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Including of Ratio of Fatigue Limits from Bending and Torsion for Estimation Fatigue Life under Cyclic Loading

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Abstract

The paper presents the estimation of the fatigue life under multiaxial cyclic loading of selected construction materials: two aluminum alloys PA4 (6068) and PA6 (2017A), alloy steel S355JOWP (in past called 10HNAP) and cast iron GGG 40. Calculations were based on three criteria of multiaxial fatigue, which is based on the concept of critical plane and the coefficients present in the expressions for the equivalent stresses are calculated on the basis of classical fatigue limits.

Keywords: fatigue life, multiaxial criteria

1. Introduction

The phenomenon of fatigue of materials and structures is a significant issue of the day. Fatigue occurs in various fields of industry, i.e. aerospace, machinery, mining or transport. The main objective of the bulk of research on predicting the fatigue strength is to identify a method of estimating the fatigue strength already on the stage of design and construction of components of machines and devices. The fatigue criterion in multiaxial loading is based on establishing such equivalent value that would enable comparison of multiaxial load with uniaxial loading. Literature of the subject provides a number of multiaxial fatigue criteria (Kurek and Łagoda, 2012). Such criteria are based on various assumptions and parameters of the fatigue process. A separate group of criteria among them are based on the critical plane concept (Karolczuk and Macha 2005). Some of the criteria include the ratio of bending fatigue to torsional fatigue. The paper discusses estimation of fatigue strength depending on the changing orientation of the critical plane of proportional torsional bending for specific construction materials. The paper also compares the

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calculation and experimental results for fatigue strength of specific materials, using three different multiaxial fatigue criteria that take into account the ratio of fatigue limits.

Nomenclature

A_σ, m_σ	coefficients of regression equation for oscillatory bending
A_τ, m_τ	coefficients of regression equation for torsion
B, K	constants used for selection of specific criterion form
B_1	constant depending on material type
N_{cal}	calculated number of cycles to failure
N_{exp}	experimental number of cycles to failure
N_f	number of cycles to failure
σ_a	amplitude of normal stress induced by bending
τ_a	amplitude of shear stress induced by torsion
σ_{af}	fatigue limits for bending
τ_{af}	fatigue limits for torsion
σ_{eq}	equivalent stress
σ_η	normal stress component on the critical plane
$\tau_{\eta s}$	tangent stress component on the critical plane

2. Fatigue Strength Algorithm

To estimate calculation fatigue life used standard model, which consists of several stages. The first step includes measurement, generation or calculation of component of stress tensor, according to the following equations:

$$\sigma_{xx}(t) = \sigma_a \sin(\omega t), \tag{1}$$

$$\tau_{xy}(t) = \tau_a \sin(\omega t - \varphi), \tag{2}$$

where:
σ_a – amplitude of normal stress induced by bending, τ_a – amplitude of shear stress induced by torsion, ω – angular frequency, φ – angle of phase shift, t - time.
In the discussed model, the course of normal stress $\sigma_{xx}(t)$ refers to stress induced by bending, while $\tau_{xy}(t)$ refers to torsion-induced stress. The next step involves determination of the orientation angle of the critical plane, which can be done using one of three established methods: weight functions, damage accumulation or variance. In this paper, the orientation of the critical plane was determined using damage accumulation method. If the criterion proposed by Carpinteri (Carpinteri and Spagnoli, 2001) is used, the inclination angle of the critical plane is increased by the angle

$$\beta = \frac{3}{2}\left[1 - \left(\frac{1}{B_2}\right)^2\right]45^\circ, \tag{3}$$

with respect to the angle determined by maximum normal stress, where:

$$B_2 = \frac{\sigma_{af}}{\tau_{af}}. \tag{4}$$