

MINISTRY OF EDUCATION OF REPUBLIC OF BELARUS

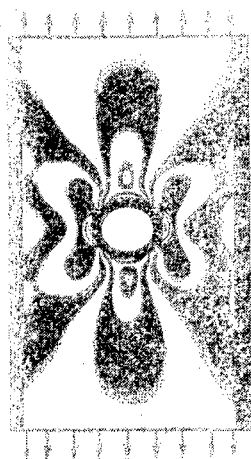
**ESTABLISHMENT OF EDUCATION
"BREST STATE TECHNICAL UNIVERSITY"**

DEPARTMENT OF APPLIED MECHANICS

LABORATORY WORKS ON RESISTANCE OF MATERIALS

For students day studies faculty of industrial and civil engineering

Part 1



Brest 2017

When studying resistance of materials the experiment plays extremely important role. It gives the chance to receive the mechanical characteristics of materials necessary for creation of the theory of calculations on strength. With the help of the experiment the check of theoretical conclusions and formulas of materials resistance is made. Usually these conclusions and formulas turn out on the basis of assumptions (hypotheses) and therefore demand check on experience.

The main objective of methodical instructions is to help students with their independent preparation for laboratory works. It is published in two parts. Part I.

Authors: A. Zheltkovich, associate professor
A. Veremeichik, associate professor
V. Hvisevich, professor

CONTENTS

1. Introduction	3
2. Accident prevention	3

Laboratory researches

Part I. Determination of physical and mechanical characteristics of materials

Work No. 1	4
Work No. 2	8
Work No. 3	13
Work No. 4	15
Work No. 5	21
Work No. 6	23
Work No. 7	26
Work No. 8	29

1. Introduction

Resistance of materials is engineering science about strength, rigidity and stability of building constructions, elements mechanisms and machines. All constructions are made of real materials, each of which has its own physicommechanical characteristics.

The program of a course of strength of materials provides in parallel with studying of theoretical material, realization of a number of laboratory works. A part of these works is connected with studying of mechanical properties of materials, for realization of calculations on strength, rigidity and stability. The other part is devoted to experienced check of the calculated formulas received in the theoretical way.

A very important question is verification of the fundamental law of strength of materials the Hooke's law for different materials. Besides, on laboratory practicums a student gets acquainted with a technique and technology of carrying out tests of samples and structural elements, with measuring instruments and test machines. The completion of laboratory works is the report executed by the student in the established form with the subsequent defense.

2. Accident prevention

In the laboratory of department of Applied mechanics there is complex equipment with high voltage, life-threatening and also with a number of floor and desktop installations with relatively heavy loads which can lead to an injury.

For the purpose of accident prevention students are obliged to follow the following basic rules:

- 1) to fulfill requirements of the teacher and educational personnel of laboratory about observance of safety regulations;
- 2) to start performance of laboratory work only after permission of the teacher or educational personnel of laboratory;
- 3) it is forbidden to put self-willed in action mechanisms, to load installations;
- 4) when performing work not to be distracted by external actions;

5) at failure detection immediately to declare it to the teacher or educational personnel of laboratory;

6) it is forbidden to touch devices, installations and test machines on which this laboratory work isn't performed;

7) only the students informed of the provided requirements under the personal signature are allowed to laboratory works.

In laboratory works precise highly sensitive measuring instruments are used. For the purpose of prevention of their damage it is forbidden to regulate self-willed them or to rearrange.

LABORATORY WORK №1

Measuring instruments

When carrying out tests of samples and elements of constructions there is a necessity for measurement of their initial sizes and also the displacement and deformations caused by loading. The corresponding measuring instruments with the scale division (α) are used for this purpose.

For measurement of the sizes measured tapes ($\alpha=1\text{mm}$), calipers ($\alpha=0.05$ or 0.1 mm), micrometers ($\alpha=0.01\text{mm}$), and for measurement of displacement – needle indicators ($\alpha = 0.001$ and 0.01 mm) are used. Deformations in construction material which in an elastic stage are very small are measured by tensiometers of different designs mechanical and optical ($\alpha = 0.001$ mm) or electric ($\alpha = 0.001$ mm).

1. Caliper

The caliper is applied for measurement of external and internal dimensions of samples and parts. In laboratory practice calipers with a measurement limit to 125 mm and up to 500 mm with an accuracy of counting of 0,05 and 0,1 mm are used.

The caliper (fig. 1.1) consists of the bar 2 ending in sponges 1 – for measurement of external dimensions, and 3 – for measurement of internal dimensions, and a frame 4 (with the same sponges) which is freely moved on a bar.

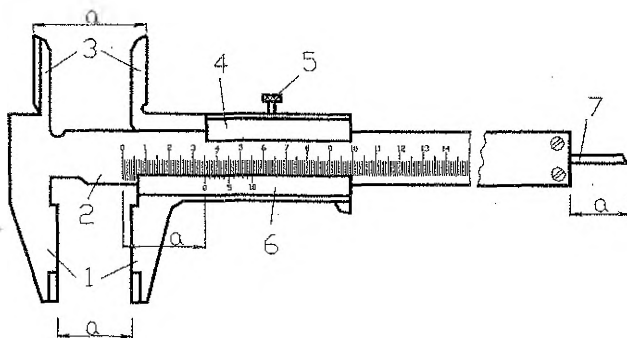


Fig. 1.1. Caliper of 0 – 125 mm:

1 sponges, 2 – crossbar, 3 – sponges, 4 – a frame, 5 – a stopper, 6 – the nonius,
7 – a ruler

On a bar 2 there is a scale with divisions from 0 to 125 mm through one millimeter, and on a frame 4 – ten divisions of the nonius 6 allowing to do counting with an accuracy of 0.1 mm are put. On the caliper back the ruler 7 sliding in a groove of a bar is attached to a frame 4 and designed for measurement of depths. The frame 4 is supplied with a stop screw 5 by which it is fixed on a bar not movably, if necessary to receive a size template. Calipers of other sizes with an upper limit more than 300 mm differ from described. They have one-sided sponges only for measurement of external dimensions.

2. Micrometer

Micrometers are designed for measurement of external dimensions with an accuracy of 0,01 mm. The micrometer (fig. 1.2) consists of a bracket 1 on which one end the heel 2 is established, on the other – there is a sleeve 5. In a sleeve the micrometer screw 3 moves set in motion by the drum 6. On a sleeve the longitudinal line and cross strokes through 1 mm are located. On the strokes located from longitudinal line down and noted by digits through each 5 mm the counting of the whole millimeters is made. The strokes which are carried out from longitudinal line up divide each millimeter of the lower scale in half.

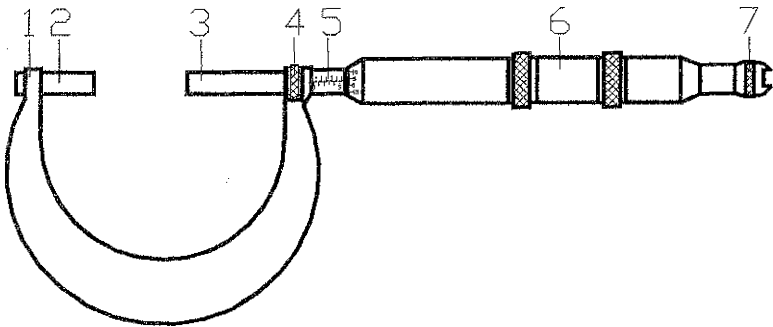


Fig. 1.2. Micrometer:

1 – a bracket, 2 – a heel, 3 – a micrometer screw, 4 – a stopper, 5 – a sleeve,
6 – a drum, 7 – a head with a ratchers

The drum comes to an end with a cone on which circle the scale from 50 equal divisions is located. The thread pitch of a micrometer screw is equal 0,5 mm. Therefore, at one turn of the drum a micrometer screw receive longitudinal displacement relative to the sleeve of 0,5 mm, and the scale of conic edge of the drum undergoes all 50 divisions. Thus, the scale of one division of a scale of a drum is 0.01 mm.

The 100-th portion of millimeter are read on a scale of conic edge of the drum 6 directly if the next to this edge is the lower cross stroke of a sleeve. If the edge of the drum has an upper cross stroke of a sleeve, then to number of the 100-th of millimeter, read on a drum, it is necessary to add 0.5 mm.

