Ministry of Science and Higher Education of the Russian Federation
Ufa University of Science and Technology

LABORATORY WORKSHOP

about discipline

« Fundamentals of mechanics, design and manufacturing technology of products made of composite materials »

Ufa 2024

Ministry of Science and Higher Education of the Russian Federation
Ufa University of Science and Technology

Department of Strength of Materials

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Methodological instructions for conducting laboratory classes in the course “ Fundamentals of mechanics, design and manufacturing technology of products made of composite materials ” are provided.

Intended for students studying in the field of training for certified specialists 05/24/02 – “Design of aircraft and rocket engines”, bachelors 03/25/01 – “Technical operation of aircraft and engines”

Il.

The laboratory workshop was developed as part of the implementation of an innovative educational program for training personnel in the field of information technologies for the design, production and operation of complex technical objects (Priority National Project “Education”)

Content

INTRODUCTION

The use of composite materials in structural elements is becoming increasingly widespread, which requires knowledge of their behavior under various types of deformations.

Laboratory work No. 1 [9] presents a method for experimentally studying the anisotropy of the elastic properties of fiberglass.

In laboratory work No. 2 [12], a method for determining the mechanical characteristics of a layered composite material under three-point bending is considered.

Laboratory work No. 3 presents a method for experimentally determining the impact strength of composite materials.

Each laboratory work contains: a brief theoretical part, a description of the testing equipment, a methodology for conducting laboratory work, an analysis of the results obtained, and test questions.

LABORATORY WORK №1

STUDY OF ANISOTROPY OF ELASTIC PROPERTIES OF FIBERGLASS PLASTICS

Purpose of the work

Experimental study of the anisotropy of elastic properties of fiberglass and determination of quantitative values of the main parameters of the generalized Hooke's law.

Theoretical part

When working with composite materials, there is a need to know their elastic properties.

Composite materials have a significant anisotropy of elastic properties, depending on the layout of the reinforcing fibers.

Many composites are layered with reinforcing fibers laid in mutually perpendicular directions.

In this case, an orthotropic material is obtained with the main axes X, Y directed along the directions of the reinforcement (Fig. 1.1).

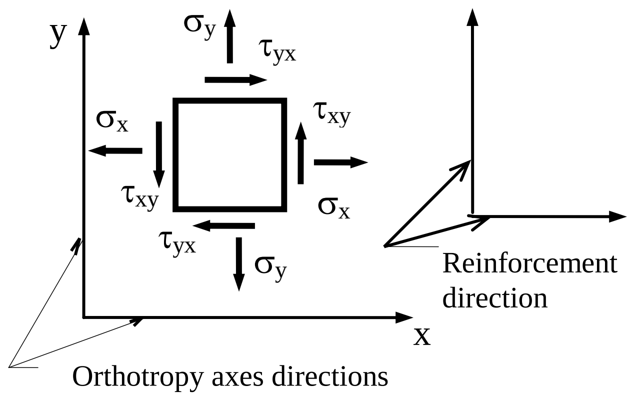


Figure 1.1 - Orthotropic X,Y axes direction and assignment stress state components

With respect to these X, Y stress axes we denote σ_x, σ_y, τ_{xy}, and deformations ε_x, ε_y, γ_{xy}.

The generalized Hooke's law in this case has the form [7]

$$
\begin{cases}
\varepsilon_x = \dfrac{1}{E_x}\sigma_x - \dfrac{\nu_{xy}}{E_y}\sigma_y, \\
\varepsilon_y = -\dfrac{\nu_{yx}}{E_x}\sigma_x + \dfrac{1}{E_y}\sigma_y, \\
\gamma_{xy} = \dfrac{1}{G_{xy}}\tau_{xy},
\end{cases}
\tag{1.1}
$$

there

$$
\frac{\nu_{xy}}{E_y} = \frac{\nu_{yx}}{E_x}, \tag{1.2}
$$

where E_x and E_y – elastic moduli of the composite along axes X and Y; ν_{xy} and ν_{yx} – Poisson's ratios; G_{xy} – shear modulus.

Let us now consider the coordinate axes X_1, X_2, rotated relative to the base axes X, Y by an angle φ (Fig. 1.2).

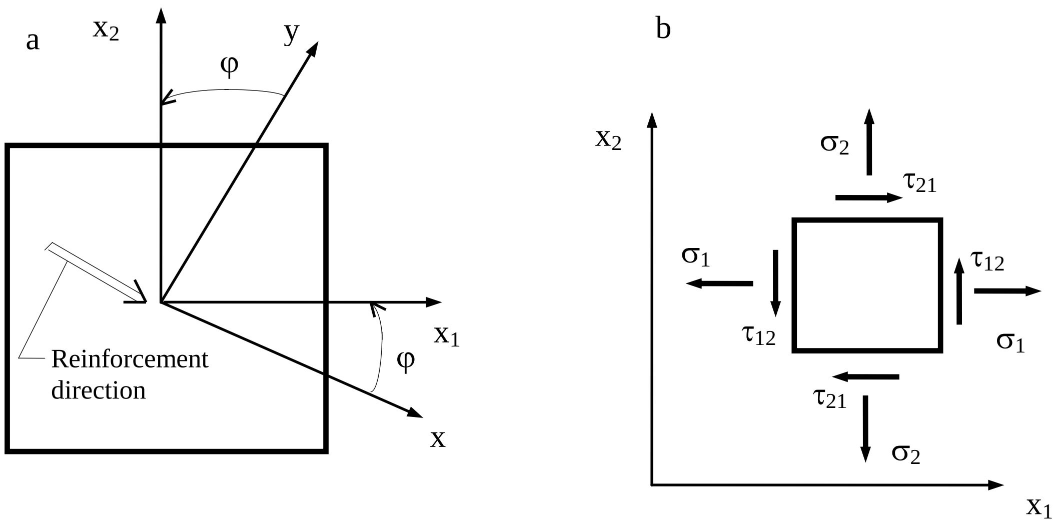


Figure 1.2 - Location of the axes of the new (X_1, X_2) and old (X, Y) coordinate systems relative to the direction of composite reinforcement and setting the positive direction of the angle reference φ (a). Components of the stress state with respect to the axes X_1, X_2 (b)

Let us denote stresses relative to the X_1, X_2 axes by σ_1, σ_2, τ_{12} and deformations by ε_1, ε_2, γ_{12}.

