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Abstract

Full Text

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ELASTIC-STRENGTH PROPERTIES OF PLASTIC DISPERSE SYSTEMS IN CONNECTION WITH THE PHENOMENON OF THIXOTROPY

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Shear moduli (g) and yield stresses (τ) are the most important parameters characterizing the mechanical properties of plastic disperse systems. The special importance of measurements of the quantity g lies in the fact that the small relative elastic deformations (γ) at which they are usually determined do not cause any noticeable destruction of the structure of the systems under study.

The work was carried out on an elastoviscosimeter with concentric cylinders ([1]). The surfaces forming the concentric gap were macroscopically rough. The uniformity of the shear-stress field (τ) was 94%. Deformation of the specimens was effected by rotation, at a constant speed (n), of the cylindrical core (rigid dynamometer–) or by twisting an elastic thread connected with the core (soft dynamometer–). The moduli of the dynamometers used were respectively equal to $4.9 \cdot 10^5$ and 29 $g \cdot cm/radian$. The deformations γ are readily determined as the ratios of the linear displacement of the layer of the material being deformed, entrained by the core, to the width of the concentric gap. By recording the deformations of the dynamometers, the shear stresses acting in the gap are determined. In the experiments described below, the dependence $\tau(\gamma)$ was determined and g was found both under static conditions and under steady and unsteady regimes of rotation of the core (under conditions of low speeds). The tests were carried out on various plastic lubricating greases at 20°.

Fig. 1. Curves of the dependence of shear stresses and shear moduli on deformations and time for a fatty solidol

In Fig. 1 the curve $BC \dots H$ shows the dependence $\tau(\gamma)$, obtained on the rigid

Fig. 2. Curves of the dependence of shear stresses on deformations for fat solidol under different sequences of its testing

Figure 2: Fig. 2. Curves of the dependence of shear stresses on deformations for fat solidol under different sequences of its testing

dynamometer at $n = 2.4 \cdot 10^{-4}$ rev/min for a fatty solidol. Since the various processes studied proceed at different rates, it is convenient to use different time scales for their description. Taking this into account, and also the fact that some processes proceed for a long time, the graph shown in Fig. 1 is constructed with breaks corresponding to transition from one time scale to another or to omission of a known time interval during which the experiment proceeded but which is not reflected in the graph. The segment GH on the curve $\tau(\gamma)$ corresponds to attainment of a stationary flow regime of the system under test and of the equilibrium shear stress (τ_r) at the above-mentioned rotation speed of the core. After 40 hours (point H on the curve $BC \ldots I$) the core was stopped and the system was left under stress. In view of the weak ability of pseudogels to relax and the rapid thixotropic recovery of the fat solidol, on the segment HI of the curve $BC \ldots I$ only a slight decrease in stresses is observed.

The results of measurements of the shear moduli of the fat solidol after filling the instrument with it, during its rest in the instrument, and during tests are presented in Fig. 1 by the curve $A'B' \ldots I'$. In these experiments the instant at which the elastoviscosimeter was filled with solidol was taken as the time origin.

Fig. 2. Curves of the dependence of shear stresses on deformations for fat solidol under different sequences of its testing

The segment $A'B'$ of the curve $A'B' \ldots I$ corresponds to its rest, during which thixotropic recovery of the grease and growth of g occur. In the process of continuous deformation of the system (which corresponds to obtaining the curve $\tau(\gamma)$), without stopping this process, g was determined, as a result of which the curve $B'C' \ldots H'$ was constructed. The application of stress causes a decrease in the shear moduli, which reach their smallest values at $\tau = \tau_{\text{p}}$ (point C' on the curve $B'C' \ldots H'$). Then g slowly increases until the value $\tau = \tau_{\text{p}}$ is reached. From the moment the rotation of the core ceases (point H' on the curve $B'C' \ldots I'$), as a result of thixotropic recovery of the structure of the grease, growth of g is observed; moreover, already 5 hours after the core is stopped the value of g reaches the values that were recorded at the beginning of the experiment (point B' on the curve $A'B' \ldots I'$).

Along with measurement of the moduli during continuous slow rotation of the core, they were measured 0.5-1 sec after stopping the core (higher rates). It was found that, in comparison with statics, a decrease in g by 10% is detected already at n of the order of 10^{-5} rev/min. Changing n by 7 orders of magnitude causes, under the experimental conditions indicated above, a decrease in g by

Figure 3

Figure 3: Figure 3

approximately a factor of 10, whereas τ_{p} changes by only a factor of 2.

When considering the curves $\tau(\gamma)$ from which τ_{p} is found, the principal significance lies in determining at what stage of the deformation process of the systems their destruction occurs and they undergo irreversible changes with respect to shear strength. The solution of this question is clarified by the data of Fig. 2, which pertains to the same testing conditions as Fig. 1. First the curve $OA \dots G$ is obtained for the dependence $\tau(\gamma)$. Then, on a new portion of the sample, a certain value τ_A is reached (point A on the curve $OA \dots G$), after which the sample is unloaded (shown by the dashed arrow going downward from point A) and the experiment is begun again. In this and other similar tests the time interval corresponding to transition to the new loading is about 5 min. In the indicated repeated

experiments, point O was again taken as the origin for the quantities τ and γ, and the dependence $\tau(\gamma)$ coincided with the curve $OA \dots G$. A new (third) portion of grease was tested up to $\tau = \tau_B$; then the load was removed and repeated testing of the specimen was begun. The function $\tau(\gamma)$ for this test is also represented by the curve $OA \dots G$. Thus it was shown that testing plastic bodies under conditions of continuously increasing stresses, with $\tau < \tau$, may not cause a decrease in their shear strength. The change in the structure of soft plastic bodies that leads to a decrease in their shear strength begins after τ , or γ corresponding to τ , has been reached. Indeed,