At micrometers with the lower limit of measurement equal to zero, at contact between a heel and the screw the conic edge of the drum coincides a zero stroke of a sleeve, and a zero stroke of a scale of a drum – longitudinal line of a sleeve.

The drum at the free end is supplied with a head 7 with a graggers. At rotation of a head the drum is rotated until the measured sample isn't clamped between the measuring surfaces of the screw end and a heel with a certain pressure then the head is turned with a graggers. The continuous effort of a micrometer screw is provided with it and influence of deformations of a sample on the accuracy of measurements is excluded.

The stop screw 4 is intended (designed) for motionless fixing of a micrometer screw at given size.

3. Needle indicator

The needle indicator (fig. 1.3) is intended for measurement of linear displacement of separate points of the samples, parts and constructions caused by their deformations.

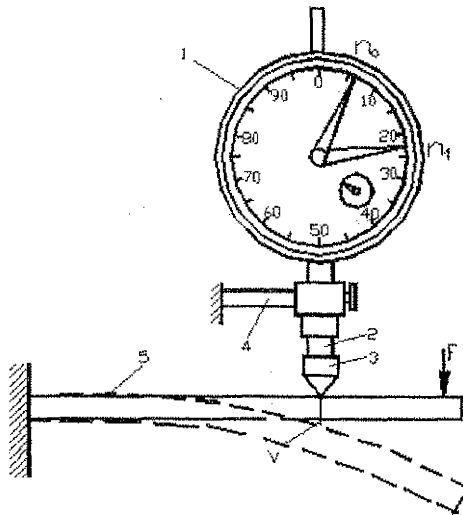


Fig. 1.3. Needle indicator:

- 1 – shell with a scale, 2 – contact rod, 3 – head, 4 – support,
5 – part (construction)

The scale of a small circle has 10 divisions, each of which corresponds to 1 mm of a contact rod. The scale of a big circle has 100 divisions with the scale of one division $\alpha = 1 \cdot 10^{-2}$ mm or $\alpha = 1 \cdot 10^{-3}$ mm. At turn of a small arrow on one division the big arrow of the indicator does a whole revolution.

For carrying out of the measurement the indicator is fixed by the shell to a fixed part of a construction or a support 4, and a head 3 touches a part 5 in a point which displacement is measured.

The measured displacement of a point of a construction is due to the indicator before and after deformation of a part of a construction.

$$V = (n_1 - n_0) \cdot \alpha_i = \Delta n \cdot \alpha_i,$$

V - the measured linear displacement, n_0 - counting on the indicator before deformation, n_1 - counting on the indicator after deformation, Δn - an increment of indications of the indicator, α - the unit of scale division of the indicator.

4. Electrotensiometers

The electric tensiometer is the device measuring relative linear deformation on a certain site of the construction by an electric method. It consists of three parts: strain gauge, amplifier and indicator. The strain gauge (or the sensor) is the sensitive element perceiving the measured deformation and transforming it to this or that electric parameter. Wire resistance strain gauges (tensoresistors) are often used.

The wire sensor (fig. 1.4a) is manufactured of a wire with a big unit resistance (a constantan, nichrom, etc.) diameter of $d = 0.02 - 0.05$ mm and represents a flat loop-shaped grid with contacts on the ends. The wire grid is glued on a thin rectangular strip of the special paper or a film 0.05 mm thick forming for a grid a basis and isolating it from material of the measured part.

Sensors of resistance are characterized by L_0 base (5 - 100 mm) and rated resistance of R (10 - 800 of Ohms).

The scheme of the four-shoulder bridge (Witstone bridge) consisting of four consistently connected sensors D_1, \dots, D_4 , power supply E and indicator U (fig. 1.4b) is most distributed in an electrotensometry..

One of sensors of the left shoulder of the bridge, for example, of D_1 is glued on the studied surface (the working sensor). To exclude influence of temperature, other sensor, for example, of D_2 , is placed on not deformed part of a construction (thermocompensatory) (see fig. 1.4c).

For measurement of deformation different electrometric devices are used.

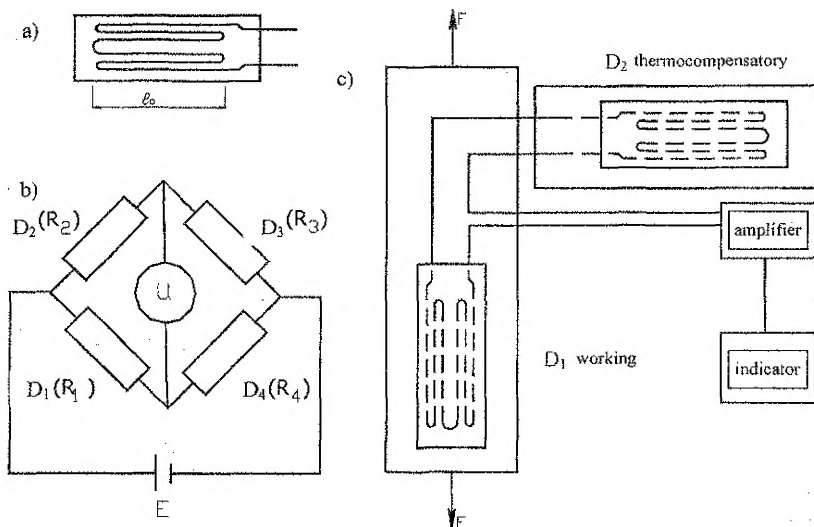


Fig. 1.4. Scheme of the electrotensiometer

LABORATORY WORK №2

Subject: "Testing of a steel sample for stretching".

I. Work purpose: Definition of mechanical characteristics and characteristics of ductility of low-carbon steel.

II. Content of work

For a research of different materials on stretching special samples are made. The sample has to possess such form that within a certain part of its volume during testing the central stretching was carried out. This part of a sample carries the name of a working part.

In order to test results, carried out by different laboratories, are possible to compare among themselves, types and the sizes of samples are established (GOST 1479-73).

Usually at tests the sample which computational length is accepted equal $10d_0$, where d_0 - diameter of a working part of a sample (fig. 2.1) is applied.

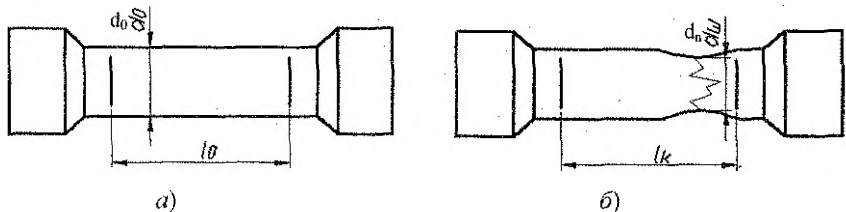


Fig. 2.1 a) sample for testing of metals at stretching;
b) the nature of destruction of a sample from ductile material

On a working part of a sample risks are caused to have an opportunity to judge about the change of length of a sample after experience.

Testing is made by the universal discontinuous machine (YMM-100). It is supplied with the self-recording device which automatically draws the diagram of stretching in a certain scale in coordinates $F - \Delta l$. At static tests on stretching the sample is deformed at smoothly increasing loading up to a rupture. The curve (it is automatically drawn) showing functional dependence between force of F acting on a sample, and the deformation of Δl (fig. 2.2).

It should be noted that this diagram (fig. 2.2) characterizes not properties of material, but property of a sample. To give the characteristic to properties of material, it is necessary to reconstruct the diagram of stretching $F - \Delta l$ in coordinates $\sigma = F/A_0$ and $\varepsilon = \Delta l/l_0$ where A_0 and l_0 - respectively the cross-sectional area and working length of a sample before loading. The diagram received this way is called the conditional stress-strain diagram.

At the beginning of testing on the diagram it is observed horizontal and curvilinear sites which are explained by elimination of gaps both in the machine mechanism, and between heads of a sample and captures of the machine. After this the curvilinear site observes rapid growth of loading. On the diagram the direct OA

corresponding to proportional dependence between loading and lengthening of a sample is drawn. To exclude the curvilinear site arising at elimination of gaps from the diagram it is necessary to continue the straight section corresponding to Hooke's law to abscissa axis. On their crossing we will receive a point O – the beginning of coordinates of our diagram.