Relationships between stresses σ_1, σ_2, τ_{12} and strains ε_1, ε_2, γ_{12} are given by the relations of the generalized Hooke’s law in the following form:

$$\begin{cases} \varepsilon_1 = A_{11}\sigma_1 + A_{12}\sigma_2 + A_{13}\tau_{12}, \\ \varepsilon_2 = A_{21}\sigma_1 + A_{22}\sigma_2 + A_{23}\tau_{12}, \\ \gamma_{12} = A_{31}\sigma_1 + A_{32}\sigma_2 + A_{33}\tau_{12}, \end{cases} \tag{1.3}$$

where the coefficients A_{ij}, $i = 1, 2, 3$, $j = 1, 2, 3$ according to [7] are determined by the expressions

$$\begin{cases} A_{11} = \dfrac{\cos^4\varphi}{E_x} + \left(\dfrac{1}{G_{xy}} - \dfrac{2\nu_{yx}}{E_x}\right) \sin^2\varphi \cos^2\varphi + \dfrac{\sin^4\varphi}{E_y}, \\ A_{12} = \left(\dfrac{1}{E_x} + \dfrac{1}{E_y} + \dfrac{2\nu_{yx}}{E_x} - \dfrac{1}{G_{xy}}\right) \sin^2\varphi\cos^2\varphi - \dfrac{\nu_{yx}}{E_x}, \\ A_{13} = \left[2\left(\dfrac{\sin^2\varphi}{E_y} - \dfrac{\cos^2\varphi}{E_x}\right) + \left(\dfrac{1}{G_{xy}} - \dfrac{2\nu_{yx}}{E_x}\right)\left(\cos^2\varphi - \sin^2\varphi\right)\right]\sin\varphi\cos\varphi, \\ A_{21} = A_{12}, \\ A_{22} = \dfrac{\sin^4\varphi}{E_x} + \left(\dfrac{1}{G_{xy}} - \dfrac{2\nu_{yx}}{E_x}\right) \sin^2\varphi\cos^2\varphi + \dfrac{\cos^4\varphi}{E_y}, \\ A_{23} = \left[2\left(\dfrac{\cos^2\varphi}{E_y} - \dfrac{\sin^2\varphi}{E_x}\right) - \left(\dfrac{1}{G_{xy}} - \dfrac{2\nu_{yx}}{E_x}\right)\left(\cos^2\varphi - \sin^2\varphi\right)\right]\sin\varphi\cos\varphi, \\ A_{31} = A_{13}, \\ A_{32} = A_{23}, \\ A_{33} = 4\left(\dfrac{1}{E_x} + \dfrac{1}{E_y} + \dfrac{2\nu_{yx}}{E_x} - \dfrac{1}{G_{xy}}\right)\sin^2\varphi\cos^2\varphi + \dfrac{1}{G_{xy}}. \end{cases} \tag{1.4}$$

Thus, knowledge of the five elastic characteristics allows to establish $E_x, E_y, \nu_{xy}, \nu_{yx}, G_{xy}$ on the basis of (1.1) and (1.3), an unambiguous relationship between the components of stress and strain for an arbitrary orientation of the axes of the coordinate system.

Let us determine E_x, E_y, $\nu_{xy}, \nu_{yx}, G_{xy}$ from the results of tests during longitudinal deformation of flat samples cut from sheet composite material at different angles to the directions of reinforcement (Fig. 1.3).

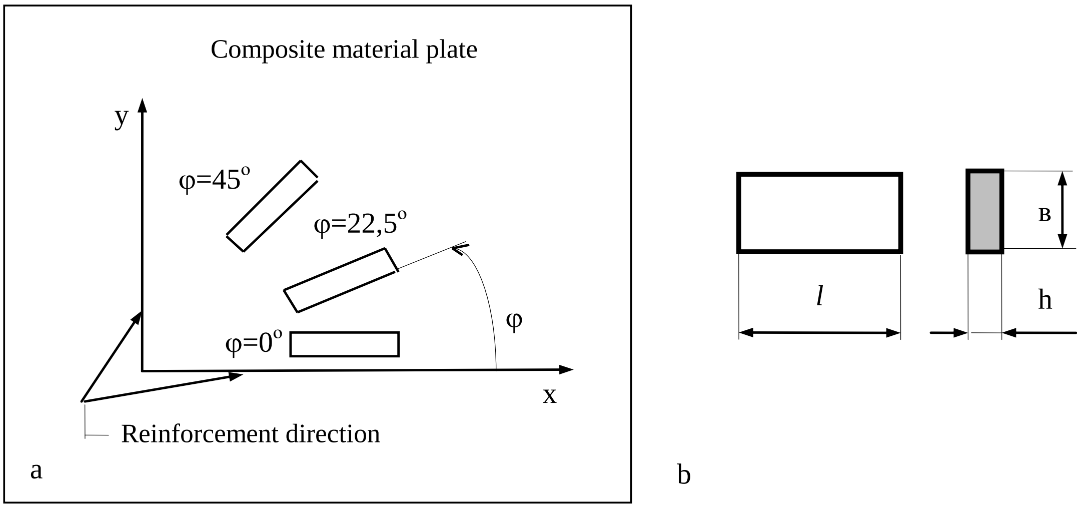


Figure 1.3 – Geometric parameters of samples:
a - cutting directions; b - shape of samples made of composite material

We conduct three experiments.

Experiment 1.

A sample with a cross-sectional area A is cut along the main axis of orthotropy X ($\varphi = 0^{\circ}$) and stretched by a longitudinal force P_x.

In this case, a linear stress state is realized at

$$\sigma_x = P_x / A,\ \sigma_y = 0,\ \tau_{xy} = 0. \tag{1.5}$$

Longitudinal ε_x and transverse ε_y deformations are recorded.

Let's substitute (1.5) into (1.1)

$$\begin{cases} \varepsilon_x = \dfrac{1}{E_x}\sigma_x, \\ \varepsilon_y = -\dfrac{\nu_{yx}}{E_x}\sigma_x = -\nu_{yx}\varepsilon_x. \end{cases} \tag{1.6}$$

From (1.6) we obtain

$$\begin{cases} E_x = \dfrac{\sigma_x}{\varepsilon_x}, \\ \nu_{yx} = -\dfrac{\varepsilon_y}{\varepsilon_x}. \end{cases} \tag{1.7}$$

Experiment 2.

