Fracture energy consumption in speed loading experiments

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Abstract

The nonlinear damage summation law expressed in terms of relative values of energy consumption is proposed. For the verification of the damage summation law the experiments on the plane specimens made of polymethylmetacrylate under the several values of speed loading were carried out. As it follows from the experiments the deviation from the linear damage law is essential and the value of the fracture energy depends on the application sequence of speed loading. For example, for two levels of speed loading ($1mm/min$ and $8mm/min$) the energy consumption at fracture is minimal, when the speed of initial loading is equal to $1mm/min$. So from the received experimental results follow that the energy consumption at fracture is dependent on the regimes of speed loading and they should be taken into account in design and exploitation of different equipments for processing and milling the solid materials.

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In many practical applications such as building industry, mining and processing, food industry, pulp and paper industry and others the most important problem is to define the regimes of loading with the minimal fracture energy consumption. In many of mentioned industries the energy consumptions for fracture are significant and not well grounded. To solve the problem it is necessary to compare the different regimes of loading and find those with the optimal value of energy consumption for fracture, so they can be recommended in the designing and running of different processing and fracture equipments.

To estimate the optimal energy consumption for fracture, the energy consumptions in different loading programs are compared. The energy consumptions are defined in accordance with the damage summation law, expressed in terms of relative value of energy consumption [1]. If the sum of the relative value of energy consumption is less one then the energy consumption is optimal. So we can define the reliable boundary of optimal value of the fracture energy.

The notion of damages and the linear laws of summation of damages [2-5] were considered in the beginning of the last century as applied to fatigue fracture by Palmgren (1924) and fracture under creep condition by Robinson (1938) and Baily (1935). Miner (1945) formulated a linear law of summation of damages for the case of alternation of cyclic and prolonged static loadings. In the case of the multi stage fatigue loading a specimen is tested by the stress σ_1 during N_1 cycles, after that it is tested by the stress σ_2 during N_2 cycles up to fracture, etc. At stress level σ_k the specimen is tested up to fracture at the number of cycles N_k. If N_{iR} $(i = 1, 2, ..., k)$ is the number of cycles to fracture under the action of stress σ_i, then the relations $N_1/N_{1R}, N_2/N_{2R}, ..., N_i/N_{iR}, ..., N_k/N_{kR}$ are the fractions of damage during the first, second and k-th stages of loading cycles.

The same way can be introduced the damage concept for the case of speed loading experiments. Let during the time t_1 a specimen is tested under the speed level V_1 after that it is tested during the time t_2 under the speed level V_2 up to fracture and so on. If t_{iR} $(i = 1, 2, ..., n)$ are the time to fracture at the speed level V_i in sustained loading, so the relations $t_1/t_{1R}, t_2/t_{2R}, ..., t_i/t_{iR}, ..., t_n/t_{nR}$ are the fractions of damage in the processes of the first, the second and the n stages of speed loadings.

The linear law of summation of damages during alternation of different speed loadings can be expressed as

$$\sum_1^n \frac{t_i}{t_{iR}} = 1. \tag{1}$$

If $n = 2$, then the linear damage summation law is

$$\frac{t_1}{t_{1R}} + \frac{t_2}{t_{2R}} = 1. \tag{2}$$

In our experiments, carried out under the action of different speed loading regimes, the systematic deviations from the linear damage summation law (2) were established. In this connection, the non linear modifications of the linear damage summation law will be considered. In particular,

$$\left(\frac{t_1}{t_{1R}}\right)^m + \left(\frac{t_2}{t_{2R}}\right)^m = a, \tag{3}$$

where m, a are constants.

As it was mentioned, in many applications the problem is to choose the regimes of loading with the minimal consumptions of the fracture energy, so they can be recommended in the designing and running of different processing and fracture equipments.

To find such loading regimes we will operate on the damage concept defined in terms of relative value of energy consumption and the damage summation law will be formulated using such definitions. In the case of relation (3) we have the following relation.

$$\left(\frac{W_1}{W_{1R}}\right)^m + \left(\frac{W_2}{W_{2R}}\right)^m = a, \tag{4}$$

where W_1, W_2 are the current values of energy, respectively, during the V_1 and V_2 speed levels loadings, W_{1R}, W_{2R} are the values of energy consumption for fracture at speed levels V_1 and V_2 sustained loading.

The experimental evaluation of hypotheses of summation of damages was investigated in experiments for the specimen made of polymethylmetacrylate for two levels of speed loading $V_1 = 1mm/min$ and $V_2 = 8mm/min$. Experiments were carried out at room temperature for plane specimens of the following sizes: the length of the working part was 60 mm, the width was 10 mm, and the thickness was 5 mm. The speed loading were performed on Lloyd 30k PLUS machine.