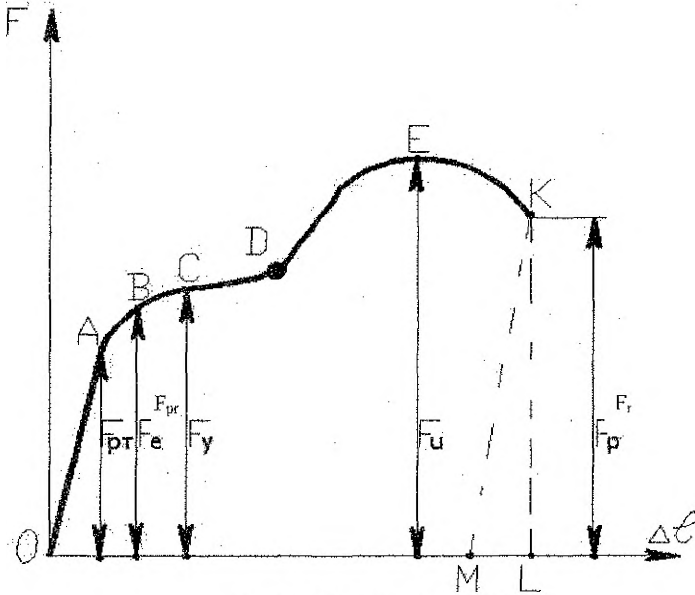


Fig. 2.2. Diagram of stretching

The straight section of the diagram goes to some point A behind which Hooke's law is terminated. The loading corresponding in a point A (F_{pr}) serves for calculation of a *limit of proportionality*. A limit of proportionality is called the maximum stress up to which the law of proportionality between stress and deformations is carried out.

$$\sigma_{pr} = \frac{F_{pr}}{A_0} \text{ [MPa]}. \quad (2.1)$$

If to suspend testing at loading less than F_{pr} and to unload a sample, then it is possible to notice linear dependence between loading and deformation when unloading which will be expressed by the same direct OA. Such situation remains to some limit – an *elasticity limit*. A limit of elasticity is the largest stress up to which there are only elastic deformations (according to some standards from 0,05 to 0,005%):

$$\sigma_e = \frac{F_e}{A_0} \text{ [MPa]}. \quad (2.2)$$

For the majority of materials the difference between a *limit of elasticity* and a limit of proportionality is insignificant and therefore one of them is often define.

On the site of the diagram behind a point C deformation will grow without noticeable increase of the stretching force.

The site of CD of the diagram is called a *yielding zone* which represents almost the straight line parallel to a deformation axis. In the period of yielding material undergoes the essential structural changes caused by shifts of separate particles of material. If the sample is rather smooth and polished, then in the period of yielding it is possible to notice tarnishing of its surface, and in magnifying glass it is possible to see a grid from the small lines inclined at an angle close to 45° as on these platforms acts τ_{\max} . These lines are the result of shift of particles of material of a sample and are called Chernov-Lyudersa's lines.

Force corresponding to a yielding zone on the diagram is denoted by F_y , and stress corresponding to it is called a *yielding limit*. The limit of yielding σ_y – is the stress at which the sample is deformed without increase in a tensile load:

$$\sigma_y = \frac{F_y}{A_0} \quad [\text{MPa}], \quad (2.3)$$

However not all materials have a pronounced (expressed) yielding zone on a stretching curve. Such materials as duralumin, alloyed steel, steel with the increased content of carbon and others, have almost no yielding zone. In this case it is recommended to define a so-called conditional limit of yielding it is the tension at which relative lengthening reaches 0,2% of length of a calculated part of a sample. Behind a yielding zone the loading begins to grow again as material was strengthened, got an opportunity again to resist the increasing loading. There is no direct proportionality any more, and the diagram has curvilinear character with a maximum in a point E. The greatest loading (F_u) which the sample at stretching can sustain carries the name *ultimate strength*, and the conditional stress (σ_u) corresponding to this loading is called the *ultimate resistance* or temporary resistance of material:

$$\sigma_u = \frac{F_u}{A_0} \quad [\text{MPa}]. \quad (2.4)$$

During the experience it is possible to observe that behind of *ultimate strength* the deformation in a sample extend not evenly on all volume, and concentrate in one section called a neck. The neck is a sharp narrowing of section in any place of a sample. At reduction of section smaller force for a rupture is required. Therefore behind ultimate strength decreases and destruction quickly occurs.

It should be noted that the true stress counted with taking into account neck cross-sectional area, all the time increases up to destruction of a sample:

$$\sigma_r' = \frac{F_r}{A_n} \quad [\text{MPa}], \quad (2.5)$$

where A_n – the area of a neck, F_r - loading at which there is a rupture of a sample (a point K of the diagram).

According to the diagram of stretching it is possible to count full lengthening of a sample at the time of a rupture, it will be expressed by a piece of OL (fig. 2.2). To allocate only residual or only elastic deformations, it is enough from a point K the diagram of stretching (fig. 2.2) to draw the straight line parallel to a straight section of the diagram OA. Then the piece of OM will represent residual deformation of a sample, and a piece of ML elastic one. Elastic deformations disappear at the time of a rupture of a sample, and residual remain thanks to what the lengthening received by

direct measurement of the broken-off sample, corresponds to a piece of OM of the diagram.

The nature of destruction of a sample from ductile material (fig. 2.1b) is interesting.

In the place of a rupture "a cup" which bottom is perpendicular to a sample axis, and edges are inclined at an angle $\alpha = 45^\circ$ to its axis is formed. This results from the fact that in the plane of transverse section of stress are distributed under the difficult parabolic law with a maximum on a sample axis. Therefore the rupture of a sample begins in the central part. The remained ring part of a sample collapses from the largest tangent stress.

Except mechanical characteristics of material, by results of rupture test characteristics of plasticity are also defined: relative lengthening after the rupture and relative narrowing of a sample.

Relative lengthening:

$$\delta = \frac{l_1 - l_0}{l_0} \cdot 100\%. \quad (2.6)$$

For determination of length of a rated part of a sample after a rupture both of its parts densely connect and the measurement is made.

Relative narrowing:

$$\delta = \frac{A_0 - A_n}{A_0} \cdot 100\%, \quad (2.7)$$

where A_n – the area of a neck.

For definition of A_n both parts of a sample after a rupture densely connect and the minimum diameter of a neck is measured in two mutually perpendicular directions, then as an arithmetic average of these two measurements, the area of a neck of A_n is calculated.

III. Order of carrying out tests

1. Measure diameter of a sample (before testing) by a caliper and results of measurements enter in table 2.1.
2. Calculate the initial area of a working part of a sample of A_0 .
3. Apply strokes, denoting the computational length of a sample $l_0 = 10d_0$.
4. Establish samples in captures of the discontinuous machine.
5. Load samples and watch the drawn diagram; loading increases to final fracture of a sample.
6. In the course of loading values of the loadings corresponding to characteristic points on the diagram in table 2.1 are entered.
7. Measure the sample sizes after a rupture and enter them in the table.

IV. Processing of results of an experiment

1. Note on the diagram the characteristic points corresponding to loadings of F_{pr} , F_y , F_n , F_r .
2. Establish diagram scale.
3. Calculate mechanical characteristics of σ_{pr} , σ_y , σ_u , σ_r , σ_r^t . The results are entered in tab. 2.1.

4. Measure distance between strokes after a rupture of a sample of l_1 , densely add two of its parts and also the diameter of a neck of d_n .

5. Calculate relative residual lengthening of a sample and results of calculations enter in table 1.

6. Calculate relative residual narrowing of cross-sectional area in the place of a rupture of a sample and results of measurements enter in table 2.1.

7. Build the diagram of conditional stress (fig. 2.3).

Table 2.1.

material	Sample size						F_{pr} N	F_y N	F_u N	F_r N	Mechanical characteristics				Characteristics plasticity	
	Before experience			After experience							σ_{pr}	σ_y	σ_u	σ_r	δ %	ϕ %
	d_s m	l_o m	A_0 m ²	d_n m	l_1 m	A_n m ²					MPa					
steel																

By the results received from the experience it is possible to judge about the quality of the material. Using help data on mechanical characteristics, brand of material is established and according to it decide in what designs this material can be applied.