The sample, cut along the axis Y ($\varphi = 90^0$), is stretched by force P_y and a linear stress state is realized

$$\sigma_x = 0,\ \sigma_y = P_y / A,\ \tau_{xy} = 0. \qquad (1.8)$$

Longitudinal ε_y and transverse ε_x deformation.

Substitute (1.8) into (1.1)

$$\begin{cases} \varepsilon_y = \dfrac{1}{E_y}\sigma_y, \\ \varepsilon_x = -\dfrac{\nu_{xy}}{E_y}\sigma_y = -\nu_{xy}\varepsilon_y. \end{cases} \qquad (19\ )$$

From (1.9) we obtain

$$\begin{cases} E_y = \dfrac{\sigma_y}{\varepsilon_y}, \\ \nu_{xy} = -\dfrac{\varepsilon_x}{\varepsilon_y}. \end{cases} \qquad (1.10)$$

Thus, from the first two experiments, four characteristics are found E_x, E_y, ν_{xy}, ν_{yx}, related to each other by equality (1.2). It remains to be determined G_{xy}.

Experiment 3.

The sample is cut at an angle $\varphi = 45^0$ and loaded with a longitudinal force P_{45}. A linear stress state is realized

$$\sigma_1 = \sigma_{45} = P_{45} / A,\ \sigma_2 = 0,\ \tau_{12} = 0 \qquad (1.11)$$

and the longitudinal deformation $\varepsilon_1 = \varepsilon_{45}$ in the direction of the cutting angle $\varphi = 45^o$ is recorded.

Substitute (1.11) into (1.3) and get

$$\varepsilon_{45} = A_{11}\sigma_{45}. \qquad (1.12)$$

From (1.12) we obtain

$$A_{11} = \varepsilon_{45} / \sigma_{45} = 1 / E_{45}, \qquad (1.13)$$

where E_{45} – the modulus of elasticity at an angle $\varphi = 45^0$.

Let us use the first relation of system (1.4) and at $\varphi = 45^0$ we obtain

$$\frac{1}{E_{45}} = A_{11} = \frac{1}{4E_x} + \frac{1}{4}\left(\frac{1}{G_{xy}} - \frac{2\nu_{yx}}{E_x}\right) + \frac{1}{4E_y}. \tag{1.14}$$

From (1.14) we obtain

$$G_{xy} = \frac{1}{\frac{4}{E_{45}} + \frac{2\nu_{yx}}{E_x} - \frac{1}{E_x} - \frac{1}{E_y}}. \tag{1.15}$$

Knowledge of all five elastic characteristics E_x, E_y, $\nu_{xy}, \nu_{yx}, G_{xy}$ based on (1.4) allows to determine the elastic modulus at any angle φ

$$E_\varphi = \frac{\sigma_1^{(\varphi)}}{\varepsilon_1^{(\varphi)}} = \frac{1}{A_{11}^{(\varphi)}}. \tag{1.16}$$

Specimens and equipment

The work is performed on flat samples measuring 2 x 15 x 300 mm, cut from fiberglass plates at different angles $\varphi = 0^0$, 15^0, 45^0 with respect to the direction of the base of the reinforcing fabric (axis X) in the material. Fiberglass is called EF-TS-V and is a layered material based on TS-10 fiberglass and an epoxyphenol binder. The plate consists of 8 layers with a thickness $h_{сл}$ = 0.25 mm. Slab thickness $h_{пл}$ = 2 mm. The testing machine scheme is shown in Figure 1.4.

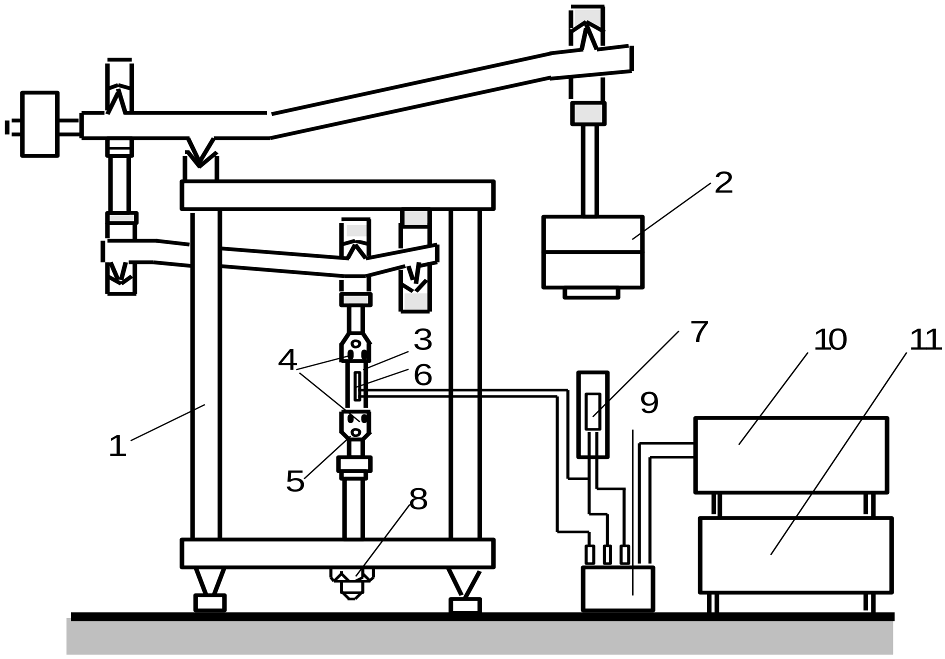


Figure 1.4 – Testing machine scheme:

1 – lever loading device, 2 – weights, 3 – specimen, 4 – grippers, 5 – pins, 6 – active strain gauge, 7 – compensation strain gauge, 8 – adjusting nut, 9 – block for connecting strain gauges, 10 – strain gauge station, 11 – recording device

The samples are loaded on lever devices with a maximum force P_{max} = 500 N with a testing machine gain factor of 50.

Deformations are measured using strain gauges glued to the samples, the signal from which is recorded using strain gauge stations TA-5 or 8ANCH-23 (Fig. 1.5).

Laboratory work procedure and processing of results

Test sample 3 with strain gauges 6 glued to it is installed on the loading device (Fig. 1.4).

When the adjusting nut 8 is loosened, the lever system should be in a balanced position so that the upper arm of the loading device remains in a horizontal position.

