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THE MECHANICAL PROPERTIES OF ANISOTROPIC LAMINATED PLASTICS IN SHORT-TIME TESTS

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N.T.Smotrin and V.M.Chebanov

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Procedure and equipment for testing of the mechanical properties of Russian-produced glass-fiber anisotropic laminated plastics and textolite sheets, with epoxy-phenolic and bakelite binders at various ratios of longitudinal to transverse fibers, are described. Tabulated data and graphs give results of tensile, compression, impact, and shear tests. An equation is derived for calculating the tensile strength σ_b in various directions of the fibers and for computing the variations in proportional limit σ_p, showing close agreement between experimental and calculated values. Tensile and compressive strength were excellent, but shear strength was extremely low (25 to 30 kg/cm^2).

author

Laminated plastics, glass-textolite, glass-fiber anisotropic material (SVAM), textolite, etc. are used in various fields of industry as independent structural materials. The future more extensive use of these materials requires a thorough study of their mechanical properties and the development of methods for calculating their strength and rigidity. It is of great importance to investigate their elastic and strength properties under loads of various directions relative to the fiber direction as well as to define the class of aniso-

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* Numbers in the margin indicate pagination in the original foreign text.

tropic materials with which these plastics can be grouped and to determine the stress limits within which the fairly well-developed theory of elasticity of an anisotropic body can be applied.

The mechanical properties of glass-textolite have been investigated in considerable detail (Bibl.1, 2, 3). It has been found that, with an accuracy sufficient for practical use, this plastic may be regarded as an elastic anisotropic material with a linear stress-strain relation up to rupture.

The properties of SVAM are generally judged by the highly valuable but far from complete data given by the developers of this material, A.K.Burov and G.D. Andriyevskaya (Bibl.4). That paper gives only a few of the basic properties of SVAM prepared by the authors under laboratory conditions. The properties of such SVAM types naturally will differ from those of a similar material produced on an industrial scale.

In this paper we will give and discuss the results of studies of the mechanical properties of SVAM and textolite sheets produced by a laminated plastics manufacturer at Leningrad. The SVAM sheets were manufactured with epoxy- /220 phenolic and bakelite binders at 5:1, 5:4, and 1:1 ratios of longitudinal to transverse fibers. Below, we will designate these materials as SVAM-EF(5:1); SVAM-EF(5:4) and SVAM-B(1:1).

Specimens and Equipment Used

Figure 1 shows the shape and dimensions of the tensile test specimens. The specimens for the compression test to rupture were rectangular parallelepipeds with a base of 11 × 11 and 18 mm in height; for determining the elastic constants, we used specimens of the same shape but of 17 × 22 × 30 mm dimensions. The specimens were notched in seven directions in the plane of the sheet at 15°

spacings, from 0 to 90°*. The basic zero direction was taken as the strongest one, along the greater part of the fibers of the SVAM and along the base in the

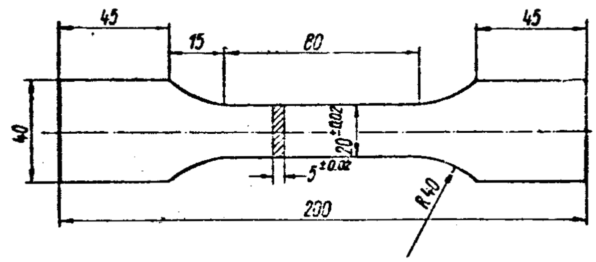

Fig.1 Tensile Test Specimen

textolite. The specimens were prepared by the following procedure: First, the blanks were cut on a mechanical jig saw in the form of strips and were then reduced to the required dimensions by hand using a template; the planes were then ground so as to ensure uniform thickness of the specimen. Specimens prepared in this manner will reveal, in tensile or compression tests, mechanical properties of the material in different directions in the plane of the sheet. The tests were run on a Gagarin press, using a special reversing gear with wedge clamps for the tensile test. The longitudinal and transverse deformations were measured by resistance pickups using an ID-2 instrument with an accuracy of ±1% of the measured quantity $\pm 10^{-5}$. To take the readings, the instruments were stopped at certain loads for up to 2 min.

