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Technical note

Fatigue life estimation for 2017A-T4 and 6082-T6 aluminium alloys subjected to bending-torsion with mean stress

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ABSTRACT

This paper proposes a model for estimating fatigue life under multiaxial stress states, based on critical plane concepts, taking into account the effect of mean shear stress. The fatigue life test results, calculated on the basis of the proposed model, are compared to the experimental ones related to 2017A-T4 and 6082-T6 aluminium alloy specimens under constant-amplitude bending, torsion and proportional combinations of bending and torsion. For the results obtained a statistical analysis is performed by comparing the calculation results with experimental data.

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1. Introduction

Despite the growing number of studies on materials fatigue and the growing interest of researchers in this issue, so far these studies have failed to unequivocally develop an effective method to predict the degree of fatigue damage and a safe operational life of structural components, systems, as well as whole machines and structures. This is because fatigue phenomenon is very complex, and fatigue failure depends on many factors, such as the type and condition of the material, geometry of the structural components, type of load or the state of stress. In multiaxial load conditions, parameters such as stress amplitudes and mean load can lead to reorientation of the principal stress directions, and it is difficult to predict how they affect the fatigue life. The non-zero mean value of stress is often the result of the effect of the deadweight of a working element or the entire structure, and is also the result of the initial tension of load-bearing elements (such as V-belts in transmissions). The mean stress include also residual stress resulting from material connections.

As the design and structural requirements have grown, the industry demands from the researchers faster and more accurate methods for estimation of fatigue life in multiaxial load condition, so as to face the challenges related to computer-aided design due to complex geometry and load history. It is necessary to reduce the multiaxial condition to an equivalent uniaxial stress state. Such a reduction is made possible by so-called fatigue criteria [1–12]. Although there are several approaches for life estimation of metallic materials reported in the literature [13–16], those associated with the concept of critical plane have gained widespread usage. The main difference between them relies upon the fatigue damage measure which is considered to determinate the critical plane. Fatigue life depends on a combination of stresses acting in that plane. Depending on the stress condition, environment, component geometry and stress amplitude, the fatigue process is dominated by cracking in either the maximum shear or normal stress plane. However, in such criteria, only the effect of the mean normal stress is assumed, and the effect of shear stress is not taken into account.

In the recent years, alternative approaches to classic models based on critical plane have been proposed. Morel [17] presented a critical plane model associated with the accumulated plastic strain at the grain level (in a mesoscopic scale). Papadopoulos et al. [18–20] proposed a fatigue criterion where fatigue strength is determined by a linear combination of the maximum hydrostatic stress, $\sigma_{H,\max}$, and amplitude of generalised shear stress, $\langle T_a \rangle$, defined in the critical plane. In the Dang Van criterion [21,22] the mesoscopic scale (grain level) of stress observation is applied. The Dang Van criterion assumes that the material fatigue will not occur if all grains achieve the elastic shakedown state. The Dang Van criterion determines the fracture initiation condition and does not allow calculation of fatigue life. The condition of exceeding the elastic shakedown state has been made dependent on the mesoscopic shear stress, τ_μ, and hydrostatic stress, $\sigma_{H,\max}$. However, the above criteria do not take into account mean shear stress either. Additional approaches were proposed by Carpinteri,

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Nomenclature

A_σ	regression constant of the fatigue curve for plane bending
E	Young's modulus
k_σ	normal mean stress reduction coefficient
$k_{\tau 1}$	shear mean stress reduction coefficient
$k_{\tau 2}$	compound (shear and normal) mean stress reduction coefficient
m_σ	slope coefficient of the fatigue curve for plane bending
N	number of loading cycles to failure
N_{cal}	calculation fatigue life
N_{expf}	experimental fatigue life
α	critical plane orientation angle
σ	applied normal stress
σ_a	amplitude of the applied normal stress
σ_m	mean value of the applied normal stress
σ'_f	fatigue strength coefficient
$\sigma_{a,f}$	fatigue limit for bending
σ_{UTS}	tensile strength limit
τ	applied shear stress
τ_a	amplitude of the applied shear stress
τ_m	mean value of the applied shear stress
$\tau_{a,f}$	fatigue limit for torsion

Subscripts

a	amplitude
eq	equivalent
m	mean
η	normal to the critical plane
η,a	amplitude of stress component normal to the critical plane
η,m	mean value of stress component normal to the critical plane
ηs	shear plane
$\eta s,a$	amplitude of stress component shear to the critical plane
$\eta s,m$	mean value of stress component shear to the critical plane

who uses its criterion to calculate the random loads in a multiaxial stress state using the Power Spectral Density (PSD) [23] and other approaches using the Maximum Rectangular Hull (MRH) [24].