Six specimens were used to define the energy consumptions for fracture in tension experiments at the speed levels V_1 and V_2 in sustained loading. The typical diagrams, received in these experiments are shown in Fig. 1.

The results of calculation of damage defined in terms of the relative value of energy consumption based on the experiments are shown in Fig. 2 and Tables 1, 2.

The solid circles in Fig. 2 correspond to the case when the initial loading is in V_1 regime, the cross marked points go to the case when the initial loading is in V_2 regime.

As it follows from Fig. 2 and Tables 1, 2, the energy consumption for fracture is minimal, when the speed of initial loading is equal $1mm/min$.

Table 1: The energy consumption during the alternation of two levels of speed loading ($V_1 = 1mm/min$ and $V_2 = 8mm/min$). First loading is in V_1 regime.

W_1/W_{1R}	W_2/W_{2R}	$W_1/W_{1R} + W_2/W_{2R}$
0,127	0,883	1,010
0,125	0,501	0,626
0,135	0,754	0,889
0,010	2,029	2,039
0,011	1,335	1,346
0,395	0,304	0,699
0,371	0,312	0,683
0,048	1,375	1,423
0,054	0,759	0,813
0,238	0,498	0,736
0,225	1,203	1,428

Table 2: The energy consumption during the alternation of two levels of speed loading ($V_1 = 1mm/min$ and $V_2 = 8mm/min$). First loading is in V_2 regime.

W_2/W_{2R}	W_1/W_{1R}	$W_2/W_{2R} + W_1/W_{1R}$
1,461	0,078	1,539
2,133	0,080	2,213
1,222	0,127	1,349
0,019	1,083	1,102
0,020	0,715	0,735
0,620	0,349	0,969
0,592	0,634	1,226
0,080	0,733	0,813
0,166	0,634	0,800
0,199	0,688	0,887
0,251	0,651	0,902
0,366	0,532	0,898
0,368	0,472	0,840

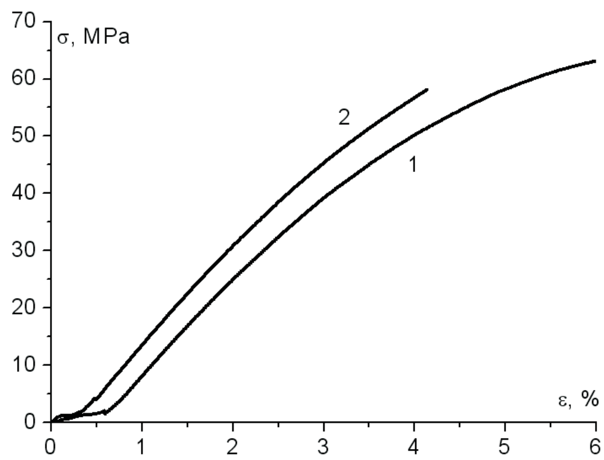

Figure 1: Tension stress-deformation diagrams: at the speed levels V_1 (curve 1) and V_2 (curve 2).

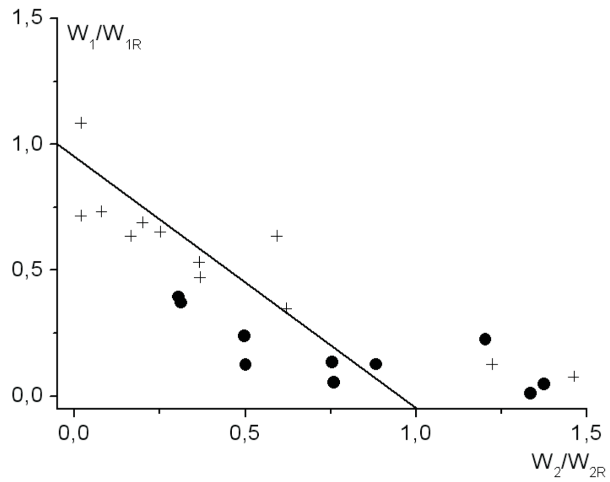

Figure 2: Accumulation damages by the energy consumption during the alternation of two levels of speed loading ($V_1 = 1mm/min$ and $V_2 = 8mm/min$). $\bullet$ - first loading is in V_1 regime, $+$ - first loading is V_2 in regime.

Conclusions

The nonlinear damage summation law expressed in terms of relative values of energy consumption in speed loading experiments is suggested.

To estimate the optimal energy consumption, energy consumptions for fracture for two levels of speed loading ($V_1 = 1mm/min$ and $V_2 = 8mm/min$) were defined. It is shown, that the energy consumption at fracture is minimal, when the speed of initial loading is equal to 1 mm/min.

The received results may be used in designing and running of different processing and fracture equipments.

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