Test Results /221

Figure 2 gives graphs of the mean relation between the stress σ and the

* It will be noted that, in preparing the specimens, the fibers are cut, thereby introducing certain errors into the quantitative values of the mechanical characteristics of the material. Application of epoxy resin to the lateral surfaces of the specimens to reinforce the notched fibers does not greatly change the test results.

elongation ϵ for SVAM-EF(5:1) and textolite in specimens notched at various angles to the principal direction. The stress-strain diagrams have a similar form for all materials studied, both in tension and in compression. The mean

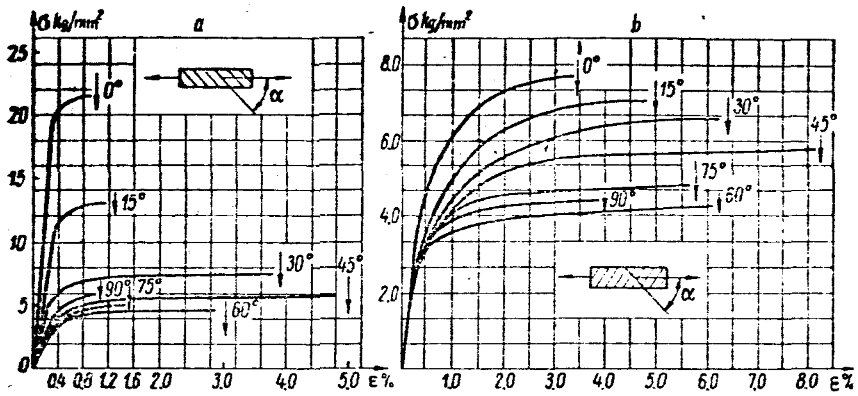

Fig.2 Tension Diagrams for various Directions
a - For SVAM-EF(5:1); b - For textolite

values of the proportional limits σ_p^*, the tensile strength σ_b, and the mean values of the elastic constants E and u are given in the Table for various directions in one and the same material. These mean values were obtained from the test results of five specimens, in each direction. The Table also shows the greatest deviations of the individual quantities from their mean values.

To establish the existence of residual deformation in the test materials, we ran experiments with unloading and prolonged "rest", during which we observed the disappearance of the deformation with time. The experiments with reloading immediately after unloading and after various "rest" times yielded an answer to certain questions as to the effect of prior deformation. As an example, Fig.3 shows the σ - ϵ diagrams in tension, unloading at various stresses, and repetition of stress for individual specimens of SVAM-EF(5:1) notched at an angle of

* The proportional limit σ_p was taken as the stress at which the modulus of longitudinal elasticity decreased 20% below its initial value (Bibl.5).

Table

Angle $\alpha°$	σ_p in kg/mm²	Deviation from mean value, in %	σ_b in kg/mm²	Deviation from mean value, in %	E in kg/mm²	Deviation from mean value, in %	μ	Deviation from mean value, in %
SVAM - EF (5 : 1) - Tension								
0	20.3	+16.8 −13.5	21.5	+17.4 −19.2	5100	+ 6.7 − 8.5	0.148	+10.3 − 9.6
15	11.6	+13.1 −14.6	13.1	+20.7 −23.3	3290	+12.3 −13.6	0.334	+11.4 −16.1
30	5.90	±18.2	6.6	+15.8 −24.3	1630	+10.1 −12.5	0.415	+12.4 − 8.6
45	3.10	+ 8.0 −16.1	3.9	+20.8 −15.6	1030	+16.5 −17.6	0.419	+ 6.4 − 6.0
60	3.80	+ 8.4 −12.6	3.7	+10.3 −14.9	810	+14.5 −15.0	0.250	+ 7.2 − 7.4
75	3.30	+14.6 −12.8	4.2	+ 3.5 −12.2	836	± 9.8	0.113	+ 6.2 − 8.3
90	4.00	±15.4	4.9	+10.7 − 9.8	953	+15.6 − 9.7	0.03	+ 5.9 − 4.7
SVAM - EF (5 : 4) - Compression								
0	27.3	+16.1 −16.7	30.4	+17.2 −17.8	6470	±11.5	0.122	+12.3 −11.6
15	19.5	+17.5 −11.3	23.5	+19.9 −19.2	4740	+18.6 −15.4	0.290	+ 8.3 −10.7
30	12.3	+17.4 −10.3	18.5	+11.5 −14.0	2835	+ 9.6 −11.2	0.486	+11.4 −13.6