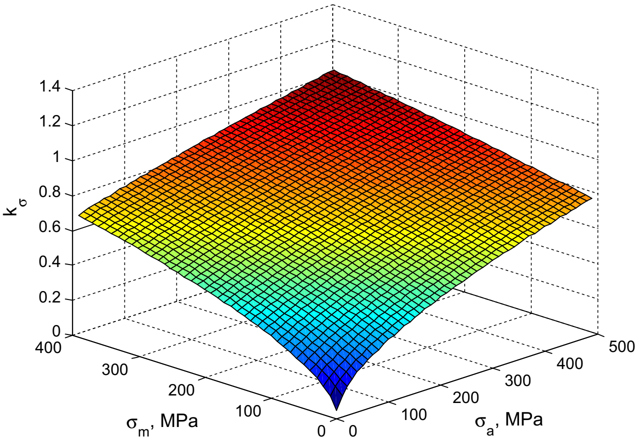

Fig. 1. The dependence of the k_σ coefficient on the applied normal stress amplitude and corresponding mean value.

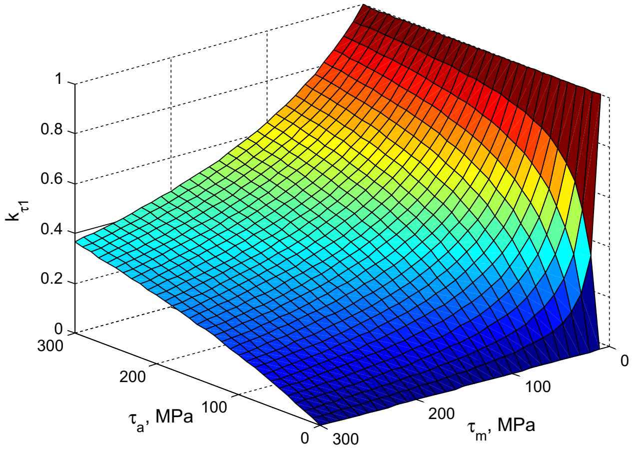

Fig. 2. The dependence of the $k_{\tau 1}$ coefficient on the applied shear stress amplitude and corresponding mean value.

In the literature on high-cycle fatigue, the effect of the mean shear stress is not examined [6–22]. Classic Sines approach [25] is often quoted to support that opinion. Sines concluded that application of the mean torsion stress does not affect fatigue strength of metals subjected to cyclic torsion. Such an assumption was based on data collected by Smith [26,27], who gathered independent test results on the fatigue limit in torsion of various metals, including steels, aluminium alloys and bronze.

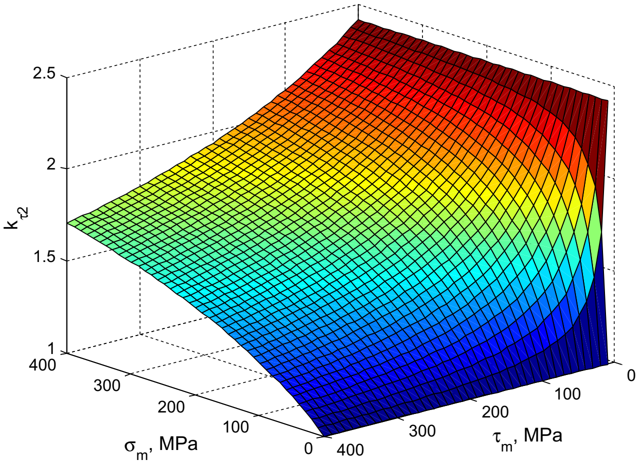

Fig. 3. The dependence of the $k_{\tau 2}$ coefficient on the mean value of the applied normal and shear stresses.

Table 1
Strength and fatigue properties of the tested materials.

		2017A-T4	6082-T6
Young modulus	E (GPa)	72	72
Tensile strength	R_m (MPa)	545	385
Tensile yield strength	$R_{p0.2}$ (MPa)	395	365
Fatigue strength coefficient	σ'_f (MPa)	987	651
Slope coefficient of fatigue curve for bending	m_σ	7.03	8.00
Regression constant of fatigue curve for bending	A_σ	21.87	23.83
Fatigue limit for bending at 10^7 cycles	σ_{af} (MPa)	142	126
Fatigue limit for torsion at 10^7 cycles	τ_{af} (MPa)	78	74

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