The balance position is adjusted by moving a special counterweight located on the upper lever.

By rotating the adjusting nut, the gap in the sample loading chain is eliminated.

Active 6 and compensation 7 strain gauges are connected to block 9 using a half-bridge circuit (Fig. 1.4, 1.5). The necessary measurement limits are established on the strain gauge equipment and the recording device.

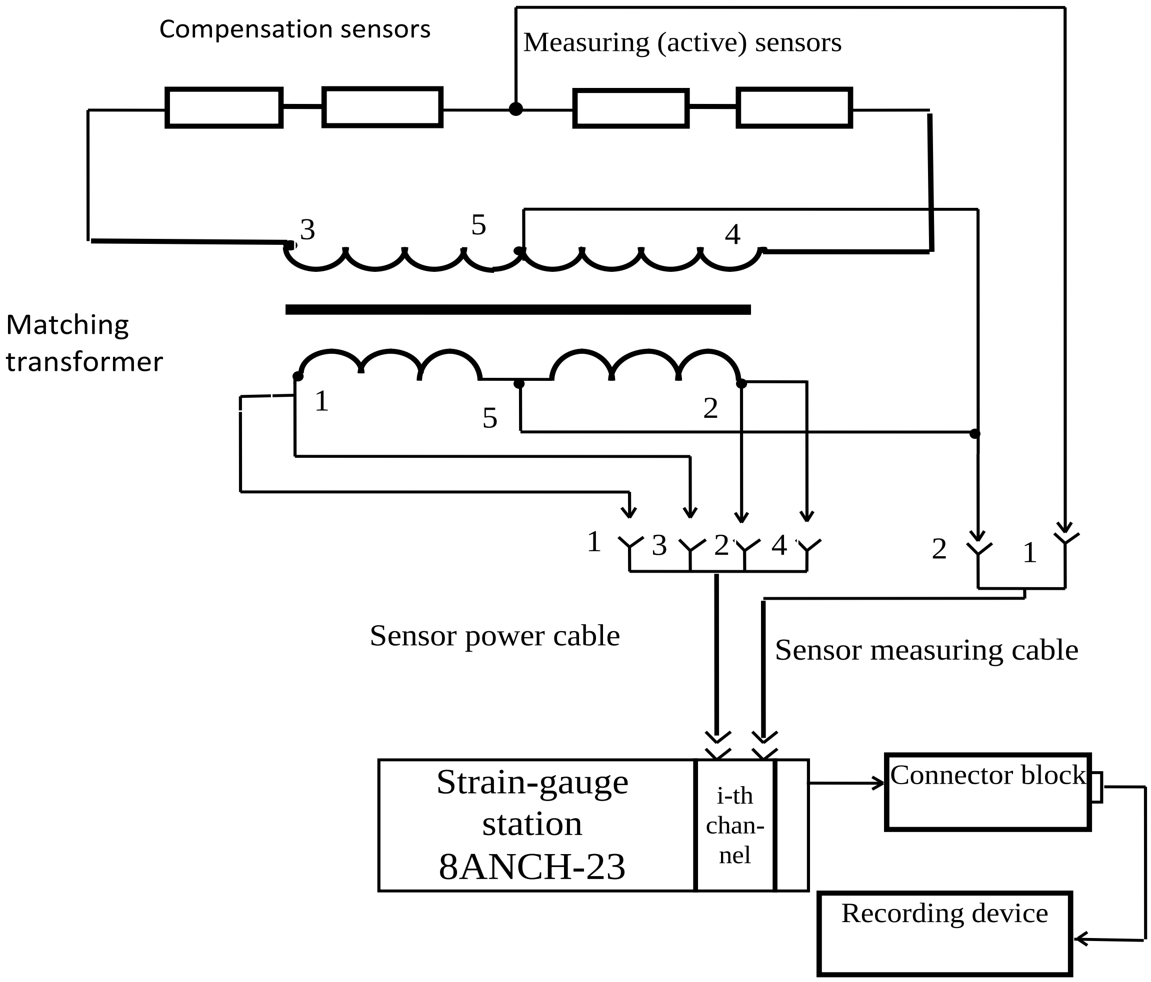


Figure 1.5 - Connection diagram of strain gauges to strain gauge station 8ANCH-23

The loading of the samples is stepwise, with equal load increments, carried out by installing weights 2 (Fig. 1.4) on the load receiver of the loading device. 5 - 6 loading stages are implemented.

With the weight of the load Q_i the sample is stretched by force

$$P_i = K_\text{p} Q_i,$$

Where K_p – load device gain (K_p = 50).

Tensile stresses arise in the sample

$$\sigma_i = P_i / A,$$

Where A – cross-sectional area of the sample.

Values P_i and σ_i are entered into table 1.1.

Deformations can be recorded in two directions: along and across the longitudinal axis of the sample (Fig. 1.6).

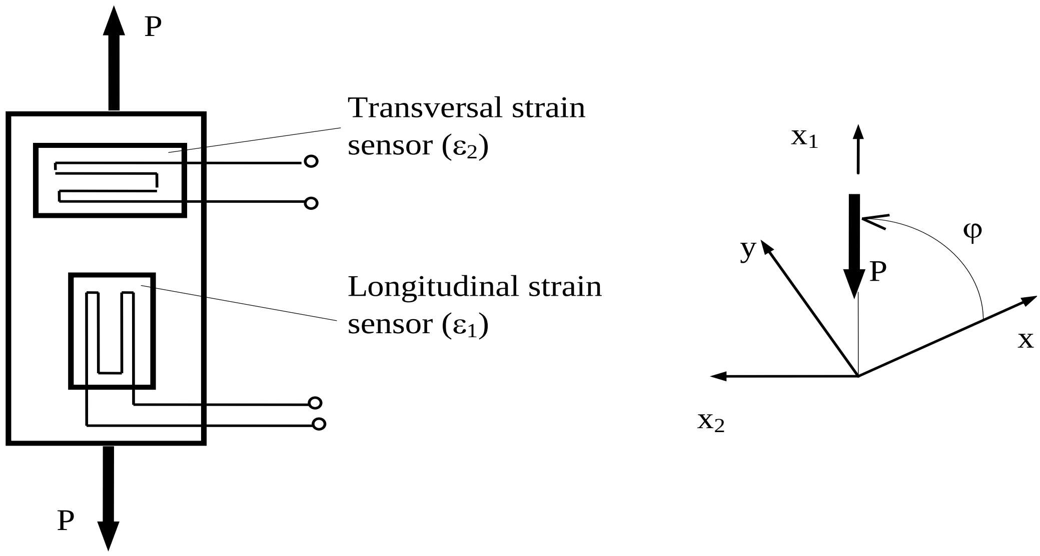


Figure 1.6 - Scheme for measuring longitudinal ε_1 and transverse ε_2 deformations for sample cut at an angle φ to the direction of reinforcement (*X,Y axis*)

Relative deformation measurement

Deformations are measured by strain gauges glued to the samples, the signal from which is amplified by strain amplifiers TA-5 or 8ANCH-23 and recorded on a digital voltmeter.