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Table, continued

Angle $\alpha°$	σ_p in kg/mm^2	Deviation from mean value, in %	σ_b in kg/mm^2	Deviation from mean value, in %	E in kg/mm^2	Deviation from mean value, in %	μ	Deviation from mean value, in %
45	11.3	± 8.6	15.3	+16.8 −13.8	2680	+ 3.6 − 8.3	0.561	+ 9.1 +13.2
60	12.5	±10.4	16.2	±13.5	2990	+14.5 −11.3	0.480	+ 8.8 − 3.6
75	19.1	+10.5 − 9.0	21.0	+22.7 −17.5	4380	+17.2 −13.1	0.216	+11.6 − 8.9
90	22.6	+15.6 −10.7	24.6	+ 9.5 −17.6	5330	+ 7.4 − 9.3	0.070	+13.4 −12.3
Textolite - Tension								
0	3.65	+6.3 −7.5	7.81	+5.1 −3.8	1340	+4.8 −7.1	0.138	+7.2 −2.4
15	3.18	±5.8	7.38	+6.3 −7.1	1121	+3.6 −2.8	0.254	+3.9 −5.6
30	3.43	+3.4 −6.2	6.82	±5.6	1214	+6.5 −4.1	0.412	+4.8 −4.3
45	3.38	+5.9 −4.5	5.71	+6.4 −3.6	820	+7.3 −6.9	0.630	±6.5
60	2.90	+7.1 −6.3	4.35	+4.6 −5.3	980	+5.8 −6.1	0.501	+1.6 −2.9

Table, continued

Angle $\alpha°$	σ_p in kg/mm²	Deviation from mean value, in %	σ_b in kg/mm²	Deviation from mean value, in %	E in kg/mm²	Deviation from mean value, in %	μ	Deviation from mean value, in %
75	3.26	+2.6 −5.4	4.68	+4.9 −3.6	964	+5.6 −5.3	0.264	+3.7 −2.6
90	2.95	+4.5 −1.8	4.28	+7.3 −4.9	1100	+7.4 −5.2	0.110	+6.1 −5.3
				Textolite - Compression				
0	6.62	+1.6 −3.8	14.04	+3.4 −6.5	3300	+3.8 −4.5	0.341	+5.6 −3.4
15	6.11	+7.1 −5.9	12.93	+4.8 −3.2	1820	+7.3 −7.6	0.512	+2.8 −5.1
30	4.83	+3.6 −4.9	12.60	+6.1 −7.3	830	+5.1 −6.2	0.681	+6.4 −1.3
45	4.10	+6.5 −3.8	11.98	+5.8 −4.2	625	+3.4 −5.6	0.736	+6.8 −5.2
60	3.96	+6.1 −4.9	11.80	±5.9	726	+1.9 −3.6	0.645	+3.2 −6.7
75	4.09	+5.4 −5.1	13.40	+1.6 −5.4	1198	+4.3 −4.9	0.395	±4.4
90	3.70	+6.9 −7.2	13.47	+3.2 −4.8	1570	+6.5 −4.8	0.170	+3.1 −5.9

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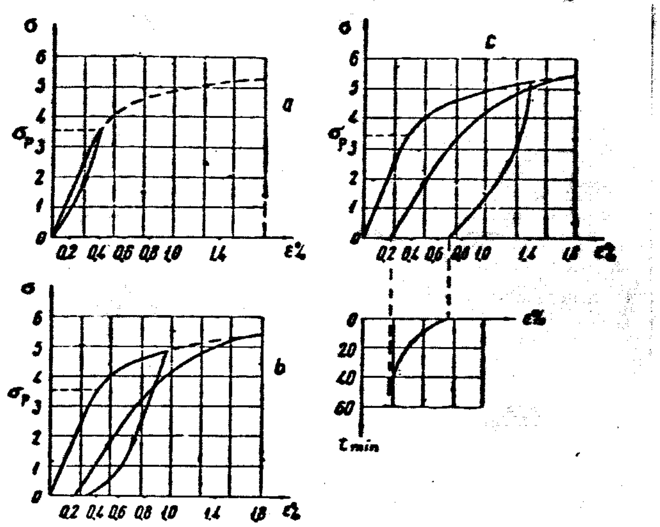

