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Damage Models and Durability Prediction for Structural Elements of Transport under Variable Loading

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Abstract

At present, there are two approaches to fatigue life prediction. There is an approach of continuous damaging popular among the Russian scientists and engineers that is based on the crack initiation implicit modelling and the damage determination contributed by each cycle. In this approach, fatigue damage is determined as a fatigue crack occurring and a structural element failure. Another approach is presented with failure mechanics allowing the small crack existence and describing its growth up to the size limit. The present work aims at studying the problem of applicability of the fatigue damage models, which are efficient for standard samples and the simplest structural elements, for complex transport structures subjected to variable amplitude loading, and proposing the joint use of approaches to model fatigue damage, while preliminary describing advantages, disadvantages and assumptions of this approach.

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Keywords: damage model; variable loading; fatigue, transport structures.

1. Introduction

The rational choice of a damage model is the reliable foundation to calculate fatigue. Although modern models take into account various fatigue factors, the forming role here plays the fatigue type determined by the external loading direction and the structure geometry. So, the models of uniaxial continuous damaging are used to calculate fatigue for the running gear, the suspension, the body and the powertrain of vehicles. Usually, uniaxial model is correct, but during the multiaxial fatigue calculating its results are very non-conservative (5-10% of service life). Multiaxial damaging in the context of crack growth is even more difficult.

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Nowadays, the universal multi-damaging model is missing. The most simple and common models are that of Smith-Watson-Topper and Liu, using tensile strains and the Brown-Miller's, Fatemi-Soshi and Liu's models, based on the tangential strains [1].

Smith-Watson-Topper's model is used for materials that are destroyed due to the micro cracks growth on the action planes of the largest tensile strains or stresses (cast iron, ductile steel, stainless steel). This model is also applicable for materials which are loaded in mode I of crack growth. The model formula:

$$\sigma_{n,\max}\frac{\Delta\varepsilon_1}{2}=\frac{\sigma_f^{'2}}{E}\left(2N_f\right)^{2b}+\sigma_f^{'}\varepsilon_f^{'}\left(2N_f\right)^{b+c} \qquad (1)$$

where $\frac{\Delta\varepsilon_1}{2}$ - the amplitude of the largest main strain ; $\sigma_f^{'}$ - the fatigue life coefficient (for normal stresses); $\varepsilon_f^{'}$ - the coefficient of fatigue ductility (for normal stresses); $2N_f$ - the number of half-loops before failure; b , c - the stress-strain plot parameters.

Brown and Miller paid their attention to micro cracks occurring and growing. The range of normal strain on the plane of maximum tangential strain depends on the ratio of stretching and torsional strains. The combined action of normal and tangential strains reduces fatigue life, and this fact was taken into account by the model developers. Cyclic tangential strain provokes cracks occurring and normal strain causes their growing. The Brown-Miller's model formula is shown below:

$$\frac{\Delta\gamma_{\max}}{2}+S\Delta\varepsilon_n=A\frac{\sigma_f^{'}-2\sigma_{n,cp}}{E}\left(2N_f\right)^{b}+B\varepsilon_f^{'}\left(2N_f\right)^{c} \qquad (2)$$

where $\sigma_{n,cp}$ - a normal average strain; $\Delta\gamma_{\max}$ - the largest range of tangential strain; S - the parameter of normal strain, describing the impact of normal strain on the micro crack growth and determined with the correlation of axial and torsional strains (default $S=1$); $\Delta\varepsilon_n$ - the normal strain range in the plane of the tangential strain maximum range; $A=1.3+0.7S$ - the empirical coefficient; $B=1.5+0.5S$ - the empirical coefficient.

The most appropriate model is chosen for the loading conditions and for the material of the structural element on the basis of the mentioned above description. Obviously, these models take into account some factors affecting fatigue, or can be completed by them.

2. The main factors affecting transport structures fatigue

Among many fatigue factors for transport structures the most important are as follows: average stress, peak stress, cconcentrators and surface treatment [2].

1. Average stress.

Decreasing of fatigue life with stretching average stress by the reason of microcracks opening and sliding processes intensifying related to fatigue, and vice versa, increasing of fatigue at compressing average stress due to inverse processes are considered to be the main manifestations of average stress effect. To record this effect the amplitude of stress should be adjusted, for example, as per Goodman's formula:

$$\frac{\Delta\sigma}{2}=\left(\frac{\Delta\sigma}{2}\right)_{R=-1}\left(1-\frac{\sigma_{av}}{\sigma_u}\right) \qquad (3)$$

where $\frac{\Delta\sigma}{2}$ – the amplitude of stress; R – the coefficient of cycle asymmetry; σ_{av} - the average stress; σ_u - the ultimate resistance.