The deformation values when using the TA-5 strain amplifier are determined by the formula

$$\varepsilon = \frac{2\varepsilon_k A_i}{s_T A_k} \text{[rel. units]}, \tag{1.17}$$

where are

A_i – the recorder indications when reading the measured signal;

$$A_i = A'_i - A'_0,$$

A'_i – recorder indications at the current value of the measured signal;

A'_0 – recorder indications at the initial value of the measured signal;

ε_κ –calibration strain values $\left(\varepsilon_\kappa = 8,6 \cdot 10^{-3}\right)$;

s_T – strain gauge sensitivity coefficient $\left(s_T = 2,16\right)$;

$A_\kappa = A_{\kappa'} - A_{k0}$ with notation:

$A_{\kappa'}$ – recorder indications when counting the control signal in "K" mode;

A_{k0} – recorder indications when counting the control signal in mode "0".

Let us represent formula (1.17) in the form

$$\varepsilon = K_\varepsilon A_i \text{ [rel. units] }, \tag{1.18}$$

Where

$$K_\varepsilon = \frac{2\varepsilon_\kappa}{s_T A_\kappa}. \tag{1.19}$$

The deformation values when using 8ANCH-23 strain gauge equipment are determined by the formula

$$\varepsilon = 2{,}83 \frac{4 A_i K}{A_\kappa \Pi s_T K_D} \varepsilon_\kappa \text{ [rel. units]}, \tag{1.20}$$

Where

K – coefficient determined by marking the limit at which the measurement was carried out;

P – is the number of active bridge arms (P = 1);

K_D – the value of the additional gain when operating in the “St-Dyn K ≥ 1” and “Dyn” modes;

By analogy with (1.18), we represent formula (1.20) in the form

$$\varepsilon = K_\varepsilon A_i \text{ [rel. units] }, \tag{1.21}$$

Where

$$K_\varepsilon = \frac{4K}{A_\kappa \Pi s_T K_D} \varepsilon_\kappa . \tag{1.22}$$

During testing for a specific strain gauge amplifier, the values of the coefficients are determined $\varepsilon_k, A_{k'}, A_{k0}, K_\varepsilon$ and are entered into table 1.1. The measured values A'_i are also entered into table 1.1 and the deformation values ε_i can be calculated for two directions $\varphi = 0^o$ and $\varphi = 90^o$, which correspond to the deformations, respectively $\varepsilon^{(1)}$ and $\varepsilon^{(2)}$. Then, diagrams $\sigma \sim \varepsilon^{(1)}$ and $\sigma \sim \varepsilon^{(2)}$ corresponding material deformation are constructed. On the diagram $\sigma \sim \varepsilon^{(1)}$ straight section is selected and the elastic modulus is determined using the formula

$$E_{11} = E_\varphi = \frac{\sigma_\kappa - \sigma_н}{\varepsilon_\kappa^{(1)} - \varepsilon_н^{(1)}}, \tag{1.23}$$

where is σ_κ , $\varepsilon_\kappa^{(1)}$ –the stress and strain corresponding to the end of the section;

$\sigma_н$, $\varepsilon_н^{(1)}$ –stress and strain corresponding to the beginning of the section.

In addition, the Poisson ratio can be determined

$$\nu_{21} = -\frac{\varepsilon_{к}^{(2)} - \varepsilon_{н}^{(2)}}{\varepsilon_{к}^{(1)} - \varepsilon_{н}^{(1)}}. \tag{1.24}$$

Report requirements

The report should reflect the purpose of the work, contain a brief description of the testing equipment and samples, and include the main provisions of the methodology for conducting experiments and processing the results.

Particular attention should be paid to the correct inclusion of experimental data and the results obtained from them in the report.

The report should present conclusions.

Control questions

1. Define isotropic and anisotropic material.
2. Why are composite materials anisotropic?
3. What material is called orthotropic?
4. What form does the generalized Hooke's law have for an orthotropic composite material?
5. What elastic characteristics are necessary to describe the elastic properties of an orthotropic composite material?
6. What type of loading is implemented when determining the elastic characteristics of orthotropic fiberglass?
7. What equipment is used to determine the anisotropy of the elastic properties of fiberglass?
8. How are deformations on the surface of a sample measured?

Table 1.1

Sample cutting angle φ = ______, cross-sectional area A = ______,								
Strain measuring modes: along the sample A_{ko} = ______, $A_{k'}$ = ______, ε_k=______, K_ε=______; A_o^1=______;								
across the sample A_{ko} = ______, $A_{k'}$ = ______, ε_k=______, K_ε=______; A_o^1=______;								
	Pi , N	$\sigma_i = P_i/A$, Pa	Along the sample axis			Transverse to the sample axis		
			A_i^1	$A_i = A_i^1 - A_o^1$	$\boldsymbol{\varepsilon}_i^{(1)} = K_{\boldsymbol{\varepsilon}} A_i$	A_i^1	$A_i = A_i^1 - A_o^1$	$\boldsymbol{\varepsilon}_i^{(2)} = K_{\boldsymbol{\varepsilon}} A_i$
0								
1								
2								
3								
4								
5								

LABORATORY WORK №2

FLEXURAL TESTING OF COMPOSITE FIBROUS MATERIALS

Purpose of the work

Experimental study of a method for testing specimens made of composite materials for bending.

