INVESTIGATION OF THE ACCUMULATION OF DAMAGES
IN NONSTATIONARY LOW-CYCLE RIGID LOADING

M. A. Daunis and R. A. Stasyunas

In doing work on improving the reliability and life of certain parts and design elements of modern machines it is important to know the properties of their materials under conditions of elastic - plastic cyclic nonstationary deformation.

As is known [1, 2], fatigue failure in low-cycle loading is well described by the Coffin equation

$$\Delta N_f^m = C,$$

and for determining fatigue damages use is made of the rule of linear totalling of relative lives [3-6]

$$\sum_i \left( \frac{n}{N_f^i} \right) = 1,$$

where $\Delta$ is the amplitude of plastic deformation; $N_f$ is the number of cycles until failure; and $n$ is the accumulated number of cycles at one of the levels of loading.

However, in determining fatigue damage of materials which are cyclically increasing or decreasing in strength by linear totalling of relative lives there is adjustment on the basis of damageability of the cycles with dissimilar plastic deformation. In connection with this it is proposed to use for such materials linear totalling of cyclic relative deformations accumulated in the process of elastic - plastic deformation [7):

$$\sum_{k_1}^{k_i} \delta_{k_1} + \sum_{k_2}^{k_i} \delta_{k_2} + \ldots + \sum_{k_n}^{k_i} \delta_{k_n} = 1,$$

where $\sum \delta_{k}$ is the accumulated cyclic plastic deformation at the i-th level of stationary loading; $k_f$ is the number of half cycles until failure at the i-th level of stationary loading; and $C_n$ is a constant of the material determined from the equation

$$\delta_{k_i}^{(av)} k_f^m = C_n.$$

Experimental checking of the proposed relationships was done under nonstationary symmetric ($R = -1.0$) and asymmetric ($R = -0.75, -0.5$) cyclic loading in tension - compression. The testing was done on test machines with mechanical excitation of the force. To provide high accuracy in contactless reversing of the load producing machine in providing the specified value of force or deformation and also for automatic changing to the different levels of loading after the specified number of cycles electronic programmable equipment was used [8, 9].

Three contrasts of cyclic properties of a material were investigated: cyclically stable anisotropic 45 steel, anisotropic 15Kh2MFA steel which loses strength cyclically, and isotropic D16T1 aluminum alloy which gains strength cyclically, under nonstationary rigid loading (limited deformation) to four two step and one ten step programs (Fig. 1). The samples of cylindrical form with a gauge length 10 mm in diam. and 23 mm long were tested in the characteristic condition for the materials: for 15Kh2MFA steel

hardened and tempered at a high temperature, for D16T1 alloy hardened and artificially aged, and for 45 steel in the as received condition.

The basic mechanical properties of the materials tested are shown in Table 1.

Fig. 2. Totalling of accumulated damages for 15Kh2MFA steel with $R = -1.0$ (white points), $R = -0.75$ (black points), and $R = -0.5$ (black and white points): 1) $100 \varepsilon_{ai} - 100 \varepsilon_T$; 2) $100 \varepsilon_T - 100 \varepsilon_{ai}$; 3) $300 \varepsilon_{ai}$ - to failure; 4) $350 \varepsilon_T$ - to failure; 5) stationary loading (broken lines show spread of the sums of relative lives).

Fig. 1. Programs for nonstationary rigid loading.

Fig. 2. Totalling of accumulated damages for 15Kh2MFA steel with $R = -1.0$ (white points), $R = -0.75$ (black points), and $R = -0.5$ (black and white points): 1) $100 \varepsilon_{ai} - 100 \varepsilon_T$; 2) $100 \varepsilon_T - 100 \varepsilon_{ai}$; 3) $300 \varepsilon_{ai}$ - to failure; 4) $350 \varepsilon_T$ - to failure; 5) stationary loading (broken lines show spread of the sums of relative lives).