Fig.3 Tension Diagrams for SVAM-EF (5:1) on Loading, Unloading, and Reloading

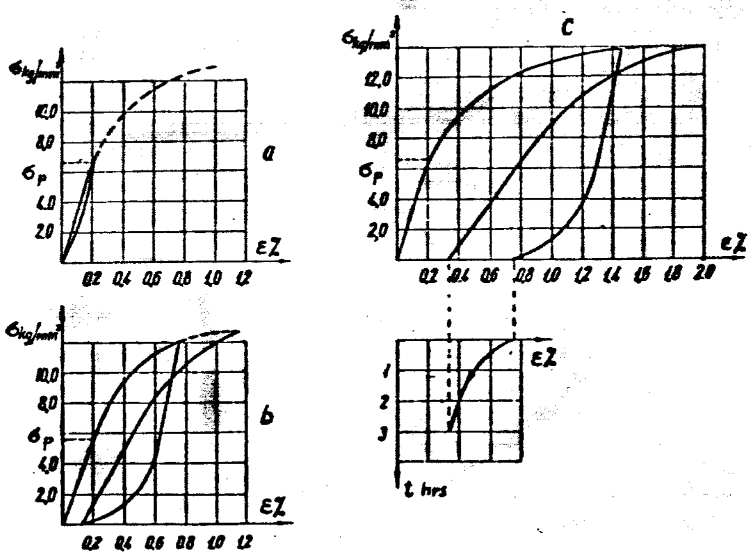

Fig.4 Compression Diagrams of Textolite on Loading, Unloading, and Reloading

$\alpha = 45^{\circ}$ to the principal direction. Figure 4 gives similar graphs for the compression of textolite specimens notched along the base $\alpha = 0^{\circ}$. Figures 3a and 4a give the $\sigma - \epsilon$ relation on initial loading to stresses below σ_p, on unloading and reloading. Figures 3b and 3c (as well as Figs.4b and 4c) give graphs of the same relation on initial loading to stresses above σ_p. Reloading in one case (Figs.3b and 4b) immediately followed unloading, while in the other case (Figs.3c and 4c) it followed a "rest" of the unloaded specimen. During the "rest" period, the strain produced during unloading decreased, as shown in Figs.3c and 4c in the coordinates $\epsilon - t$. /226

Discussion of the Results

The relation between the stress σ and the relative longitudinal strain was practically linear for both SVAM and textolite up to the proportional limit σ_p. The tensile strength σ_b of SVAM is slightly higher than the value of σ_p while the strain ϵ_b at rupture is appreciably higher than the strain ϵ_p corresponding to the proportional limit. For textolite, σ_b is about twice as great as σ_p.

The experiments with unloading both after tension and after compression for specimens notched in all directions showed no residual deformation or permanent set for stresses up to the proportional limit. It should be noted that the $\sigma - \epsilon$ relation in unloading differs somewhat from a linear dependence on the direct loading. On reloading, the $\sigma - \epsilon$ relation remains practically the same as in the case of the original loading. In other words, the modulus of elasticity under initial load and reloading remains practically unchanged*. In this case there is a rather faint hysteresis loop, characterizing the existence of

* An increase of 2 - 3% in the modulus of longitudinal elasticity was most frequently observed on reloading of the SVAM.

elastic defects in the material.

In unloading from stresses above σ_p, there will be some residual deformations. Some of these disappear again after various periods of time, while others remain in the material and do not disappear even after a prolonged "rest". The magnitude of the "true" permanent set, i.e., those that do not disappear with time, increases with increasing angle from the principal direction or from the direction perpendicular to it, and reaches a maximum at $\alpha = 45^\circ$. In our experiments, we observed a maximum "true" permanent set of 0.35 - 0.40% for the SVAM and 0.8 - 1.1% for the textolite. Reloading after unloading shows in- /227
creased yield of the material and thus a decreased modulus of longitudinal

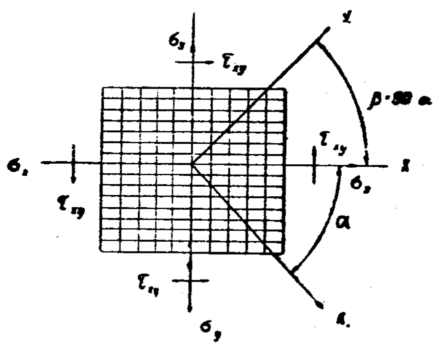

Fig.5 Stressed State of the Element

elasticity. It is entirely natural that the width of the hysteresis loop should vary, and should increase more the greater the deformation at unloading had been.

These experiments justify the grouping of SVAM and textolite with the class of anisotropic viscoelastoplastic materials. The viscoelastic behavior of SVAM is entirely natural since its components - glass fiber and binder - both are viscoelastic materials. The existence of plastic deformation or of permanent set may hypothetically be explained by the destruction of some fibers during deformation and the reorientation of others; by the disruption of continuity of certain zones of the binder; and by separation of the binder from the fibers*. The propagation of these defects or of new break foci on subsequent deformation leads to loss of the load-carrying capacity of the material and to its ultimate failure.

