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ON FATIGUE WEAR EQUATION WITH REGARD TO THERMAL EFFECTS

Abstract

The fatigue wear equation with regard to thermal effects that admits define the time and number of cycles of the fatigue wear of materials is constructed.

As is known, there exist some classifications of wear forms [1]. Fatigue wear occupies a special place among them [2]. It is stipulated by multiple repeated deformation of surface layers that reduce to formation of damages, and as a final result to the disturbance of strength (continuity) of surface layers. Therefore the investigation of fatigue wear process of surface layers from the point of view of accumulation of damages [3-7] has a real meaning. In this direction a good attempt was made in paper [8], where on the basis of the conception of Kachanov-Rabotnov damages the fatigue wear equation is obtained. And here residual deformation in a surface layer is chosen as a fatigue wear factor. However, as known, temperature of surface layer plays an essential role at fatigue wear that is not taken into account in [8]. We make up a deficiency in some degree.

Following [5-7] we introduce some scalar $0 \le \Pi \le 1$. The quantity Π characterizes the damageability of the surface layer of material; it increases depending on the time t or the number of cycles N from 0 to 1. Here $\Pi(0)=0$, $\Pi(t_c)=1$ or $\Pi(N_c)=1$, where t_c is time, N_c is the number of cycles under which the fatigue wear of material occurs. If we denote the beginning of the k-th cycle by t_k $(t_0=0)$ the duration of the k-th cycle will be $t_k - t_{k-1}$ $(k=1,2,\dots,N_c)$. In addition $t_c=\sum_{k=1}^{N_c}(t_k - t_{k-1})$. If we adopt the duration of each cycle equal t_* among themselves, we have $N = t/t_*$, $N_c = t_c/t_*$. The residual intensity of deformations ε_{+p}^0 for each embedding cycle we take as a defining parameter effecting on the fatigue wear process as in [8]. The temperature $T(x,t)$ where $(x)=(x_1,x_2,x_3)$, $t\in[0,t_c]$ we adopt as the other defining parameter. We adopt that the quantities $\varepsilon_{+p}^0(x,t)$ and $T(x,t)$ are known from the solution of corresponding problems. In further records we omit the arguments x.

We adopt the alternation of accumulated damages in the form

$$\frac{d\Pi}{dt} = f(\Pi)\varphi_1\left(\varepsilon_{+p}^0, T\right). \tag{1}$$

In (1) it is admitted an independent effect of the quantities $\frac{d\Pi}{dt}$ and Π on $\varphi_1\left(\varepsilon_{+p}^0, T\right)$.

As a result of integration of the equation (1) provided $\Pi(t_c)=1$ we get

$$\int_0^{t_c} \varphi\left(\varepsilon_{+p}^0(t), T(t)\right)dt = 1, \tag{2}$$

where $\varphi = \frac{\varphi_1}{A}$, $A = \int_0^1 \frac{d\Pi}{f(\Pi)} = const$.

We approximate the function $\varphi\left(\varepsilon_{+p}^0, T\right)$ in the form of power functions

$$\varphi\left(\varepsilon_{+p}^{0},T\right)=B\left(\varepsilon_{+p}^{0}\right)^{\beta}\left(\frac{T}{T_s}\right)^{\delta}, \tag{3}$$

where B,β,δ are universal constants of material, T_s is some constant reduction temperature which is chosen from the alternation range of temperature T.

We adopt the relation (2) with regard to (3) in the form of

$$\int_0^{t_c}\left(\varepsilon_{+p}^{0}(t)\right)^{\beta}\left(\frac{T(t)}{T_s}\right)^{\delta}dt=\frac{1}{B}. \tag{4}$$

Under arbitrary constants $\varepsilon_{+p}^{0}=\varepsilon_{+p}^{00}=const$, $T=T_0=const$ it follows from (4) that

$$\left(\varepsilon_{+p}^{00}\right)^{\beta}\left(\frac{T_0}{T_s}\right)^{\delta}t_0=\frac{1}{B}, \tag{5}$$

where t_0 is fatigue wear time under the constants ε_{+p}^{00} and T_0.

We use the results of experiments of the fatigue wear with equal duration t_* of each cycle. Let ε_c and T_c be critical intensities of deformation and temperature after single imbedding for time t_*. Moreover it follows from the equation (4) that

$$\varepsilon_c^{\beta}\left(\frac{T_c}{T_s}\right)^{\delta}t_*=\frac{1}{B}. \tag{6}$$

Comparing the relations (5) and (6) we get

$$\frac{t_0}{t_*}\left(\varepsilon_{+p}^{00}\right)^{\beta}=\varepsilon_c^{\beta}\left(\frac{T_c}{T_0}\right)^{\delta}$$

or

$$N_0^{\frac{1}{\beta}}\varepsilon_{+p}^{00}=\varepsilon_c\left(\frac{T_c}{T_0}\right)^{\frac{\delta}{\beta}}, \tag{7}$$

where $N_0=\frac{t_0}{t_+}$ is the number of cycles before the fatigue wear begins for $\varepsilon_{+p}^{0}=\varepsilon_{+p}^{00}=const$ and $T=T_0=const$.

In references there are tests represented by the relations [9-11]

$$N_0^{\alpha}\varepsilon_+^{00}=C. \tag{8}$$

And they note that one can consider the quantity α not depending on temperature, and the quantity C is, generally speaking, a difference function of temperatures $\Delta T_0=const$, i.e. $C=C(\Delta T)$. For example, in [11] the equation of fatigue wear is obtained experimentally for the alloy of the mark 45 $\varepsilon_{ip}^{00}N_0^{0,4}=0{,}06$.

The quantity C which is contained in relation (8) in references in majority of cases is represented as

$$C(T)=C_0\left(\frac{T_s}{T}\right)^{\gamma}\quad\left(C_0,\gamma=const\right). \tag{9}$$

The comparison of relations (7) and (8) with regard to (9) gives the following results:

$$\frac{1}{\beta}=\alpha\,,\ \ \varepsilon_c=C_0\ \ ;\ \left(\frac{T_c}{T_0}\right)^{\delta/\beta}=\left(\frac{T_s}{T}\right)^{\gamma}. \tag{10}$$

If for T_s we choose T_c and adopt $T = T_0$, we get from (10) $\delta/\beta = \gamma$. Hence $\delta = \beta\gamma = \frac{\gamma}{\alpha}$.

Consequently, the questions on the experimental definition of constants are settled. Since the obtained constants are considered to be universal constants of material, then equaling the relations (4) and (6) we get:

$$\int_0^{t_c} \left(\varepsilon_{+p}^0(t)\right)^\beta \left(\frac{T(t)}{T_c}\right)^\delta dt = \varepsilon_c^\beta t_* . \tag{11}$$

The relation (11) is an equation of fatigue wear of the surface layers of material. It determines time t_c and the number of cycles N_c of the fatigue wear. Note that the relation (11) for $t_k - t_{k-1} = t_*$ for any k, for $T(t) = T_c = const$ coincides with analogic equation obtained in [8].

Finally, note that the equation (11) may be used as a criterium for small cycle (mechanical) and thermal fatigue.

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