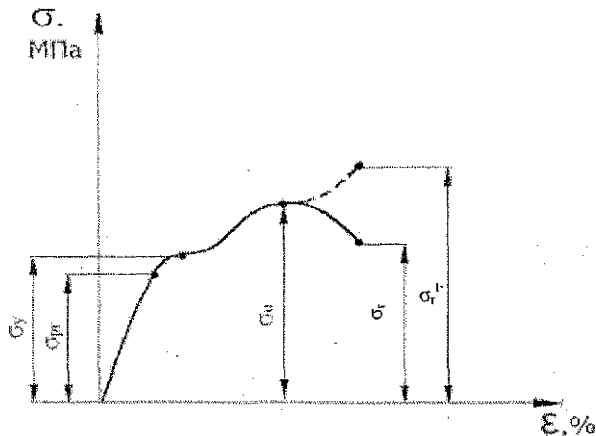


Fig. 2.3. Diagram of conditional stress

Control questions

1. What requirements are imposed to the sizes of an experimental sample?
2. Call the mechanical characteristics of *strength* and *ductility* known to you. Give their definitions.
3. How did you define mechanical characteristics of strength and *ductility* after carrying out experience?
4. Did you receive true or conditional values of stress at calculation of mechanical characteristics of strength?

5. Show the diagram of the true and conditional stress corresponding to the experiment.

6. How to determine the size of residual and elastic deformation at any moment of testing by the diagram of stretching of a sample?

7. How residual deformations were distributed longwise a sample until the neck began to develop?

8. What is the strengthening phenomenon essence? Show the diagrams of stretching of not riveted and riveted material on the example of the experiment.

LABORATORY WORK № 3

Subject: "Experimental determination of the module of longitudinal elasticity and lateral (transversal) deformation coefficient (Poisson's coefficient)".

I. Work purpose: Acquaintance with a technique of experimental determination of the module of elasticity E and Poisson's coefficient of ν .

II. Content of work

The *module of elasticity* E at stretching is called the proportionality coefficient between normal stress of σ and the relative lengthening of ϵ corresponding to it:

$$\sigma = E\epsilon.$$

The module of elasticity E reflects the material elasticity to elastic deformations at stretching (compression). The more this value, the less is stretching (compression) of a rod with other things being equal (length, cross-sectional area A , force F). It follows from the formula expressing Hooke's law:

$$\Delta l = \frac{F \cdot l}{E \cdot A}.$$

The module of elasticity E is one of the main elastic characteristics of material. It is important for calculation of elastic deformations of different elements of constructions.

The module of elasticity is from dependence:

$$E = \frac{F \cdot l}{\Delta l \cdot A} = \frac{F}{\epsilon \cdot A}. \quad (3.1)$$

Lateral (transversal) deformation coefficient or Poisson's coefficient ν is called the relation on the module of relative lateral (transversal) deformation of a sample at stretching or compression (ϵ') to its relative longitudinal deformation (ϵ), found in proportionality limits:

$$\nu = \left| \frac{\epsilon'}{\epsilon} \right| = \left| \frac{\Delta b \cdot l}{b \cdot \Delta l} \right|, \quad (3.2)$$

where b – sample section width; l – computational length of a sample. This relation for each material within elasticity is a constant. E and ν characterize elastic properties of material.

In this work for testing the sample of rectangular lateral section is used. The module of elasticity E and Poisson's coefficient ν are kept by the constant values so

far Hooke's law is carried out. Then the value of a maximum load is defined from a ratio:

$$F_{\max} < \sigma_{pr} \cdot A$$

Having set by number of loadings of n , it is possible to count a loading interval

$$\Delta F = \frac{F_{\max}}{n}$$

For determination of the module of elasticity E and Poisson's coefficient of ν the experiment can be used: absolute longitudinal and absolute lateral deformations are measured by indicators of hour type (*needle indicator*). At the same time for definition of absolute lateral (transversal) deformation which always less than longitudinal, is installed the indicator of hour type (*needle indicator*) 2 with smaller scale of division (0,001 mm), than the indicator 1 for measurement of absolute longitudinal deformation with scale of division (0,002 mm). The scheme of installation for definition of the module of elasticity E and Poisson's coefficient of ν is shown in fig. 3.1.

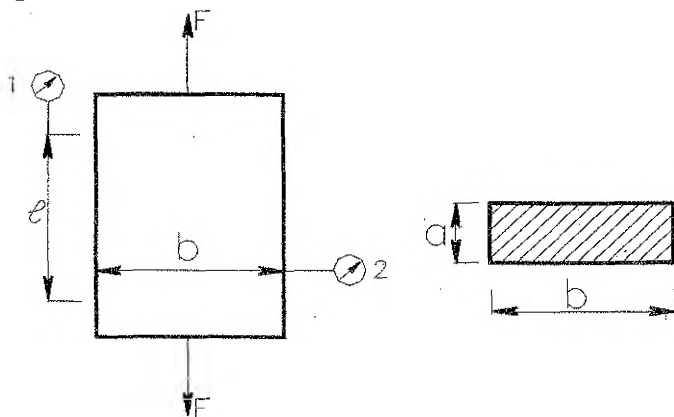


Fig. 3.1 Scheme of installation.

III. Sequence of carrying out experiment

The sizes of section of a sample of b and a , computational length of L are measured. The size of a maximum load is defined: $F_{\max} = \sigma_{pr} \cdot A$; are set by number of loadings and count a loading interval.

The sample is fixed in captures by the experienced load equal (0,1 – 0,2) F_{\max} for elimination of influence of slipping and clamping of a sample. This loading is accepted conditionally to zero.

At initial loading the first counting on indicators 1 and 2 (fig. 3.1) is made. By the indicator 1 absolute longitudinal deformation of Δl are determined, and by the indicator 2 – absolute lateral (the transversal) deformation of Δb . Then loading is increased by equal steps so that the number of steps of loading was equal n . Counting on indicators is made for each step of loading and the results are registered in the magazine of observations (table 3.1).

IV. Processing of results of an experiment

Graphs are drawn $F=f(\Delta l)$ according to experience which visually illustrates direct proportionality between loading and the deformation of a sample.

For each step of loading determine both the module of elasticity E (by formulas 3.1) and Poisson's coefficient of ν (3.2) are determined and the results in table 3.1 are entered.

Table 3.1.

material	Sample sizes			A m^2	F N	Absolute deformation		E MPa	ν	E_{cp} MPa	ν_{av}
	a (m)	b (m)	l (m)			Δl (m)	Δb (m)				
1	2	3	4	5	6	7	8	9	10	11	12
Steel											
Rubber											
Pith tree	d (m) =		l (m) =								

Control questions

1. What elastic constants are defined in this work? Give their definitions.
2. Describe a technique of carrying out the experiment by definition of elastic constants of material.
3. How it is possible to confirm that in the course of testing only elastic deformations take place and that Hooke's law isn't violated?
4. What is the formula for determination of coefficient of Poisson?
5. How when processing results the module of longitudinal elasticity of material of a sample is counted?

LABORATORY WORK №4

Subject: "Testing of materials for compression".

I. Work purpose: Studying of properties of ductile, brittle and anisotropic materials at compression test.

II. Work content

Not all materials to the same extent resist stretching and compression. Such materials as cast iron, a timber, a stone badly resist stretching, but very well work for compression. It is necessary to make tests for compression for obtaining mechanical characteristics of brittle and anisotropic materials. And the timber as anisotropic material, is tested on compression lengthwise and crosswise of fibers. When testing brittle materials *ultimate strength* is defined. It has great practical value as such materials are usually applied to production of the parts undergoing compression deformation.

Ductile materials are seldom tested on compression, generally with the research purpose (GOST 25503-80). The phenomenon of simple compression can be received only in rather short samples. In long samples along with compression there can be a so-called longitudinal bend. To avoid this phenomenon, samples are made of metals in the form of cylinders with height of l_0 which isn't exceeding three diameters [$l_0=(1+3)d_0$]. For other materials – a timber, a stone – samples are made in the form of standard cubes.

Compression of a sample from low-carbon steel

Samples for testing of ductile materials are made in the form of short cylinders (GOST 8817-80) according to which diameter of a sample of $d_0=(20+30)$ mm, and height of its $l_0=(1+3)d_0$ (fig. 4.1).