The mutually perpendicular arrangement of the glass and textile fibers in the layers of the test materials makes it possible to consider them orthotropic materials whose principal elastic symmetry axes coincide with the direction of the longitudinal and transverse fibers.

If, in an orthotropic plate, the direction of the x and y axes coincide with the principal axes of elasticity, then the equation of the generalized Hooke's law is of the form (Bibl.7)

$$\left.\begin{aligned} \varepsilon_x &= \frac{1}{E_1}\sigma_x - \frac{\mu_2}{E_2}\sigma_y, \\ \varepsilon_y &= -\frac{\mu_1}{E_1}\sigma_x + \frac{1}{E_2}\sigma_y, \\ \gamma_{xy} &= \frac{1}{G}\tau_{xy}. \end{aligned}\right\} \qquad (1)$$

Passing to the new axes x' and y', rotated through an angle α with respect to the initial axes (see Fig.5), we now write this equation of the generalized Hooke's law in the form

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$$\left.\begin{aligned} \varepsilon'_x &= \frac{1}{E_\alpha}\sigma'_x - \frac{\mu_\beta}{E_\beta}\sigma'_y + \frac{\eta_\alpha}{E_\alpha}\tau'_{xy}, \\ \varepsilon'_y &= \frac{\mu_\alpha}{E_\alpha}\sigma'_x + \frac{1}{E_\beta}\sigma'_y + \frac{\eta_b}{E_\beta}\tau'_{xy}, \\ \gamma'_{xy} &= -\frac{\eta_\alpha}{E_\alpha}\sigma'_x + \frac{\eta_\beta}{E_\beta}\sigma'_y + \frac{1}{G_\alpha}\tau'_{xy}. \end{aligned}\right\} \qquad (2)$$

where the angle $\beta = \frac{\pi}{2} - \alpha$; E_α and E_β are the moduli of longitudinal elastici-

* In textolite, permanent set may be due also to plastic deformations of the filaments of the fabric.

ty; μ_α and μ_β the Poisson coefficients; G_α the shear modulus for the new directions; η_α and η_β,"the mutual influence coefficients" that do not appear in the principal system.

The constants entering into eqs.(2) are defined by the formulas:

$$\left.\begin{aligned}
\frac{1}{E_\alpha} &= \frac{\cos^4\alpha}{E_1} + \left(\frac{1}{G} - \frac{2\mu_1}{E_1}\right)\sin^2\alpha\cdot\cos^2\alpha + \frac{\sin^4\alpha}{E_2},\\
\frac{1}{E_\beta} &= \frac{\sin^4\alpha}{E_1} + \left(\frac{1}{G} - \frac{2\mu_1}{E_1}\right)\sin^2\alpha\cos^2\alpha + \frac{\cos^4\alpha}{E_2},\\
\frac{1}{G_\alpha} &= \frac{1}{G} + \left(\frac{1+\mu_1}{E_1} + \frac{1+\mu_2}{E_2} - \frac{1}{G}\right)\sin^2 2\alpha,\\
\mu_\alpha &= E_\alpha\left[\frac{\mu_1}{E_1} - \frac{1}{4}\left(\frac{1+\mu_1}{E_1} + \frac{1+\mu_2}{E_2} - \frac{1}{G}\right)\sin^2 2\alpha\right],\\
\mu_\beta &= \mu_\alpha\frac{E_\beta}{E_\alpha},\\
\eta_\alpha &= E_\alpha\left[\frac{\sin^2\alpha}{E_2} - \frac{\cos^2\alpha}{E_1} + \frac{1}{2}\left(\frac{1}{G} - \frac{2\mu_1}{E_1}\right)\cos 2\varphi\right]\sin 2\varphi,\\
\eta_\beta &= E_\beta\left[\frac{\cos^2\alpha}{E_2} - \frac{\sin^2\alpha}{E_1} - \frac{1}{2}\left(\frac{1}{G} - \frac{2\mu_1}{E_1}\right)\cos 2\varphi\right]\sin 2\varphi.
\end{aligned}\right\} \quad (3)$$

The following expressions will be the invariants:

$$\left.\begin{aligned}
\frac{1}{E_\alpha} + \frac{1}{E_\beta} - \frac{2\mu_\alpha}{E_\alpha} &= \frac{1}{E_1} + \frac{1}{E_2} - \frac{2\mu_1}{E_1},\\
\frac{1}{G_\alpha} + \frac{4\mu_\alpha}{E_\alpha} &= \frac{1}{G} + \frac{4\mu_1}{E_1}.
\end{aligned}\right\} \quad (4)$$

Remembering that the constants with the subscript "1" in these formulas correspond to $\alpha = 0^\circ$ and those with the subscript "2" to $\alpha = 90^\circ$, we can introduce the notation $E_1 = E_0$; $E_2 = E_{90}$; etc.

