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Abstract

Full Text

PHYSICAL CHEMISTRY

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ON THE PROCESSES OF CRACK DEVELOPMENT AND CLOSURE IN AN ISOTROPIC SOLID

(Presented by Academician P. A. Rehbinder, 24 IX 1960)

The actual strength of solids, considerably reduced in comparison with the theoretical strength, is often determined not only by the physicochemical nature of the body, but also by the defectiveness of its structure ⁽¹⁾.

The principal process in the development of an individual crack takes place at its blunt end in the course of relieving the stresses concentrated there under the concentrated action of external forces and internal stresses against the forces of intermolecular cohesion of the solid phase. It is precisely here, according to P. A. Rehbinder ⁽¹⁾, that the adsorption influence of the medium (a decrease in free surface energy), as a result of the development of an adsorption layer, reaches its maximum value, constituting the most important cause of the sharp reduction in strength.

As was indicated earlier ⁽²⁾, in the dynamics of dispersion, especially under periodic, alternating, and sign-changing action of applied external forces, their effectiveness depends on the mode of operation of the dispersing mechanism. The following factors play the most important role in this: a) the rate of crack development with displacement of the points of stress concentration; b) the rate of crack closure after removal of the load; c) the kinetics of "healing" in the closed part of the crack; d) the rate of penetration of liquid into developing cracks; e) the influence of various media on the rate of crack development, on the process of their closure, and on self-healing.

With an unfavorable combination of these factors, the periodic work expended on producing cracks in their reversible (closing) part may prove to be largely ineffective—for example, in the case where the rate of crack development and closure greatly exceeds the rate of motion of molecular layers of the liquid phase along the newly formed surfaces. It is therefore important to study each of the indicated factors and to establish their regular mutual relationships, which affect the processes of fracture and deformation of solids.

Previously, crack development in thin glass was investigated and the influence of various liquids on this process was established ⁽³⁾; the development and closure of cracks in a crystalline body along cleavage planes was studied ⁽⁴⁾. We

Fig. 1

Figure 1: Fig. 1

examined the same processes on specimens of silicate glass of various thicknesses. These experiments are of interest as macromodels, making it possible visually to study elementary processes that occur in individual, complexly branched microcracks in the “fracture zone” (2). The experiments described are also of interest in that the development of a crack in a specimen can be carried out in any prescribed direction, independently of the structure, isotropically. In high-molecular glasses this must occur with the formation of free surface radicals, which can also be investigated by means of this method. The direction of the process of crack development is initially determined only by the direction of the previously introduced initial crack, while the displacement ...

the points of application of the load and the points of support, it is possible to change arbitrarily the initial direction of the crack in the course of its further growth.

Crack closure upon removal of the load occurs over a considerable distance (sometimes up to 6-7 cm) and in most cases is optically (but not mechanically!) traceless.

In Fig. 1 A an experimental plate with a crack developing under a load P , applied from below to the midpoint a , is shown schematically. The support points are indicated by arrows. The dotted segment $b-v$ denotes the closed part of the crack after removal of the load.

Fig. 1. *A*—schematic representation of an experimental plate with a developing crack. *B*—dependence of the crack length l on the deflection S of the plate during development and closure of the crack; *a*—reproducible cycle, *b, v*—non-reproducible curves.

The development of the crack with increasing deflection S (proportional to the load) and its closure upon gradual removal of the load are shown in Fig. 1 B. Cycle *a* is well reproduced under repeated cycling, despite considerable hysteresis. If, however, the load P exceeds a certain limit, then the steeply ascending branch, as is seen on curve *b*, passes into a horizontal segment and then into a new vertical segment. After this the descending branch no longer returns to the initial point on the ordinate. The irreversible part of the crack Δl is the greater, the more the load exceeds the indicated limit. Under continuous increase of the load the development of the crack proceeds stepwise.

The strength of the bond in the closed part of the crack noticeably increases with the time spent in the closed state. As shown in Fig. 2, the crack length at one and the same value $S = 0.02$ mm decreases with increasing time of “regeneration” of the molecular bonds in the fracture zone (the corresponding points on the curve are connected by a dotted line).

Fig. 2

Figure 2: Fig. 2

The influence of the liquid medium and of capillary forces is very clearly manifested in the kinetics of crack development under appropriately chosen constant loads (P). The results obtained with two specimens are given in Fig. 3 in the form of curves a and b . Their lower initial portions reflect crack development in time, proceeding with a diminishing rate or linearly, depending on the mechanical conditions. The rate increases sharply as soon as a drop of water is applied to the point of stress concentration. When the drop is applied to the crack at some distance from this point, the increase in rate occurs only after the layer of liquid penetrating along the crack reaches its dead end. The rate of crack development again decreases abruptly if the applied drop is removed from the specimen (Ch), and again increases upon the next application of a drop of water. In this way a curve with several steps can be obtained, as shown in Fig. 3 b .

This experiment is especially interesting because it very convincingly shows the mechanical compressive action of capillary forces on the po

surfaces of the menisci at the mouths of cracks. This action exceeds the adsorption and wedging pressure of the molecular layers of water remaining in the crack. If, after the drop is removed, the load is taken off ($S = 0$), then the liquid remaining in the crack protrudes outward along the entire line, collecting in the form of minute droplets, which evaporate very rapidly.

In this state specimen 6 was then dried for 90 min. During this time the crack closed over a considerable segment under the mechanical action of the elastic forces of the plate and with a substantial participation of the forces of capillary contraction⁽⁵⁾. The strength of the regenerated bonds in the closed part of the crack increased, since, when the former load (S) was restored, the crack developed more slowly. The influence of water on this closed segment is especially intense.

Fig. 2. A series of repeated cycles carried out after the cracks had remained in the closed state for different periods. The dotted line connects the points for $S = -0.02$ mm. The strength of the regenerated bonds in the fracture zone increases with the duration of the process of “self-healing” of the crack.

In Fig. 3a are presented the results of experiments with the same glass specimen, but at a greater load P . When the latter was removed ($S = 0$) and then restored again (S), the crack development proceeded very slowly. Here, too, the compressive action of capillary forces is manifested.

Nonpolar liquids (hexane, benzene, carbon tetrachloride, vaseline oil), under the conditions of the experiments described, exert an action diametrically opposite to that produced by water. This is clearly seen in Fig. 4, where the results ob-

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

tained at two different loads on the specimens are presented. Crack development ceases when a drop of carbon tetrachloride is applied to them. This retarding action continues for quite a long time and ceases after the given nonpolar liquid has evaporated from the crack. However, if, in the presence of a nonpolar liquid that has stopped the development of the crack, a drop of water is applied to the same crack, the latter instantaneously penetrates along the surface into the fracture zone and exerts its usual action.

Fig. 3

Fig. 4

This is in good agreement with the general idea expressed earlier by Academician P. A. Rehbinder and Aslanova, namely that clean surfaces of polar solids are completely wetted by both polar and nonpolar individual liquids at different values of the wetting energy. The difference is sharply manifested in the surface activity, in the capillary antagonism of liquids of different polarity, when they, without mixing, are simultaneously present on a given surface, as shown in the last experiment.

The data considered testify to the great possibilities for regulating the rate of fracture processes during dispersion, during mechanical cold working of hard metals, and during the operation of various materials under service conditions (friction, variable loads). In doing so, it is necessary to take into account the physicochemical nature of the interaction of the solid phase with the medium and the predominant importance of water for polar solids.

Further research is intended to seek reagents capable of exerting an influence in any specified directions.

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CITED LITERATURE

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