At compression there are friction forces between plates of a test machine and end faces of a sample (fig. 4.2) which interfere with free expansion of a part of material, adjacent to end faces. The sample at the same time takes the barrel-shaped form. With the help greasing of supporting surfaces of a sample with oil or paraffin it is possible to reduce friction forces considerably. Besides, influence of friction forces can be reduced, having applied a tubular sample to compression test of ductile materials. Such sample represents a pipe with conic end faces.

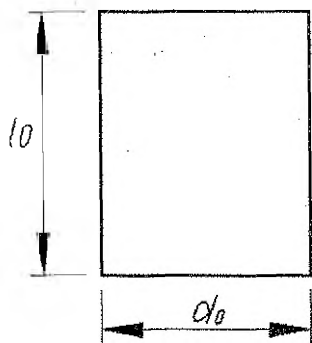


Fig. 4.1

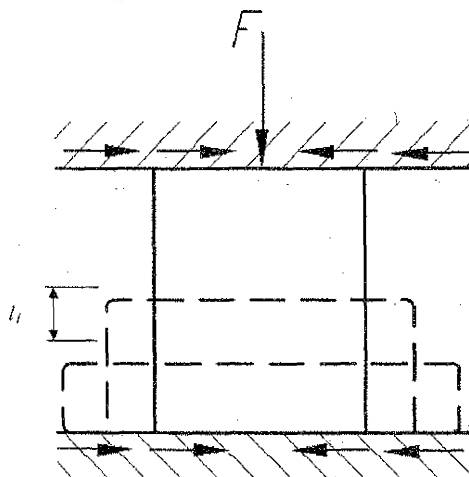


Fig. 4.2

Friction forces at compression of samples

Testing is made on the press «ИММ-125» Before installation of a sample between plates of a test machine it is exposed to measurement and external examination. At survey the attention to parallelism of end faces of a sample and to quality between plates of a test machine is paid. The sample is gradually loaded with continuously increasing loading. The recording instrument of the machine when loading automatically draws the diagram of compression in coordinates of $F-\Delta l$ (fig. 4.3).

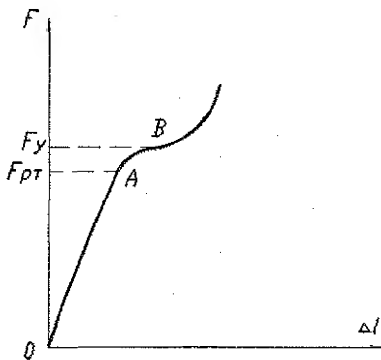


Fig. 4.3. Diagram of compression of low-carbon steel.

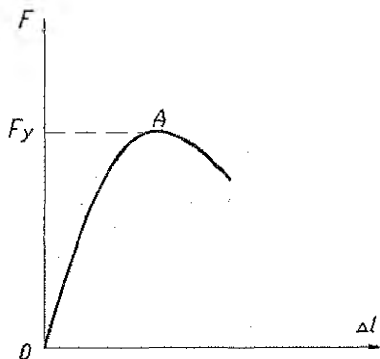


Fig. 4.4. Diagram of compression of cast iron

To some point A on the diagram, a straight line is observed; there is a proportional dependence between loading and shortening. The ordinate of a point A corresponds to a limit of proportionality of low-carbon steel. Beginning from a point A, plastic deformations grow without increase in loading which appeared behind a point B. However the *yielding zone* under compression of ductile material is weakly identified. Further the falling of loading when stretched isn't observed, and the diagram continuously goes up on some curve. This is explained by the fact that beyond a limit of proportionality noticeable residual deformations appear. The sample is shortened, its section increases and it becomes capable to maintain the increasing loading. It isn't possible to bring to destruction a sample from ductile material. The tested sample contracts in a thin disk without visible signs of destruction (fig. 4.2). Therefore it isn't possible to find a rupture loading and consequently the *ultimate strength* of ductile material under compression. Under compression of ductile material it is possible to receive a *limit of proportionality* and a *limit of yielding*:

$$\sigma_{pr} = \frac{F_{pr}}{A_0}, \quad (4.1)$$

$$\sigma_y = \frac{F_y}{A_0}, \quad (4.2)$$

where A_0 — the initial area of a sample.

We will notice that the value of a limit of proportionality and a limit of yielding under compression and at stretching is almost identical for ductile material.

Under compression of ductile materials, as well as at stretching, the strengthening takes place.

Compression of a sample made of cast iron

When testing cast iron for compression cylindrical samples are applied. GOST 2055-81 establishes the following ratios between the sizes of samples for cast iron

testing: $d_0=10+25$ mm, $l_0=(1+3)d_0$. The order of testing of a cast iron sample for compression is similar to an order of compression test of a steel sample.

At gradually increasing loading the recording instrument of the machine automatically draws the diagram of compression in coordinates of $F-\Delta l$ (fig. 4.4).

At the beginning the diagram has already no line section: there is no yielding zone. When it reaches of a maximum the loading it sharply breaks. Brittle materials under compression, as well as at stretching, collapse at small deformations. In the course of testing the sample is shortened and gets poorly expressed barrel-shaped form in view of availability of friction on sample end faces. At the moment when loading reaches the maximum value, the sample collapses, at the same time on its surface a number of inclined cracks at an angle $45^{\circ} - 50^{\circ}$ appears. The nature of destruction is shown in fig. 4.5.

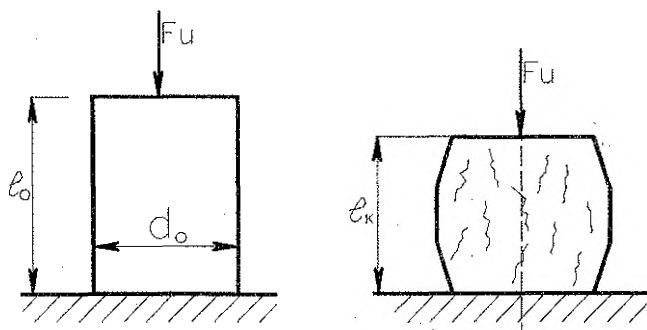


Fig. 4.5. Nature of destruction of a brittle sample

When greasing end faces of a sample with paraffin the nature of destruction will be different. The sample won't take the barrel-shaped form, and destruction will happen by formation of longitudinal cracks on its height. Destruction of cast iron happens suddenly. Sharp falling of loading characteristic of brittle materials is explained by it. Compression test of brittle materials gives the chance to receive *ultimate resistance* on compression.

$$\sigma_u = \frac{F_u}{A_0} \quad (4.3)$$

Strength for brittle materials under compression much more, than at stretching.

Timber compression lengwise and crosswise

When testing timber samples sharply different results depending on the direction of the application of loading in relation to fibers are turned out; as the timber is anisotropic material therefore it is necessary to make tests of a timber lengwise and crosswise of fibers. For testing cubes of standard sizes of 50×50 mm. are made. After measurement and external examination they are exposed to compression before destruction; external examination has to be made carefully because availability of a knots change material work.

When testing the recorder of a press builds the schedule in the form of the diagram $F-\Delta l$. The nature of destruction of a timber cube depends on the direction of application of force in relation to fibers. The sample compressed along fibers before destruction undergoes rather small residual deformations. After achievement of the greatest value of loading of F_u (fig. 4.6) destruction of a sample with the subsequent falling of loading begins (a curve 1). Destruction happens formation of cross folds and crushing of end faces. When there are knots in timber longitudinal cracks can appear. The type of destruction of a cube at compression along fibers is shown in fig. 4.7.

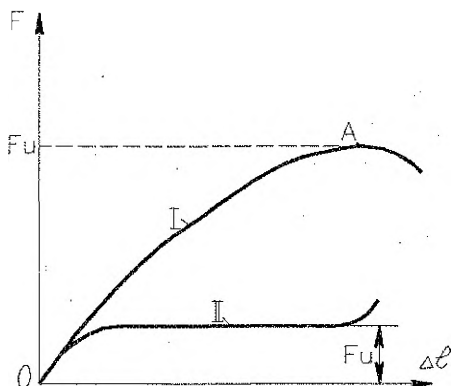


Fig. 4.6. Diagram of compression of a timber

According to experience timber strength (*ultimate resistance*) at compression along fibers is determined by a formula (4.3).