It is well known that the elastic properties of an orthotropic plate are determined by four constants. Taking various quantities as these constants, for example E_0, E_{90}, G_0, and μ_{90} or else E_0, E_{90}, E_{45}, and μ_{90}, we may obtain from eqs.(3) relations of various forms for calculating the elastic constants with respect to arbitrary axes (Bibl.1, 2). It is convenient to take E_0, /229 E_{45}, E_{90}, and μ_0 as the initial quantities. Then, the formulas for determining the elastic constants at various angles α may be represented as follows:

$$E_\alpha = \frac{E_0}{\cos^4\alpha + m\sin^2 2\alpha + n\sin^4\alpha}, \tag{5}$$

$$\mu_\alpha = \frac{\mu_0 + (2m - c)\sin^2 2\alpha}{\cos^4\alpha + m\sin^2 2\alpha + n\sin^4\alpha}, \tag{6}$$

$$G_\alpha = \frac{E_0}{2\mu_0 + 4m - 4(2m - c)\sin^2\alpha}, \tag{7}$$

$$\eta_\alpha = \frac{n - 1 + 4(2m - c)\cos^2 2\varphi}{2(\cos^4\alpha + m\sin^2 2\alpha + n\sin^4\alpha)}\sin 2\alpha, \tag{8}$$

where $n = \frac{E_0}{E_{90}}$, $c = \frac{E_0}{E_{45}}$, $m = c - \frac{n-1}{4}$.

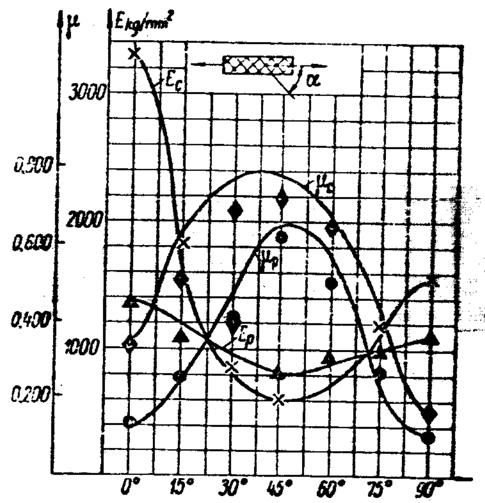

Fig.6 Variation of E and μ for Textolite in Tension and Compression

Figure 6 gives graphs for the variation in the elastic constants according to eqs.(5) and (6), for textolite in tension and compression. The experimental data of the corresponding constants, as obvious from Fig.6, are located close to the calculated curves.

For SVAM, in eqs.(5), (6), (7), and (8) we can replace the ratio $n = \frac{E_0}{E_{90}}$ by the ratio of the longitudinal to the transverse fibers $\frac{N_0}{N_{90}}$, which is about equal to n (see the Table). The curves plotted according to eqs.(5), (6), (7), and (8) are shown in Fig.7 for SVAM-EF (5:1) in tension and in Fig.8 for

