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Abstract

Full Text

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THE EFFECT OF HYDROSTATIC PRESSURE ON RESISTANCE TO DEFORMATION AND STRENGTH OF POLYMER MATERIALS

(Presented by Academician V. A. Kargin on 26 V 1964)

In previously published works, results were given from studies of the effect of hydrostatic pressure on the mechanical properties of metals and silicate materials^(1-4). Since this effect depends substantially on the physical constitution and structure of the materials being tested, it seemed necessary to us to carry out tests of a new class of structural materials. Below are given the results of tests of specimens made of vinyl plastic, Plexiglas, aminoplast, and ebonite.

Fig. 1. Dependences $\sigma(\varepsilon)$ in compression of polymer materials under conditions of atmospheric pressure (a) and a pressure of 2000 kg/cm^2 (b).
1—vinyl plastic, 2—Plexiglas, 3—ebonite, 4—aminoplast

Fig. 2. Dependences $\sigma(\varepsilon)$ in tension of vinyl plastic under conditions of atmospheric pressure (1) and a pressure of 2000 kg/cm^2 (2)

The experiments were carried out on a 30-ton Schopper testing machine on which a high-pressure chamber had been installed. The pressure-transmitting medium was mineral oil. The maximum pressure during testing was 2000 kg/cm^2. The dependence $\sigma(\varepsilon)$ was determined in tensile and compression tests at constant hydrostatic pressure. The deformation of the specimens was measured by means of a wire rheochord, and the forces by means of strain gauges glued to steel parts on which the specimens rested. The average speed of displacement of the grips was 5 mm/min; the maximum error in measuring the forces was 5%. The specimens for tensile testing had a gauge length of 10 mm and a diameter of 4 mm; the specimens for compression testing had a height of 12 mm and a diameter of 8 mm.

Figure 1 shows the dependences $\sigma(\varepsilon)$ in compression of various polymer materials at atmospheric pressure and at a pressure of 2000 kg/cm^2, po-

plotted in the coordinates σ , ε , and in Figs. 2-3—under tension of polymer materials at atmospheric pressure and at a pressure of 2000 kg/cm^2, plotted in the coordinates σ , ε' . Specimens with average values of the mechanical characteristics were selected for plotting the graphs.

Table 1

Mechanical characteristics of materials obtained in compression tests at atmospheric pressure and at a pressure of 2000 kg/cm^2

Material	σ_1, in $\frac{kg}{cm^2}$, $p = 1\ \frac{kg}{cm^2}$	σ_2, in $\frac{kg}{cm^2}$, $p = 2000\ \frac{kg}{cm^2}$	$\frac{\sigma_2}{\sigma_1}$	ε_1, in %, $p = 1\ \frac{kg}{cm^2}$	ε_2, in %, $p = 2000\ \frac{kg}{cm^2}$	$\frac{E_2}{E_1}$
Viniplast	614	1650	2.68	71	71	2
Plexiglas	1430	2640	1.84	66	54	2.07
Ebonite	1160	1570	1.35	65	66	1.45
Aminoplast	2670	3530	1.33	22	35	1.75

Table 2

Mechanical characteristics of materials obtained in tensile tests at atmospheric pressure and at a pressure of 2000 kg/cm^2

Material	σ_1, in $\frac{kg}{cm^2}$, $p = 1\ \frac{kg}{cm^2}$	σ_2, in $\frac{kg}{cm^2}$, $p = 2000\ \frac{kg}{cm^2}$	$\frac{\sigma_2}{\sigma_1}$	ε_1, in %, $p = 1\ \frac{kg}{cm^2}$	ε_2, in %, $p = 2000\ \frac{kg}{cm^2}$	s_{k1}, in $\frac{kg}{cm^2}$, $p = 1\ \frac{kg}{cm^2}$	s_{k2}, in $\frac{kg}{cm^2}$, $p = 2000\ \frac{kg}{cm^2}$
Viniplast	645	995	1.53	77	56	990 **	1450 **
Plexiglas	814	1030	1.27	17 *	14 *		
Ebonite	630	1140	1.8	16 *	23 *		

* The accuracy of measuring the deformation of specimens with conical heads is somewhat lower because of the possibility of the specimens settling in the grips.
** The resistance to fracture was determined from the section of the neck of the specimens measured after rupture.