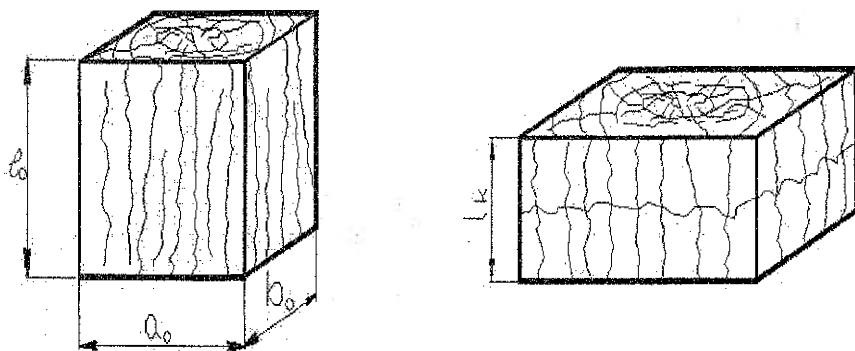


Fig. 4.7. The nature of destruction of a timber cube at compression along fibers

When testing a timber across fibers the picture turns out a bit different. The initial portion (site) of the diagram represents an inclined straight line to loading corresponding of the limit of proportionality F_{pr} (fig. 4.6, a curve of II). Then the

diagram takes a form of poorly curved curve, almost parallel to abscissa axis. The cube is quickly deformed under weak increase of loading. If timber has no defects, then destruction of a cube isn't observed, it is only considerably pressed (fig. 4.8). It is considered that significant growth in deformation at weak increase of loading indicates that bearing capacity of a sample is exhausted. Take for a rupture load such at which the cube contracts on 1/3 initial heights.

As a result of testing timber strength under compression across fibers is calculated. It is necessary to notice that timber strength along fibers is 8-10 times higher, than strength across fibers.

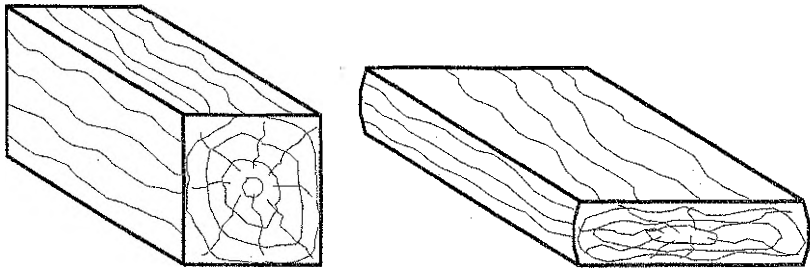


Fig. 4.8. The nature of destruction of a timber cube at compression across fibers

III. Order of carrying out tests

1. Perform measurement of samples with caliper or a micrometer and results of calculations enter into the tab. 4.1.
2. Calculate initial cross-sectional areas and results of calculations enter into the tab. 4.1.
3. Establish samples between plates of a test machine.
4. Load samples and watch the drawn diagram. Load before final fracture of samples.

IV. Processing of test results

1. Measure height l_1 after testing and the results of measurements enter into the table 4.1.
2. For ductile materials from the diagram determine forces of F_{pr} and F_p , for brittle materials – force of F_n and enter their value into the table 3.
3. On formulas (4.1 – 4.3) define σ_{pr} , σ_p , σ_n enter results of calculations into the table 4.1.
4. Determine relative deformation by a formula $\varepsilon = \frac{l_0 - l_k}{l_0} \cdot 100\%$ and results of calculations enter into the table 4.1.
5. Diagram of conditional stress for steel, cast iron and timber are constructed.

Table 4.1.

Material	Sizes of samples				F_{pr}	F_y	F_u	σ_{pr}	σ_y	σ_u	δ
	before experience			after experience							
	d_0 m	l_0 m	A_g m ²	l_f m							
Steel					N	N	N	MPa	MPa	MPa	%
Cast iron											
Timber along fibers											
Timber across fibers											

Control questions

1. On what characteristics do materials divide on ductile and brittle?
2. What tested samples behaved under compression as ductile and what as brittle?
3. What mechanical characteristics managed to be defined as a result of compression test of samples from ductile steel, cast iron, a timber lengthwise and crosswise of fibers?
4. How did the form of samples made of steel and cast iron in the course of testing change? How is it possible to explain?
5. How the cracks formed under destruction of a cast iron sample are oriented? What is it possible to explain such orientation of cracks by?
6. What materials are called isotropic and what anisotropic?

LABORATORY WORK №5

Subject: "Testing of materials for a cut".

I. Work purpose: To determine the strength of a steel sample on a cut and a timber sample on shearing.

II. Work content

Deformation of pure shear is a special case of biaxial (plane) stress when on edges of the rectangular element allocated in the neighborhood of some point of the loaded body only shearing stress (acting tangentially) are acts.

Methods of calculation of bolted, rivet joints, are guided by the theory of pure shear. Strength condition at shear is written down:

$$\tau = \frac{F}{A_{ov}} \leq R_{ov} \quad (5.1)$$

where R_{av} – the calculated resistance (reduced stress) of material on a cut. Theoretically calculated resistance of R_{av} is defined depending on the accepted theory of strength.

So according to the theory of the maximum shearing stress of $R_{ov}^{III} = 0,5 \cdot R_{st}$ where R_{st} – the calculated resistance of material at stretching. According to the

energy theory of strength $R_{ov}^{IV} = \frac{R_{st}}{\sqrt{3}}$.

The device for testing of metal for a cut (fig. 5.1) consists of an ear and an earring.

The tested sample is put into the device (fig. 5.1) which is fixed in captures of the discontinuous machine (YMM -100), and loaded gradually increasing loading up to destruction of a sample. The sample will be cut on two platforms:

$$\tau_{av} = \frac{F}{2A_{av}}; A_{av} = \frac{\pi d_0^2}{4}$$

Besides, the sample will be crushing on cylindrical surfaces: Maximum stress of crushing:

$$\sigma_{cr} = \frac{F_h}{A_{cr}}; \tag{5.2}$$

where

$$A_{cr} = t_{min} d_0. \tag{5.3}$$

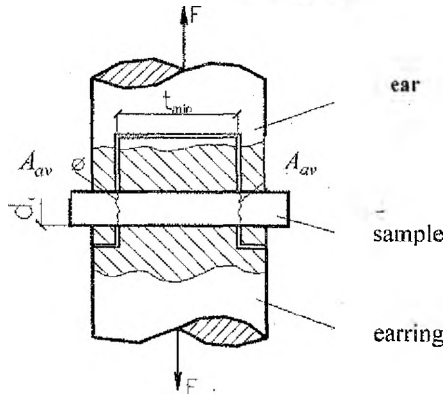


Fig. 5.1. Device for testing of metal for a cut

When testing a timber for shearing the sample is established in the conductor (fig. 5.3) which is located under plates of the machine (IIMM-125) and is loaded by continuously increasing loading up to destruction.

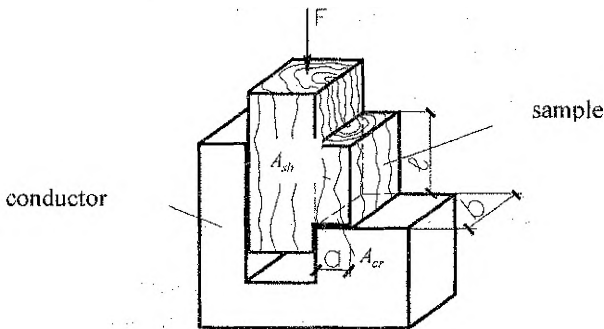


Fig. 5.2. The device and the sample for testing of a timber for shearing

Stresses of shearing determines by a formula

$$\tau_{sh} = \frac{F_u}{A_{sh}}, \quad (5.4)$$

where $A_{sh} = b \cdot l$ (m^2).

Maximum stress of crushing are determined by a formula

$$\sigma_{cr} = \frac{F_u}{A_{cr}}, \quad (5.5)$$

where $A_{cr} = a \times b$ (m^2).

III. Order of carrying out tests

1. Perform measurement of samples a caliper and the results of measurements enter into the tab. 5.1.
2. Determine the areas of a cut, crushing for a metal sample, the area of shearing and crushing of a timber sample and the results of calculations enter into the table 5.1.
3. The sample is placed into the device which is installed in test machines.
4. Make the loading of a sample before destruction and write down values of loadings.