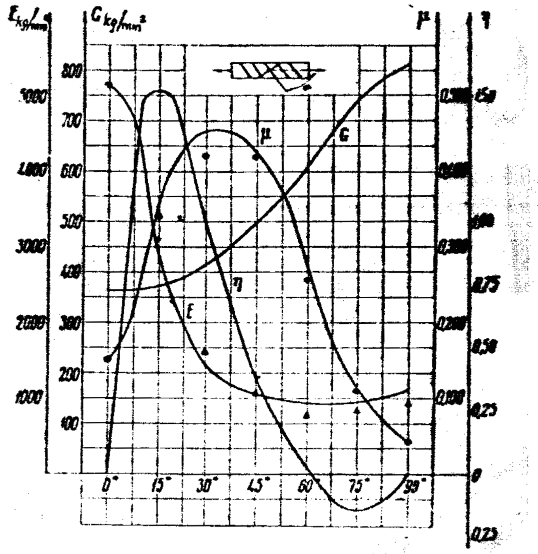

Fig.7 Variation of Elastic Constants of SVAM-EF (5:1) in Tension

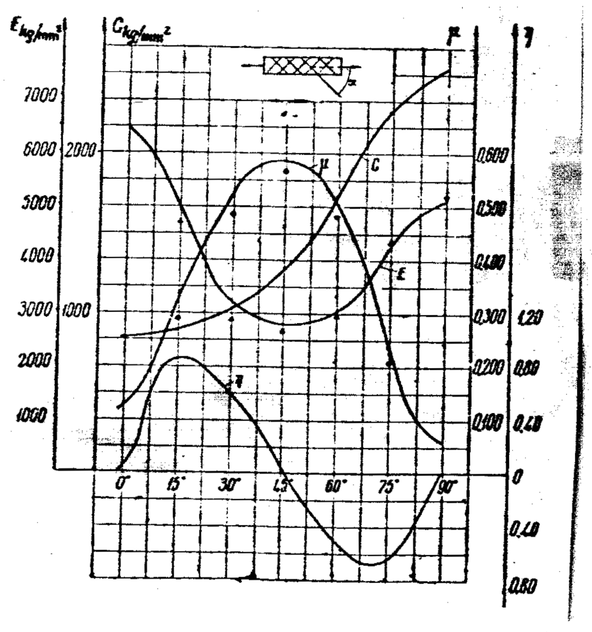

Fig.8 Variation of Elastic Constants of SVAM-EF (5:4) in Compression

SVAM-EF (5:4) in compression. The satisfactory agreement of the experimental data for E and μ confirms the validity of our assumption.

Thus, in order to determine the four initial elastic constants of orthotropic laminated plastics, we must test the specimens in three directions at α = 0, 45, and 90°. For SVAM, it is sufficient to conduct tests in only two directions at α = 0 and 45°.

To select an analytical relation describing the variation in the elastic limit of the test materials in various directions, we will analyze two formulas proposed by A.L.Rabinovich (Bibl.8) and Ye.K.Ashkenazi (Bibl.9). /231

The first formula is similar to the relation for the modulus of elasticity and has the form:

$$\sigma_\alpha = \frac{A_\sigma \sigma_0}{A_\sigma \cos^4\alpha + 2B_\sigma \sin^2\alpha \cos^2\alpha + \sin^4\alpha}, \tag{9}$$

where

$$A_\sigma = \frac{\sigma_{90}}{\sigma_0}; \; B_\sigma = B(1+\gamma) - \gamma;$$

$$\gamma = \frac{A - A_\sigma}{1 - A}; \quad A = \frac{E_{90}}{E_0}; \quad 2B = 4\frac{E_{90}}{E_{45}} - (1 + A).$$

In deriving eq.(9), the assumptions adopted were that the stress-strain relation was linear up to rupture and that the points corresponding to failure of the material in various directions on the $\sigma - \epsilon$ diagrams lie on a single straight line. Equation (9) was checked on plywood and delta-board (Bibl.8) and on several brands of glass-textolite (Bibl.1). To use eq.(9), it is necessary to experimentally determine the tensile strength σ_0 and σ_{90} along the principal axes of anisotropy and the moduli of elasticity in the three directions E_0, E_{90}, and E_{45}.

Starting from the outward similarity of the character of the surfaces in three-dimensional space of the modulus of elasticity and the tensile strength, Ashkenazi proposed the following relation for calculating σ_b in various directions:

$$\sigma_\alpha = \frac{\sigma_0}{\cos^4\alpha + b\sin^2 2\alpha + a\sin^4\alpha}, \tag{10}$$

where $a = \dfrac{\sigma_0}{\sigma_{90}}$; $b = \dfrac{\sigma_0}{\sigma_{45}} - \dfrac{a+1}{4}$.

Elementary transformations show that eq.(10) can be derived from eq.(9) if we assume that the elastic limits and moduli of elasticity are equal in the corresponding directions, i.e.,

$$\frac{\sigma_{90}}{\sigma_0} = \frac{E_{90}}{E_0} \text{ and } \frac{\sigma_{90}}{\sigma_{45}} = \frac{E_{90}}{E_{45}}.$$

The equality of these relations is obviously valid for many orthotropic materials, since the results of a calculation by means of eq.(10) are in satisfactory agreement with the experimental data obtained in tests on glass-textolite (Bibl.10), plywood, and wood (Bibl.9). It is a basic advantage of eq.(10) that it requires no preliminary determination of the elastic constants, as is necessary when using eq.(9).

