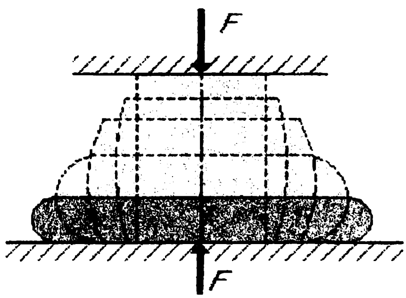
MINISTRY OF EDUCATION OF REPUBLIC OF BELARUS

ESTABLISHMENT OF EDUCATION
«BREST STATE TECHNICAL UNIVERSITY»

DEPARTMENT OF APPLIED MECHANICS

LABORATORY WORKS
ON STRENGTH OF MATERIALS

For students full time mode of study
Faculty of industrial and civil engineering
Semester I



Brest 2020

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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.

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1. INTRODUCTION

Strength of materials is engineering science about strength, rigidity and stability of building constructions, elements of mechanisms and machines. All constructions are made of deferent materials, each of which has their own physics mechanical characteristics.

The program of a course of strength of materials provides in parallel with studying of theoretical material, includes realization of a number of laboratory works. A part of these works is connected with studying of mechanical properties of materials, in order to acquainting with calculation on strength, rigidity and stability building constructions, elements of mechanisms and machines. The other part is devoted to check of the calculation formulas received in the theoretical way.

The verification of the fundamental law (the Hooke's law) of strength of materials for different materials is a very important issue. Besides of laboratory practicum students get acquaintance with: a technique and technology of carrying out tests of samples and structural elements, with measuring instruments and with testing machines. The completion of laboratory works has to be a report executed by the student in the established form with the subsequent defenses.

2. ACCIDENT PREVENTION

There are complex equipment with high voltage, with relatively heavy loads, a number of floor and desktop installations there which can threatening of a health or lead to an injury in the laboratory of department of applied mechanics.

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 in action mechanisms, to load installations by self-willed;

4) Do not be distracted by external actions when performing work;

5) Immediately to declare to the teacher or educational personnel at failure detection;

6) To touch devices, installations and testing machines on which the laboratory work isn't performed is forbidden;

7) Only the students who were informed of the requirements of accident prevention and only after teacher signature are permitted to the laboratory works.

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

LABORATORY WORK № 1
MEASURING INSTRUMENTS

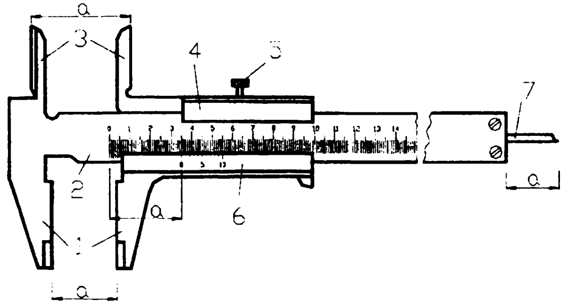
During the tests necessary to carry out measurement of initial sizes of samples or elements of constructions and also displacements and deformations caused by loading. The corresponding measuring instruments with the appropriable scale division (α) are used for these purposes.

For measurement of the sizes the rulers (*a=1mm*), calipers (*a=0,05 mm* or *0,1 mm*), micrometers (*a=0,01 mm*), and for measurement of displacement – needle indicators (*a=0,001 mm* and *0,01 mm*) are used. Deformations in construction material which in an elastic stage are very small by different design tensiometers (mechanical and optical (*a=0,001 mm*) or electric (*a=0,001 mm*) are measured.

3.1. Caliper

For measurement of external and internal dimensions of samples and parts the caliper is applied. In laboratory practice calipers with a measurement limit to *125 mm* and up to *500 mm* with an accuracy of counting of *0,05 mm* 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 freely on a bar is moved.

