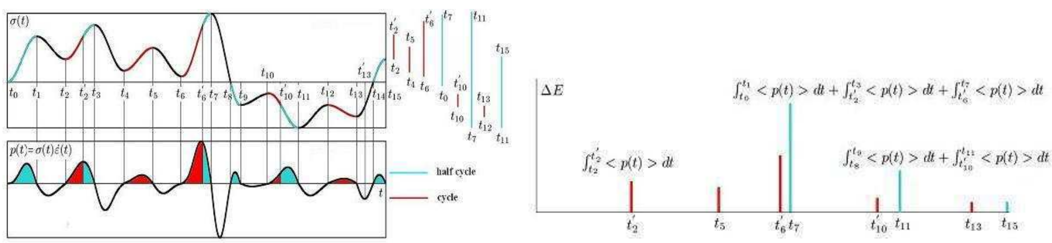

Fig 1. Exemplary histories of stress and power with distinguished of stress σ(t), where the power history p(t) is integrated.

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Calculated fatigue lives obtained from evaluation according to the strain energy density criterion from Eq. (2). Fig. 2 presents comparison of calculated and experimental fatigue lives for 10 combinations of variable-amplitudes and 13 combinations of bending and torsion pseudo-random loading.

(a) (b)

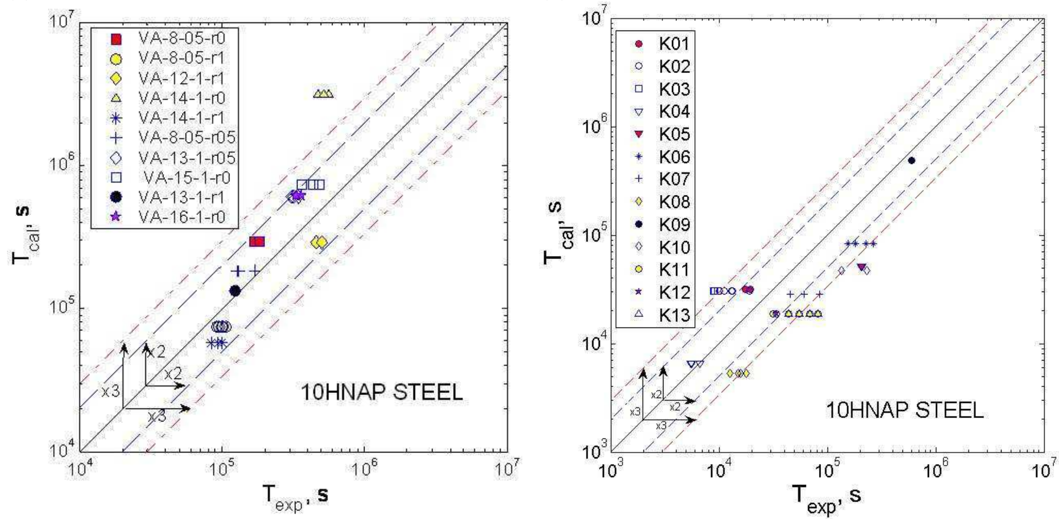

Fig 2. Comparison of fatigue lives obtained from calculations T_{cal} and experimental T_{exp} for: (a) variable-amplitudes loading, (b) pseudo-random loading.

The greatest part of compared results for variable-amplitudes loading is included in the scatter band of the factor 2 and for pseudo-random loading is included in the scatter band of the factor 3. The test results for pseudo-random loading exceeding the scatter band of coefficient 3 occurred at the safe side.
After averaging of life and taking the confidence intervals into account, all the test results were included into the scatter band equal to 3 (1/3).

References

[1] Z. Marciniak, C.T. Lachowicz, D. Rozumek & E. Macha (2007). The strain energy density in the description of fatigue lives under non-proportional bending and torsion. *Proc. of the 8th International Conference on Multiaxial Fatigue and Fracture (ICMFF8-2007)*, Sheffield Hallam University, Sheffield, UK, 88-89 and CD, ps 9.

[2] C.T. Lachowicz (2001). Calculation of the elastic-plastic strain energy density under cyclic and random loading. *Int. J. of Fatigue.*, **23**, 643-652.

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