IV. Processing of test results

1. Determine strength on a cut of a metal sample and strength on shearing of a timber sample by formulas (5.1, 5.4).
2. The received strength compare to the strength calculated on one of theories of strength.
3. Determine crushing stress for metal and timber by formulas (5.2, 5.5).
4. Compare crushing stress to strength on a shearing in this specific experience.

Table 5.1

Material	Sizes of samples, m				A_{ep} m^2	A_{cr} m^2	A_{cy} m^2	τ_{cp} MPa	σ_{cm} MPa	τ_{ck} MPa
	d_0	a	b	l						
Steel										
Timber										

Control questions

1. Describe the scheme of the device which is used to testing of a steel sample for a cut.
2. Show the platforms where is a cut, shearing and crushing of samples.
3. How was the values of strength of samples at a cut and shearing is defined on experience?
4. How crushing stress for steel and timber was defined?

LABORATORY WORK № 6

Subject: Testing of a round steel rod for torsion and screw coil springs with a small step of screws.

I. Work purpose: Definition of the shear modulus of steel and its comparison with tabular value.

II. Work content

For calculation of the structural elements working for a cut and torsion it is necessary to have the shear modulus (G) for different materials which is defined by practical consideration.

Testing of a round steel rod is made on the following installation (fig. 6.1.)

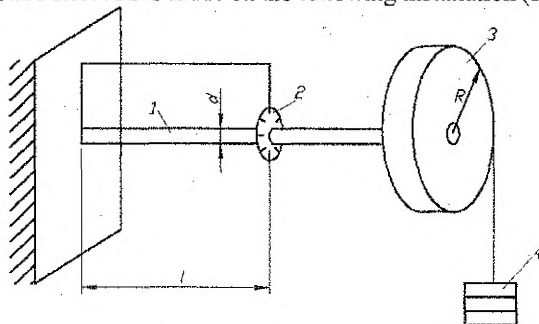


Fig. 6.1. The scheme of installation on torsion:

1 – prototypes, 2 – measuring instrument of an angle of twisting, 3 – wheel for creation of the twisting moment, 4 – loading

The shear modulus G is defined from a formula:

$$\varphi = \frac{T \cdot L}{G \cdot J_p} \quad (6.1)$$

from where

$$G = \frac{T \cdot L}{\varphi \cdot J_p}$$

where $T = F \cdot R$ – torsion torque,

$J_p = \frac{\pi d^4}{32}$ – polar moment of inertia.

The angle of twisting on installation is defined in degrees (φ^0) therefore in a formula the angle of φ has to be:

$$\varphi = \varphi^0 \cdot \frac{\pi}{180^0}$$

The final formula for definition of the shear modulus will have an appearance:

$$G = \frac{F \cdot R \cdot L \cdot 180^0 \cdot 32}{\varphi^0 \cdot \pi^3 \cdot d^4} \quad (6.2)$$

III-1. Order of carrying out tests and processing of test results

1. The load (4) is suspended and the angle of twisting (φ^0) not less than three times is measured.

2. Parameters of the unit of L, R, d are measured.

The obtained data substitute in a formula (6.2) and define G.

Results enter into the table 6.1.

The tests of a spring are made on the installation shown in fig. 6.2. At action on a spring of the stretching or compressing forces F in lateral section of a spring coil arises a torsion torque of T and lateral force of Q . When calculating only deformation of torsion and neglect shear is considered. In this case the elongation (or compression) of a spring is determined by a formula:

$$\lambda = \frac{4F \cdot R^3 \cdot n}{G \cdot r^4}, \quad (6.3)$$

from where:

$$G = \frac{4F \cdot R^3 \cdot n}{\lambda \cdot r^4},$$

where: F – the set loading; r – radius of a wire of which the spring is made; R – the average radius of a spring coil determined by a formula:

$$R = \frac{D - d}{2}, \quad (6.4)$$

where: D – outside diameter of a spring; d – diameter of a wire from which the spring is made; n – quantity of spring coils; The spring elongation (or compression) λ defined from experience.

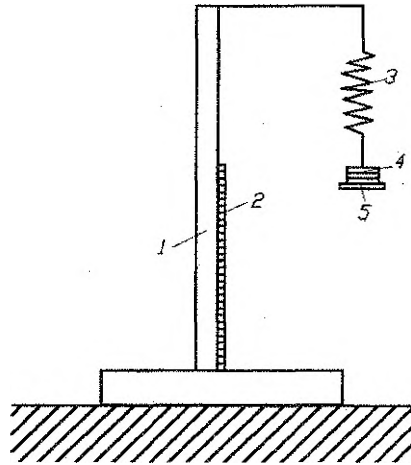


Fig. 6.2. Experimental installation for experience with a spring:
1 – rack, 2 – ruler, 3 – spring, 4 – load, 5 – suspender

III-2. Order of carrying out tests and processing of test results

1. With the help of a caliper diameter of a spring coil (D) and diameter of a wire (d) to within 0,1 mm is measured;
2. Average radius of a spring coil is determined by a formula (6.4);
3. Define the number of spring coils of n , considering also incomplete coils;
4. Load the suspender (5) with replaceable loads (4), every time measuring elongation of a spring (2) with a ruler;
5. The results of measurements and calculations are entered into the tables.

Table 6.1.

№ of items	R, mm	D, mm	L, mm	F, N	φ°	G_s , MPa	note
1	85	5	400				
2							
3							
						$G_{av} =$	

Table 6.2.

№ of items	R, mm	r, mm	n	F, N	L_0 , mm	L_s , mm	λ , mm	G_s , MPa	note
1									
2									
3									
									$G_{av} =$

Conclusions on work

1. To make the conclusion: whether material submits to Hooke's law.
2. To compare experimental values of the module G to tabular data.

Control questions

1. How Hooke's law is formulated at shear?
2. What is the angle of twisting?
3. Describe a technique of carrying out the experiences.
4. List elastic constants of materials that are known to you. Connection between them.
5. How to determine spring elongation (or compression)?
6. What is rigidity at torsion?
7. What stress arise in lateral section of a round rod?

LABORATORY WORK №7

Subject: "Determination of coefficient of concentration of stress by a polarizing and optical method".

I. Work purpose: To get acquainted with a polarizing and optical method of determination of coefficient of concentration of stress.

II. Work content

The formula $\sigma = \frac{N}{A}$ for determination of stress at stretching (compression) is fair only in that case when section is located at sufficient distance from places of sharp change of a shape of a body (bores, holes, etc.).

In places of sharp change of a shape of a body, at cuts and cracks sharp increase in stress which is called concentration of stress (fig. 7.1) is observed.

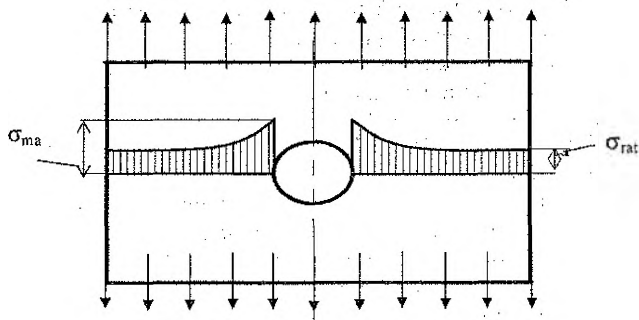


Fig. 7.1. Concentration of stress

Generally theoretical coefficient of concentration of stress is called the relation of the maximum stress calculated taking into account concentration (in an elastic zone of the diagram of deformation of material), to rated stress in the same point.

$$\alpha = \frac{\sigma_{\max}}{\sigma_{\text{rat}}}. \quad (7.1)$$

The rated stress, is the stress which is determined by formulas of resistance of materials without effect of concentration. Usually rated stress is determined for the weakened section. So, for example, for the strip weakened by an hole (fig. 7.1).

$$\sigma_{\text{rat}} = \frac{F}{A_{\text{net}}}. \quad (7.2)$$

It is obvious that the theoretical coefficient of concentration of tension can't be less unit.

As a rule, the coefficient of concentration of stress is defined experimentally.

The polarizing and optical method is based on the fact that some transparent materials under deformation become statically anisotropic, in the deformed state they acquire property of double refraction (glass, celluloid, bakelite, etc.). In an optical method not the detail, but its model made of transparent material is investigated. The model is located in the optical installation called by the polariscope where it is illuminated by a beam of the polarized light. The polarizer misses fluctuations in strictly certain plane, and liquidate the components of fluctuations, perpendicular to it.