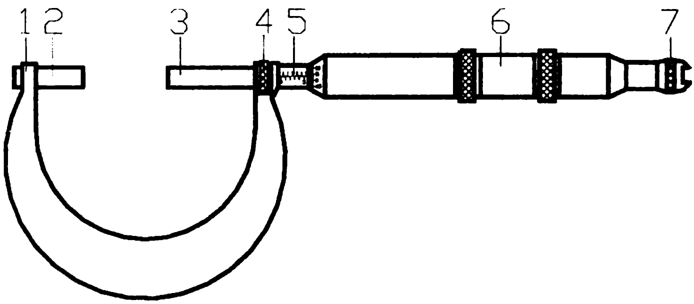


1 – sponges, 2 – crossbar, 3 – sponges, 4 – a frame. 5 – a stopper. 6 the nonius, 7 – a ruler
Fig. 1.1. Caliper of 0 – 125 mm

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. This ruler for measurement of depths is designed. To receive a size of a cavity of a sample the frame *4* fixes with a stop screw *5*. Calipers of other sizes with an upper limit more than *300 mm* here are not described. On the other hand one defers detail need to be mentioned: they have one-sided sponges only for measurement of external dimensions.

3.2. Micrometer

For measurement of external dimensions with an accuracy of *0,01 mm* micrometers are designed. 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* is set in motion by the drum *6*. On a sleeve the longitudinal line and cross strokes through *1 mm* are located. The strokes which locate from longitudinal line down and note by digits through each *0,5 mm* after revolution of drum the counting of the 0,5 millimeters is made. The strokes which with respect to longitudinal line locate up, divide each millimeter of the lower scale in half.



1 – a bracket, 2 – a heel, 3 – a micrometer screw, 4 – a stopper,
5 – a sleeve, 6 – a drum, 7 – a head with a graggers
Fig. 1.2. Micrometer

The drum comes to an end with a cone on which 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 the micrometer screw receives longitudinal displacement relative to the sleeve of *0,5 mm*, and the scale of conic edge of the drum overcomes all *50* divisions. Thus, the scale of one division of a scale of a drum is *0,01 mm*.

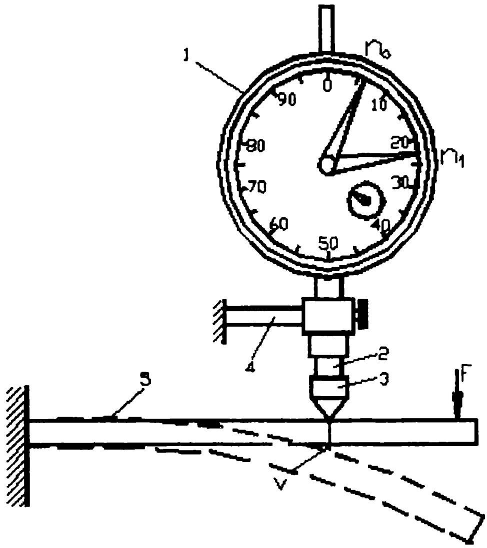
The 100-th portion of millimeter on a scale of conic edge of the drum is. At micrometers a lower limit of measurement equal to zero. At contact between a heel and the screw of conic edge of the drum a zero stroke of a sleeve and a zero stroke of a scale of a drum (on longitudinal line of a sleeve) is counted.

The drum at the free end with a head *7* with a graggers is designed. Need to rotate the drum until the measuring sample between the measuring surfaces with a certain pressure will be clamped, then the drum with a graggers is turned. The increasing of effort to a micrometer drum can influence to a deformation of a sample and as a result the accuracy of measurements wouldn't be provided.

The stop screw *4* for fixing of a micrometer screw at given position is designed.

3.3. Indicating gauge

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



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

Fig. 1.3. Indicating gauge

The small scale has *10* divisions, each of which corresponds to *1 mm* of a contact rod motion. The big scale contains *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 fixes by the frame to a fixed part of a construction or a support ***4***, and head ***3*** touches a part ***5*** in a point which displacement is measured.

