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MODULI OF ELASTICITY OF MATERIALS IN EXTENSION AND COMPRESSION

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In recent years there have been extensive developments in the multimodulus theory of elasticity. This theory assumes a material to be homogeneous, but to possess different moduli of elasticity for pure extension and compression in a fixed direction.

Experimental values of the modulus of elasticity for extension E_e and compression E_c were presented in [1]. The reliability of some of these values is doubtful.

For the vitreous plastics KS-30 and AS-30, based on capron and amide resins, respectively, the difference between the moduli at room temperature reaches about 700% of the smaller value. The equipment and methods used for testing were described in [2] (whence this information was taken). Specimens in the form of double spades were used for the extension tests. The equipment used for measurement of deformation was not indicated. Specimens 10 × 10 × 15 mm were tested under compression, with the relative velocity of the reference plates toward each other being 10 mm/min, a value which the authors of [2] erroneously term the deformation rate.

The specimens tested in extension were of a variable cross section. Under tension not only extensive stresses varying over specimen length, but also transverse and tangent stresses were produced. None of this was considered in processing the experimental results.

Due to friction on the faces and pressure of the reference plates, under compression a complex stress state developed within the specimens, inhomogeneous over volume. Calculation of this state would be extremely difficult, but its existence cannot be neglected.

The tests under consideration and the subsequent processing of the data were carried out improperly, producing unreliable data. Incidentally, the curves presented in Fig. 1 of [2] do not have linear initial segments, so that it remains unclear in what manner the moduli of elasticity were determined.

Moduli E_e and E_c for polymethyl methacrylate, taken from [3], were presented in [1]. The differences between the moduli reach 100% of the smaller value.

The stresses acting on the specimen were measured by a photoelectric-optical dynamometer, described in [4], which noted the shortcomings of this device: nonlinearity of the relation between photocurrent and stress, and the necessity of frequent calibration to allow for fatigue

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and aging of the photoelements and changes in light source intensity from experiment to experiment.

The apparatus used to test the polymethyl methacrylate was described in [5]. According to the description presented, deformations were measured from the displacement of clamps during both compression and extension. Compression tests used specimens 5 mm high and 2.5 mm in diameter, while the extension specimens had a working length of 15 mm and a diameter of 2 mm. Regarding specimen behavior during extension, [3] notes that "... with such dimensions the deformation of the working section comprised 80% of the deformation of the entire specimen."

Because specimen deformation was measured by clamp displacements and stressed by a dynamometer with unstable characteristics, the moduli of elasticity obtained for polymethyl methacrylate cannot be considered reliable.

Data for capron and Teflon-4 were presented in [6]. Tests were performed with a Gagarin press. Deformation was measured by clamp displacement, i.e., incorrectly. As a result, incorrect values were obtained for E_e and E_c.

The present author has performed two series of tests of Teflon-4 specimens under extension at fixed loading rates $\dot{\sigma}$ [7]. In the first series 20 specimens were tested, with varied $\dot{\sigma}$ varied over a range of 1247 times. There were 3-7 points located in the linear portion of the deformation curve.

It developed that the value of $\dot{\sigma}$ had practically no effect on the slope of the linear segment. At a confidence level of 95%, $E_e = 927 \pm 57$ MPa.

In the second series, 20 specimens were also tested, with $\dot{\sigma}$ varied over a range of 1547 times. There were 3-11 points in the linear segment of the diagram. In this series the effect of $\dot{\sigma}$ on E_e was somewhat greater. The mean value of E_e was found to be 755 MPa.

According to the data of [6], $E_e = 253$ MPa for Teflon-4. This is only 33.5% of the lowest value measured by the present author. This comparison gives a basis for assuming that the E_c value for Teflon-4 presented in [6] is also incorrect.

Values of $E_e = 12{,}164$ MPa and $E_c = 2963$ MPa were presented in [8] for polystyrol, which was erroneously identified with Plexiglas. The values differ by a factor of more than four.

With regard to the measurement equipment, it was said: "Longitudinal and transverse deformations were measured with electrical strain gauges and a mechanical system. Loading rate was ≈1 mm/min." The expression "machine tests of specimens" was also used, but the machine used and its uncertainty level were not indicated.

It is quite well known that the loading rate has dimensions of kgf/min or $\mathrm{kgf/cm^2 \cdot min}$ and not mm/min. Apparently resistance strain gauges which require selective calibration were used, but nothing was said about this, just as in the case of the mechanical system and the results of its calibration. All this compelled us to perform tests on polystyrol in order to obtain reliable data on E_e and E_c.

Specimens for testing were prepared from 20-mm-thick sheet polystyrol. Tests were performed on a TsD 10/90 testing machine with uncertainty of 0.7%, measured with a Tsvik reference dynamometer.