Determination of the elastic modulus at three-point transverse bending

Brief theoretical information

When calculating the bending rigidity of structural elements made of CM, it is necessary to know the bending modulus of elasticity. For isotropic materials, the modulus of elasticity in bending practically coincides with the longitudinal one in tension. For layered CMs, the flexural modulus of elasticity is, as a rule, less than the longitudinal modulus of elasticity. The reason is that the deflection during transverse bending of a laminated plastic consists of the deflection from the bending moment and the deflection caused by shear deformations from tangential interlayer stresses. Therefore, when determining the deflection of a layered element during transverse three-point bending, it is necessary to use the appropriate elastic modulus.

Bending modulus E_b (Pa), calculated by the formula

$$E_b = \frac{\Delta F \ell^3}{4bh^3 \Delta\omega}, \tag{2.1}$$

where is ΔF – the load increment (N),

ℓ – distance between supports (m),

b,h – width and height of the sample (m),

$\Delta\omega$ – increment of deflection in the middle of the sample corresponding to ΔF (N).

The tensile strength for transverse three-point bending σ_{ub} (Pa) is calculated using the formula

$$\sigma_{ub} = \frac{M_b^{\max}}{W_x},$$

Where $M_b^{\max} = \dfrac{F_{\max}\ell}{4}$ – maximum bending moment,

$W_x = \dfrac{bh^2}{6}$ – axial moment of resistance of the sample section.

Then

$$\sigma_{ub} = \frac{1,5F_{\max}\ell}{bh^2}, \qquad (2.2)$$

where $F_{\max}$ is the maximum load preceding the failure of the sample (N).

To determine the maximum breaking stresses and elastic modulus, a flat sample of rectangular cross-section is used. The shape and dimensions of the sample are shown in Figure 2.1.

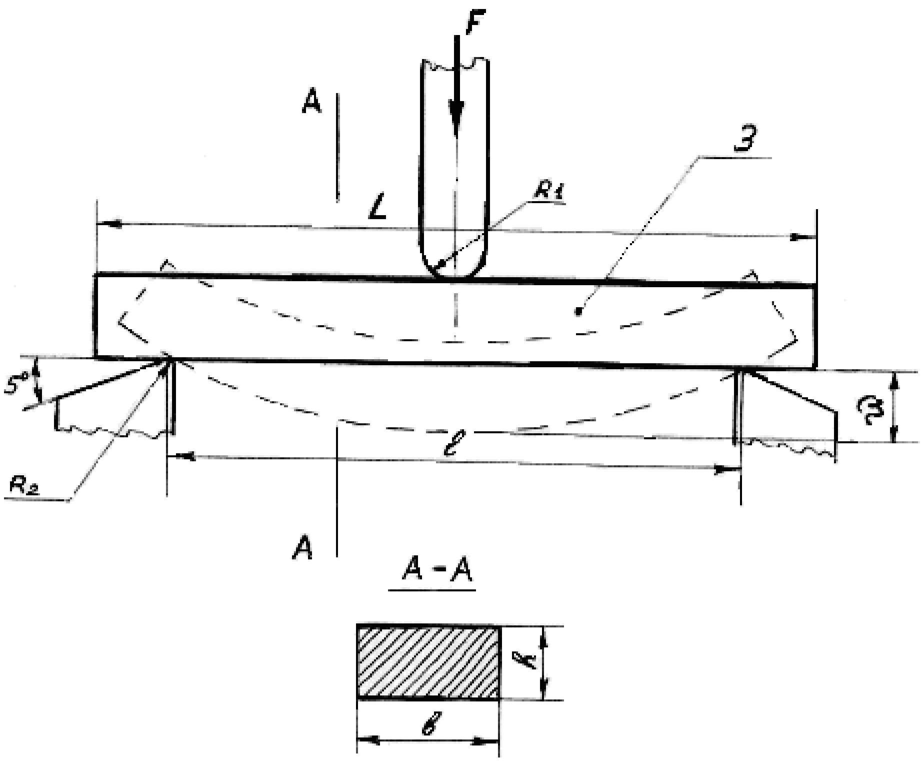


Figure 2.1 - Sample and bending scheme

Samples are molded or cut from plates in the direction of the main orthotropic axes of the material. The location of the reinforcement fibers must be symmetrical relative to the median plane of the sample, passing through its axis and parallel to the plane of the reinforcement layers stacking.

Samples must have a smooth, even surface, no rougher than $Ra = 20$ mcm in accordance with GOST 2789-73, without swelling, chips, cracks, delaminations and other defects visible with the naked eye.

The deviation of samples from the nominal dimensions in width and thickness should not exceed 0.05 mm.

Experiment

Test a laminated plastic sample for three-point bending:

– Determine the elastic modulus of the sample material during bending.

– Determine the tensile strength of the sample material in bending.

– Prepare a report according the results of laboratory work.

Guidelines for completing the task and processing the experimental results.

Equipment used

The work is performed on a machine for bending testing of plastics. Type *AS -102 (MH -1),* made in Hungary, providing: bending loading at a given constant speed, load measurement with an error of no more than 1% of the measured value, the ability to regulate the speed of sample loading.

The loading scheme is shown in Figure 2.1. In the middle of the sample, placed on two supports, a constantly increasing load is applied. At the moment of destruction, the effective force and deflection are determined.

The design of the apparatus is shown in Figure 2.2. Loading device (1), object table (2), support columns (4), force measuring device (5), deflection meter (installed separately) (6).

Operation of the device

The oil pump (8), driven by an electric motor (7), supplies oil to the cylinder (9). In this case, the piston (10) moves. An object table (2) is attached to the piston rod, on the supports (11) of which the sample (3) is installed. When the sample comes into contact with the pressure head (12), the bending test begins. Under the influence of the force generated when the pressure head is pressed on the sample, the sample bends, and the pressure head with its other end deflects the pendulum (13). The amount of deflection is determined by the indications of the meter device (6) installed on the pressure head. The force measuring device (5) shows the instantaneous load force as follows: the pendulum (13) moves the rack

(14), while the rack rotates the gear (15), with an arrow attached to it on the same axis, moving on a circular scale. The rack path changes linearly with force. The division of the circular scale is uniform.