A comparison of calculations on the basis of eq.(10) with the corresponding experimental data obtained in tensile and compression tests for textolite showed that eq.(10) can be recommended not only for calculating the tensile strength σ_b in various directions but also for calculating the variation in the proportional limit σ_p. The maximum difference between the corresponding calculated and experimental data did not exceed 7.3%. /232

It is obvious from the Table that, for SVAM, the relations between tensile strength σ_b and proportional limit σ_p along the principal axes of anisotropy $\dfrac{\sigma_0}{\sigma_{90}}$ differ only slightly from the ratio of longitudinal to transverse fibers $\dfrac{N_0}{N_{90}}$. Assuming that these ratios are equal and remembering that $\dfrac{N_0}{N_{90}} = \dfrac{E_0}{E_{90}}$, we can derive a single formula for calculating the modulus of elasticity E, the tensile strength σ_b, and the proportional limit σ_p in various directions in the plane of an SVAM sheet. This formula will be of the following form:

$$K_\alpha = \frac{K_0}{\cos^4\alpha + m\sin^2 2\alpha + n\sin^4\alpha}, \tag{11}$$

where

$$n = \frac{N_0}{N_{90}}; \quad m = \frac{K_0}{K_{45}} - \frac{n+1}{4}.$$

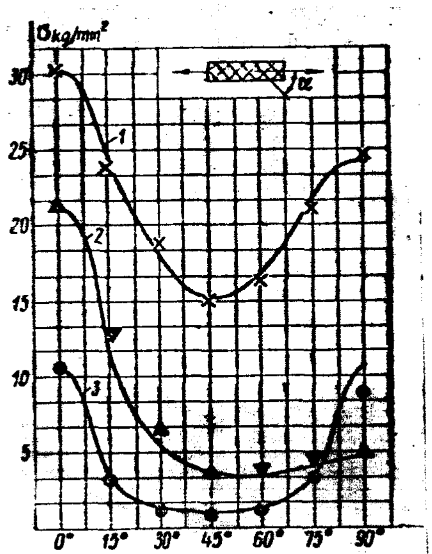

Fig.9 Variation in Tensile Strength for SVAM in Various Directions
1 - SVAM-EF (5:4), compression; 2 - SVAM-EF (5:1), tension; 3 - SVAM-B (1:1), tension

If the variation of E_α is calculated by means of eq.(11), then $E_0 = K_0$ and $E_{45} = K_{45}$ must be experimentally determined and, in calculating the variation in tensile strength or in proportional limit, K_0 and K_{45} must be taken as the /233 corresponding values of σ_b and σ_p obtained in tension or compression of specimens in the directions $\alpha = 0^\circ$ and $\alpha = 45^\circ$.

Figures 9 and 10 show the curves, calculated on the basis of eq.(11), for the variation in tensile strength and proportional limit for SVAM-EF (5:1) and SVAM-B (1:1) in tension, and for SVAM-EF (5:4) in compression. As indicated by these plots, the experimental values are all close to the calculated curves.

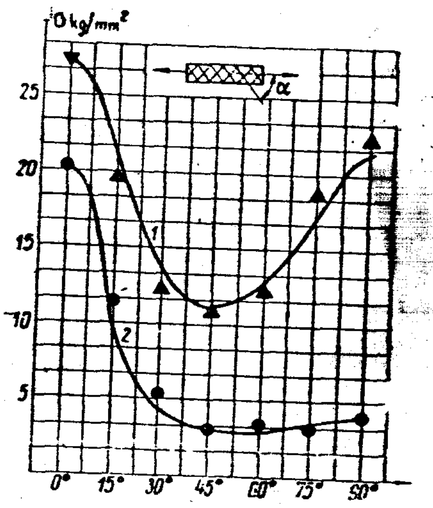

Fig.10 Variation in Proportional Limit for
SVAM-EF (5:4) (1) and for SVAM-EF (5:1) (2)

Together with the tensile and compression tests, we also made shear tests of SVAM. These tests were made on strips of material 20 mm wide, with parallel notches toward the center of the strip on opposite surfaces (with the notches spaced by 40 mm). The extension of such a strip on a Gagarin press always led to failure by shearing along planes parallel to the plane of the sheet. No signs of detachment of the layers were noted in the tests. The shear strength, calculated as the breaking load applied in the shear plane, proved to be about the same for all types of SVAM tested and was of the order of 25 - 30 kg/cm^2. Such a catastrophically low resistance to shear, by comparison with the resistance to tension or compression even in the weakest direction, is the basic shortcoming of SVAM and of its binder, which must be taken into account both in the manufacture of the material and in the stress analysis.

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