Fig. 3. Curves of the dependence of shear stresses on deformations and time for grease, during its testing on elastoviscosimeters with rigid and soft dynamometers. $OC \dots I$ –dependence of shear stresses on deformations for the soft dynamometer; $OC'K$ –the same for the rigid dynamometer; $OCD' \dots I'$ –dependence of shear stresses on time for the soft dynamometer

deforming a new portion of grease up to $\gamma = \gamma_C$, unloading it, and applying a new load gave the curve $O_1C \dots G$. Similar experiments were carried out in which specimens not previously subjected to testing were deformed up to deformations equal to γ_D, γ_E, γ_F. After this the curves O_2D, O_3E, O_4F were obtained. For these three experiments, on separately drawn time scales, it is shown over what time intervals at $n =$ const the maximum values of τ are reached. From the experiments considered it follows that preliminary deformation of specimens up to $\gamma \geq \gamma$ causes a more rapid attainment of τ in repeated tests; the decrease in the strength limit as a result of deformation at $\gamma > \gamma$ occurs down to those values of τ that were reached in the course of the preceding test. Under the conditions of the experiments described, there is no thixotropic recovery of the specimens, since in each repeated experiment that (maximum) value of τ is reached which corresponded to the completion of the preliminary test. At high

Fig. 4. Curves of the dependence of shear stresses on deformations for the plastic hydrocarbon grease GOI-54

Figure 4: Fig. 4. Curves of the dependence of shear stresses on deformations for the plastic hydrocarbon grease GOI-54

degrees of deformation (section FG on the curve $OA \dots G$), after unloading and rest of the plastic bodies, their thixotropic recovery takes place. Thus, after τ_p was reached, the load was removed (point G on the curve $OA \dots G$) and the specimen was allowed to rest for 5 min; then the curve O_5HI, with a distinct maximum, was obtained.

In the process of deformation of plastic bodies, g and τ change differently. Elasticity and shear strength are determined by different kinds of bonds between the particles of the dispersed phase, which are broken and restored with different ease.

Comparison of experiments on RD and SD is of great interest in connection with the discussion that took place between N. V. Mikhailov (^{2}) and A. A. Trapeznikov (^{3}). This comparison is shown in Fig. 3. The conditions of the experiments on RD

were the same as in the case of Fig. 1. The results of tests under MD are presented in the form of dependences $\tau(\gamma)$ and τ(time). For tests under ZhD, the time required to reach τ and τ is indicated.

It is seen from Figs. 1-3 that τ corresponds to high values of γ. In experiments under ZhD, τ is reached rapidly (even at very low η), whereas τ is reached slowly. In experiments under MD, at sufficiently low loading rates there is direct proportionality between τ and time; spontaneously alternating decreases and increases of τ are observed after transition through the strength limit (broken lines $CDEFG$ and $C'D'E'F'G'$); moreover, after

Fig. 4. Curves of the dependence of shear stresses on deformations for the plastic hydrocarbon grease GOI-54

a very slow attainment of τ , within a short time (segment CD' of the broken line OCD') a large deformation increases (segment CD of the curve OCD)– there occurs a rapid destruction of the structure, accompanied by a fall in τ. Segments GH and $G'H'$ correspond to the system being under a constant load, which, however, is not accompanied by stress relaxation in it.

The present work shows actual differences in the deformation characteristics of soft plastic bodies when they are tested under ZhD and MD, and establishes that the spontaneous alternations of the processes of destruction and restoration of the structure at low rates of deformation, first described in work (^{4}) for aqueous bentonite pastes, and the accompanying jumps in τ, are of general significance for highly structured disperse systems.

Depending on the brittleness of the systems, the jump-like change of τ in the course of their deformation appears with varying sharpness at different rates of deformation. Figure 4 shows the results of tests of the hydrocarbon plastic grease GOI-54—a system more brittle than solidol. The experiments were carried out under ZhD. In the first cycle of tests the curves $OCDE$, $O_2C_1D_1E_1F_1$, $O_3C_2D_2E_2F_2$, $O_4C_3 \ldots I_3$ were obtained. After the points E, F_1, F_2 had been reached, the load was removed from the specimen, and it was again subjected to the action of increasing shear stresses. At point H_3 the twisting of the core was stopped and the specimen remained under load, corresponding to a small stress relaxation. The curve O_1C was obtained after τ had been reached (point C). It is seen from Fig. 4 that on the non-descending branches of the curves $\tau(\gamma)$ there are oscillations of τ, the amplitude of which corresponds to the height of the hatched bands. The character of the oscillations of τ is clearly shown in the upper part of the figure, where the curve $O_3C_2D_2$ is given on a large scale. The amplitude of the oscillations of τ is determined (4) by the competing processes of destruction and restoration of the structure of plastic bodies.

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