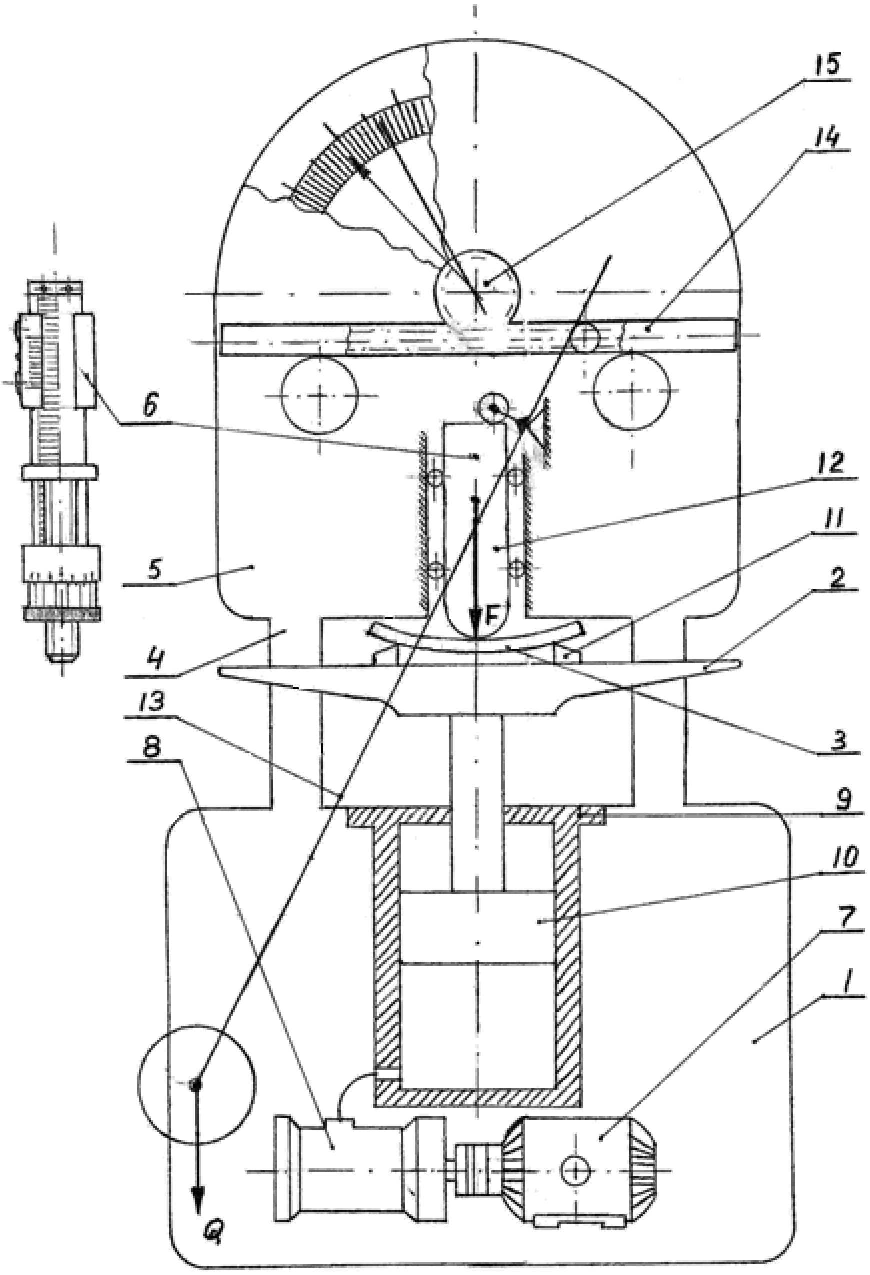


Figure 2.2 - Device design

Technical data:

measurement limits 100-500N (10-50kg),
force meter accuracy ±1%,
maximum measurable deflection 20 mm,
maximum sample thickness 45 mm,
distance between supports 20-300 mm,
speed of the object table 6-360 mm/sec,

R_1 radius of the pressure head (12) – 4mm,
R_2 radius of support (11) – 1mm,
the downward movement of the table is fast, without speed control.

When the sample is destroyed, the pendulum, under the action of a hydraulic brake, returns to its original position smoothly, without oscillation.

Deflection meter:

Deflection measuring accuracy – 0,025 mm,

The accuracy of the sample thickness scale is 0,025 mm.

The meter device hull is installed on the pressure head. The rack maintains the achieved position due to friction. It moves due to a lever in the object table. At the moment of destruction of the sample, the lever falls. Before the next measurement, the lever is raised by hand.

Device control panel (Fig. 2.3):

"start", "stop" buttons and general power supply toggle switch (16),

reverse valve for "up" and "down" table movement (17),

valve for regulating table speed during upward movement (18),

"stop" button, in the center of the control panel, to instantly stop the piston (while pressing this button, the piston does not change its position) (19).

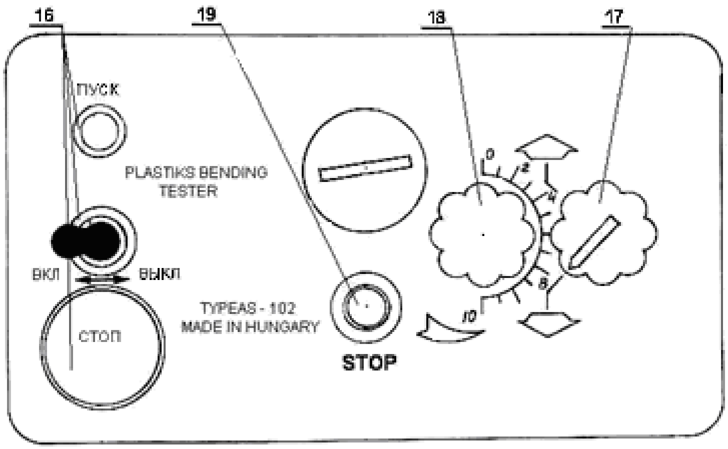


Figure 2.3 - Control panel

Carrying out the test

Before testing, the samples are numbered with paint or a soft pencil. The thickness of the sample is measured with an error of no more than 0.05 mm and the width with an error of no more than 0.025 mm in three places of its working part. The arithmetic average values of the thickness and width of the sample are determined and the results are recorded in the test report.

A pressure head and supports are installed on the device. The lever that moves the rack tongue rises to a horizontal position.

The distance between the supports ℓ is set equal to $\mathbf{40h \pm 1.0mm}$ and is measured with an error of no more than 0.2 mm.

The sample is mounted on supports so that its axis and the longitudinal axis of the object table are parallel.

Tests are carried out at room temperature $20 \pm 2°C$. The toggle switch turns on, supplying general power. Then the reverse valve is set to the "up" position. Using the speed control valve, the preliminary speed of the table is set and the "start" button turns on the pump motor.