In fig. 7.2 the arrangement (disposition) of the main parts of the polariscope with flat polarization of light is schematically shown.

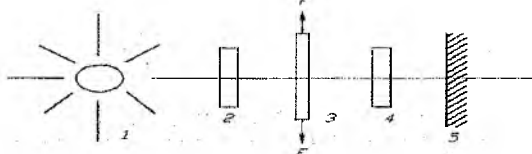


Fig. 7.2. Scheme of installation:

1 – Light source; 2 – Polarizer; 3 – Model; 4 – Analyzer; 5 – Screen

One of the main parts of the polariscope are the polarizer and the analyzer, but in on-position turned so that their planes of polarization are mutually perpendicular. In this case the ray of light which passed through a polarizer will be liquidated by the analyzer if the model is absent or it isn't loaded. This position of a polarizer and the analyzer is called installation on darkness.

If to put loading to the model, then it will be deformed, material of model will become optically anisotropic, and it will behave as the crystalline solid having property of double refraction.

In other words, under loading the model acquires property to turn the plane of polarization of light passing through it depending on the value of stress. Then light with the turned polarization plane partially passes through the analyzer, giving the image of the studied model on the screen. The intensity of the image and its color depends on the value of stress.

III. Order of carrying out tests and processing of test results.

With the help of a caliper to within 0,1 mm measure the sizes of lateral section of samples from transparent material. The sample without concentrators of stress is accepted as standard, by samples with concentrators – models.





A reference sample is fixed in captures of the discontinuous machine; establish a polarizer and the analyzer on darkness. A reference sample is loaded and observe the screen. At appearance on the screen of the color caused earlier, the value of the corresponding loading is written down.

In this way the models are tested. In models on the screen the color corresponding to tests of a reference sample appears earlier at edges of the concentrator. Having divided the load matching this color of a reference sample (or model) on the cross-sectional area of a reference sample (or model), we find medium stress in models and stress in lateral section of a reference sample:

$$\sigma_{ref} = \frac{F}{A_{ref}} [N/M^2] \quad \sigma_{mod} = \frac{F}{A_{mod}} [N/M^2]$$

The coefficient of tests is entered in to the tab. 7.1.

Table 7.1.

Sketches of holes	A, m ²	F, N	σ, MPa	α
1	2	3	4	5
				
				
				
				

Control questions

1. Give the definition of theoretical coefficient of stress concentration.
2. Describe the schematic diagram of installation for experimental determination of coefficient of stress concentration by a polarizing and optical method.

3. What materials the studied models are made of. What properties do these materials have?

4. How were experimental values of coefficients of stress concentration defined?

5. How does the radius of curvature of an holes influence the values of coefficient of stress concentration?

LABORATORY WORK №8

Subject: "Determination of impact strength of materials".

I. Work purpose: To determine impact strength at a dynamic bending of a steel sample with a cut.

II. Work content.

In engineering practice, is often met a dynamic load which rather quickly changes the value and position.

Dynamic action of loading is not boils down to that fact that stresses are different, than at static loads. Material differently reacts to a dynamic load, than to slowly increasing. Especially it is noticeable at a strike when the yield limit sharply raises. Therefore at the choice of material make so-called shock test for the parts (structures) which are exposed to dynamic influences. The test for shock (at a bend) is often used.

For determination of impact strength of materials the greatest spread was gained by pendular copras (the scheme of installation is shown in fig. 8.1)

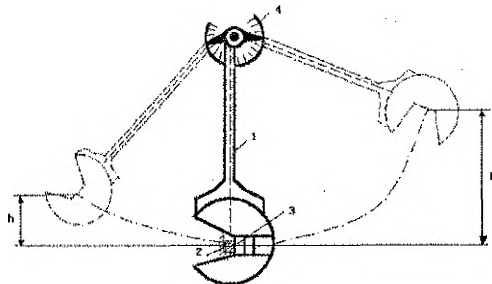


Fig. 8.1. Pendulum hammer (copra):

1 – the pendulum, 2 – a sample, 3 – peen (knife), 4 – a scale of measurements

When testing standard samples (fig. 8.2) pendular copra with an energy reserve no more than 30 kgm are applied.

In our case tests are made on pendular MK-30A copra.

According to GOST 9454-60 samples must have standard sizes and the cut size established for a sample (fig. 8.2).

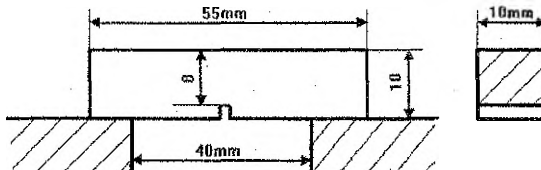


Fig. 8.2. Standard samples for shock test.

If the amount of the energy spent for a break of a sample is equal to U , and sample cross-sectional area in the place of a break is equal A , then the value of impact strength is defined:

$$\alpha = \frac{U}{A} \left(\frac{\text{kg} \cdot \text{m}}{\text{sm}^2} \right) \quad (8.1)$$

The sense of a cut is that material in works concerning shock loads try to set the most severe conditions. The local stress arising at the same time represent such system of stress at which material is in triaxial (volumetric) stress; in this case plastic deformations are at a loss, and material near the bottom of a cut appears in a brittle state.

III. Order of carrying out tests.

1. Before testing the sample is exposed to careful external examination.
2. With the help of a caliper the sizes of lateral section of a sample are measured in the weakened section.
3. The pendulum a copra is lift up on height of H and on a measuring instrument scale an amount of potential energy U_0 is fixed.
4. The sample is established between support a copra a cut aside, opposite struck.
5. A blow is maid and an amount of potential energy after destruction of U_1 is fixed.

IV. Processing of test results.

1. Sample cross-sectional area in the weakened section A is calculated.
2. Amount of the energy spent for break $U = U_0 - U_1$ is found.
3. On a formula (8.1) coefficient of impact strength of material is found.
4. The percentage content of carbon is determined by table 7 and a conclusion about plastic properties of steel is drawn.

Table 8.1.

Characteristics steels and their chemical composition	Heat treatment			
	Annealing		Tempering and issue	
	σ_u (MPa)	$\alpha \left(\frac{\text{kg} \cdot \text{m}}{\text{sm}^2} \right)$	σ_u (MPa)	$\alpha \left(\frac{\text{kg} \cdot \text{m}}{\text{sm}^2} \right)$
Carbon steels				
$c < 0,15$	350 – 450	> 25	360 – 500	> 25
$c = 0,15 - 0,20$	400 – 500	> 22	450 – 650	> 20
$c = 0,20 - 0,30$	500 – 600	> 20	550 – 750	> 15
$c = 0,30 - 0,40$	600 – 700	> 16	700 – 850	> 12
$c = 0,40 - 0,50$	700 – 800	> 12	800 – 950	> 9
$c = 0,50 - 0,60$	800 – 900	> 10	900 – 1050	> 5
$c = 0,60 - 0,70$	850 – 950	> 8	> 1000	> 3
$c > 0,70$	> 950	> 6	> 1050	> 2

Control questions

1. What is the impact strength of material?
2. What is the feature of behavior of materials at shock loads consist?
3. Describe the installation for testing for impact strength.
4. What does impact strength characterizes for testing steels?
5. Describe the standard sample and what purpose the cut is made for?
6. What it is more dangerous for steels – temperature increase (in the plus side) or lowering below zero from the point of view of their resistance to shock loads?

EDUCATIONAL EDITION

Authors: A. Zheltkovich, associate professor
A. Veremeichic, associate professor
V. Hvisevich, professor

LABORATORY WORKS ON RESISTANCE OF MATERIALS

For students day studies faculty of industrial and civil engineering
(Part 1)

Responsible for release: *A. Zheltkovich*
Editor: *E. Borovikova*
Imposition: *K. Kolb*

It is passed for the press 22.11.2017. Paper writing No. 1.
Font of Times New Roman. Condish. print. page 1,86. Ed. edit. 1. 2.
Order No. 1167. Edition 30 copies. .
It is printed on risograph educational institutions Brest state technical university.
224017, Brest, Moskovskaya St., 267.