Fig. 3. Dependences $\sigma(\varepsilon)$ under tension of ebonite and plexiglas under atmospheric pressure (a) and a pressure of 2000 kg/cm^2 (b). 1 –plexiglas, 2 – ebonite

Figure 2: Fig. 3. Dependences $\sigma(\varepsilon)$ under tension of ebonite and plexiglas under atmospheric pressure (a) and a pressure of 2000 kg/cm^2 (b). 1 –plexiglas, 2 – ebonite

Tables 1 and 2 give the values of the strength limits, Young' s moduli, and relative elongations under tension and compression. As can be seen from the tables, hydrostatic pressure considerably increases the strength limit of all the materials investigated; moreover, in compression the increase in strength of thermoplastic materials is the most significant. Young' s modulus also increases substantially. As regards elongation, it changes little, and only in aminoplast under compression does it increase from 22 to 35%.

Under hydrostatic pressure, the nature of fracture changes in some cases. Thus, for example, at atmospheric pressure viniplast, after the formation of a neck, begins to turn white; under hydrostatic compression, however, whitening does not occur. Evidently, hydrostatic pressure hinders the opening of cracks, as a result of which no color change occurs.

Fig. 3. Dependences $\sigma(\varepsilon)$ under tension of ebonite and plexiglas under atmospheric pressure (*a*) and a pressure of 2000 kg/cm^2 (*b*). 1 –plexiglas, 2 – ebonite

Specimens of plexiglas and ebonite under tension fractured in a brittle manner both at atmospheric pressure and at a pressure of 2000 kg/cm^2; however, in the latter case the fracture surface was perpendicular to the axis of the specimen and smooth, whereas at atmospheric pressure it was rough.

As follows from Figs. 3 and 4, after the strength limit is reached and yielding begins, no further strengthening of the specimens occurs.

With further compression, softening begins, which is subsequently masked by friction of the specimen end faces against the punches. Measurement of the microhardness of specimens after deformation showed that, in specimens tested in tension and compression at atmospheric pressure and at a pressure of 2000 kg/cm^2, the hardness decreases as a result of deformation.

At first glance, the experimental results obtained indicate a special sensitivity of polymeric materials to hydrostatic pressure, since a comparatively small value of hydrostatic pressure leads to a significant increase in strength characteristics. However, in order to explain the results obtained it is necessary to correctly estimate the relative magnitude of the pressure used by comparing it with the magnitude of the bonding forces in the given body. A structurally insensitive characteristic proportional to the bonding forces is Young' s modulus (^{5}). Therefore, to estimate the hydrostatic pressure used, we relate it to Young' s modulus.

For the materials tested, the following ratios of hydrostatic pressure to Young' s modulus were obtained:

Material	Vinyl plastic	Plexiglas	Ebonite	Aminoplast
σ_{hydr}/E	0.12	0.097	0.116	0.05

In experiments with metals, the maximum value of the ratio σ_{hydr}/E was of the order $10^5/2 \cdot 10^6 = 0.05$ (the maximum pressure in Bridgman' s experiments was of the order 10^5 kg/cm^2, $E_{\text{steel}} \sim 2 \cdot 10^6$ kg/cm^2). Thus, in our experiments the relative magnitude of the hydrostatic pressure was equal to or higher than the maximum value of this quantity in experiments with metals. Naturally, the influence of hydrostatic pressure also proved to be very significant; moreover, as is evident from the data in the tables, the influence of pressure is, in general, the greater, the greater the ratio σ_{hydr}/E.

It follows from the data presented above that, in polymeric materials, their potential strength capabilities are utilized considerably better than in metals. If the theoretical strength of materials is taken to be of the order of $0.1E$ (^{5}), then the actual strength of metals turns out to be 2–3 orders of magnitude lower than the theoretical value, whereas that of polymeric materials is only 1-2 orders of magnitude lower.

The results of the investigations show that, in calculating the strength and stiffness of the materials tested and, as further investigations have shown, of most other polymeric materials, it is necessary to take into account the magnitude of the spherical stress tensor, as well as the difference in resistance to fracture under tension and compression.

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Note: Figure translations are in progress. See original paper for figures.

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