The speed of load application is established experimentally at $5 \div 20\ mm/min$ (depending on the properties of the material being tested).

When determining the elastic modulus, the sample is loaded at a constant speed according to a stepwise scheme. The magnitudes of the loads and the corresponding deflections at each loading stage are entered in Table 2.1. The number of loading stages must be at least 4, every $5-10\%$ of the maximum load preceding the failure of the sample. The ultimate load should not exceed 50% of the breaking load. If the diagram deviates from linear, the test is stopped and the sample is unloaded.

When determining the tensile strength, the maximum load preceding failure is recorded in Table 2.2.

Processing test results

The elastic modulus is determined using formula 2.1. Using the data in Table 2.1, a deformation diagram is drawn. The elastic modulus value is averaged.

$$\overline{E}_{ui} = \frac{1}{n}\sum_{i=1}^{n} E_{ui} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Pa}$$

Determination of tensile strength is carried out according to formula 2.2, using data from table 2.2. To obtain a value that corresponds to reality with a sufficient degree of accuracy, the number of tested samples must be at least 5. Then the average statistical value of the tensile strength for a particular material is found.

Table 2.1

No.	b	h	ℓ	ΔF	Deflection increase $\Delta\omega$	E_b
	m			N	m	Pa
0						
1						
2						
3						
4						
5						

Table 2.2

No.	b	h	ℓ	Fmax	Type of destruction; longitudinal delamination or transverse destruction	σ_{ub}
	m			N		Pa
0						
1						
2						
3						
4						
5						

Control questions

1. What is the modulus of elasticity of a laminate plastic under transverse three-point bending?
2. What assumptions are made when performing three-point bending tests?
3. What is the tensile strength for transverse three-point bending?

LABORATORY WORK №3

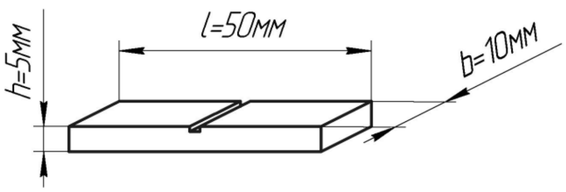
IMPACT TESTING OF COMPOSITE MATERIALS

1 **Purpose of work:**
Determination of the impact strength of a layered composite material.

2 **Object of study:**
Layered composite fiberglass with woven structure.

3 **Test equipment:**
Impact pendulum pile driver type TSV 1.5 (Maximum potential energy reserve 1.5 kg*m = 15 N*m).

4 **Test samples:**
Parallelepiped with dimensions $50 \times 10 \times 5$mm with notch



Specimen scheme

5 **Theoretical information:**

Impact strength is a measure of the energy absorbed per unit area of a material during rupture due to impact.

Impact strength characterizes the tendency of a material to undergo brittle fracture.

Composites have increased impact strength due to their heterogeneous structure, which resists crack growth more effectively than a homogeneous one.

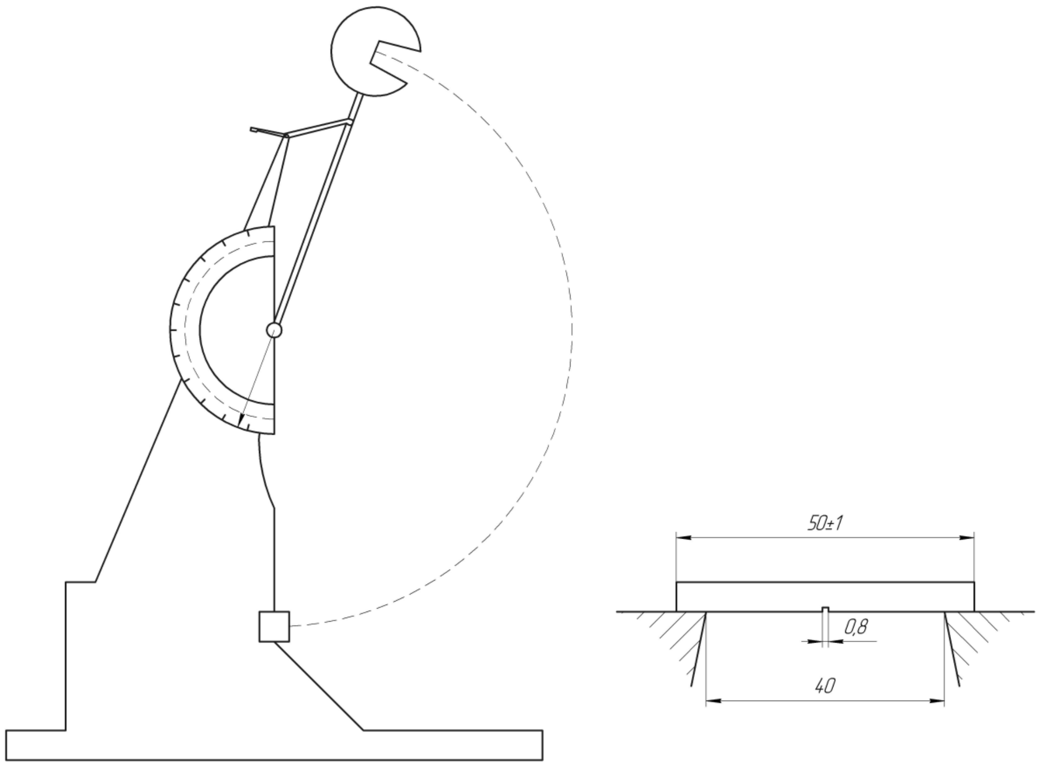
Impact strength is determined by the formula:

$$a = \frac{A_{dest}}{S},$$

where a is the impact strength, A_{dest} is the work of destruction, S is the cross-sectional area at the zone of rupture .

The work of destruction must be determined minus the work of friction forces, because otherwise, the material impact strength results will be overestimated.

6 **Test scheme:**



Testing scheme

7 Control questions

7.1 What is impact strength?
7.2 What characterizes impact strength?
7.3 Why do composites have high impact strength?
7.4 Why is it necessary to take into account the work of friction forces?
7.5 Why is a notch on the working part sometimes made on samples?

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LABORATORY WORKSHOP

by discipline
" Fundamentals of mechanics, design and manufacturing technology of products made of composite materials "

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