Five specimens 10 mm in diameter with working section 100 mm long were tested under extension. Deformation was measured by an MK-3 meter over a 50-mm base to an uncertainty of 1.7%, which was considered in processing the experimental data. The MK-3 length measurement devices were tested with a calibration device consisting of a bar divided into two sections, on which the MK-3 was installed. One half of the bar was displaced relative to the other with a micrometer screw. This displacement was measured by a micron indicator and compared to the device readout. The divergence of the device readout determined the error level.

Five specimens were also tested under compression. They were 16 mm in diameter and 100 mm long. Deformation was measured along a 50-mm base by another MK-3 with an uncertainty of 2%, which was considered in processing the results.

The linear portion of the extension diagrams contained 7-10 experimental points, while there were 10-15 points in the linear portion of the compression diagram. The method of least squares was used to determine the slopes of the linear segments from these points.

TABLE 1

Series	E_e, MPa	E_c, MPa	$(E_e-E_c)/E_c$, %
1	3500	3350	4,5
2	3950	3850	2,6
3	4300	4200	2,4

TABLE 2

Material	d, mm	E_e, MPa	ε_β, MPa	v, %	E_e, MPa	ε_β, MPa	v, %	$(E_e-E_c)/E_c$, %
LS59 brass	50	97510	±1900	2,1	96330	±1250	1,0	1,2
Alloy VT1-1	40	115960	±3050	2,5	117330	±1930	1,3	1,2
"	20	93480	±3490	3,0	—	—	—	—

The test results with a variation coefficient of 1.4% were

$$E_e = 3286 \pm 58 \text{ MPa},$$

and with a variation coefficient of 1.2%,

$$E_c = 3306 \pm 50 \text{ MPa}.$$

Here and below the ranges specified correspond to a confidence level of 95%. The difference between the mean values of the moduli comprises 0.6% instead of the 310.5% of [8]. The proportionality limit for polystyrol extension σ_e was 20.6 ± 2.9 MPa, while for compression it was 33.4 MPa or higher.

According to the data of [3], for methyl methacrylate E_e = 1344 MPa and E_c = 2688 MPa, while data from an experiment of the author, performed with tubular specimens about 30 years ago, indicated E_e = 2680 MPa and E_c = 2650 MPa (deformations measured by a Martens device). The difference in the latter case is 1.1%.

Ambartsumyan [1] presented the following values for gray cast iron: E_e = 91,498 MPa and E_c = 121,997 MPa, the difference being 33.3%.

To check these results, tests were performed on gray cast iron in pure extension and compression. Specimens were prepared from 60-mm-thick bars. Extension specimens had a working section 10 mm in diameter and 95 mm long, while the compression specimens were cylindrical, 90 mm long with 15-mm diameter. Deformations were measured by a Martens device on a 50-mm base. Five specimens were tested with various loading regimes. The results obtained were

$$E_e = 90200 \pm 8800 \text{ MPa}, \; E_c = 92200 \pm 2900 \text{ MPa}.$$

Instead of 33.3%, the difference is 2.2%.

Reliable values of moduli of elasticity for other materials can be found in [9].

Results of tests on three series of specimens of the monomer FA were performed in [10]. The first series was processed at 20°C, the second at 80°C, and the third at 120°C. Three specimens were tested in each loading regime. Results are presented in Table 1, whence it is evident that the difference of the moduli does not exceed 4.5%.

We have also performed tests on LS59 brass and the titanium alloy VT1-1 in extension and compression. The compression specimens were 35 to 40 mm in diameter and 100 mm long. The extension specimens were the same size as the polystyrol specimens. The latter were made from bars cut into two or four pieces longitudinally.

Compression tests were performed on a TsD-100 machine with uncertainty in force determination of no more than 1%. A TsD-10/90 machine was used for the extension tests.

Deformations were measured with an MK-3 unit. Because the compression specimens had diameters 3.5-4 times greater than the extension specimens, the attachment point of one of the devices was changed.

The results for LS59 and VT1-1 are presented in Table 2, where d is the diameter of the bar from which the test specimen was prepared, ε_β is the confidence interval, v is the variation coefficient, calculated from the expression

$$v = \sqrt{\Sigma(x_i - x)^2/(n-1)}/x,$$

where x is the mean value of the measured quantity x_i, and n is the number of measurements. In the experiments described, n lay in the range 5-7. It is evident from Table 2 that the difference between E_e and E_c does not exceed 1.2%, i.e., it is a small quantity less than the uncertainties of the accompanying stress and deformation measurements.

Comparison of E_e values for VT1-1 for specimens made from rods of different diameters shows a difference in the moduli which reaches 19.4% of the largest value measured. To eliminate this effect, specimens for extension and compression were made from a single rod.

The analysis presented of studies in which significant differences between the values of E_e and E_c for one and the same material in one and the same material were obtained shows that they are in error. Correctly performed experiments have given practically identical moduli. From this it can be concluded that the basic hypothesis of the multimodulus theory of elasticity [1] has no experimental confirmation.

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