The measuring displacement of a point of a construction before and after deformation of a part of a construction is measured by indicator.

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

where V – measuring 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_i – the unit of scale division of the indicator.

3.4. Electrical resistance strain gauge

The electrical-type strain gauge is the device measuring relative linear deformation on a certain area of the construction by an electric method. It consists of three parts: strain gauge, amplifier and indicator. The strain gauge (which can be named either sensor or tensiometer) is the sensitive element perceiving the measured deformation and transforming it to an electric parameter. For this purpose wire resistance strain gauges are often used.

The wire sensor (fig. 1.4a) with diameter of *d=0,02–0,05 mm* and high value of resistance from constantan or nichrom, etc. is manufactured. It represents a flat loop-shaped grid with contacts on the ends. The wire grid on a thin rectangular strip of the special film (or a paper) with thick *0,05 mm* is glued. Thereby this film forms a basis of a sensor and isolates tiny wire from measured part.

Sensors by length of base (L_0*=5–100 mm*) and resistance of wire (*R=10–800 Ohms*) are characterized.

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

One sensor – working sensor (for example, of the left shoulder of the bridge) D_1 on the studied surface is glued. To exclude influence of temperature, other sensor (for example thermocompensatory – D_2) on undeforming part of a construction (fig. 1.4c) is placed.

For measurement of deformation different electrometric devices are used.

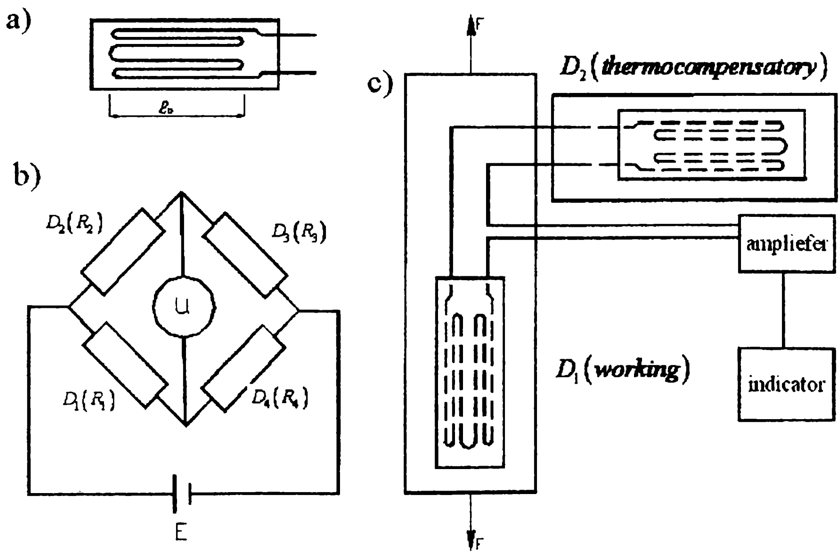


Fig. 1.4. Scheme of the electrical resistance strain gauge

LABORATORY WORK № 2

Subject: «Testing of a steel sample for stretching».

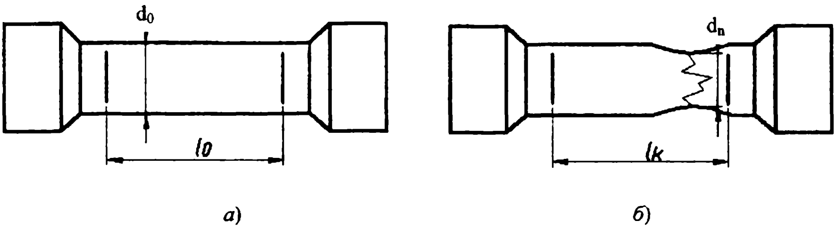
1. Work purpose: Determination of mechanical characteristics and characteristics of ductility of low-carbon steel.

2. 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 – working part.

In order to compere results, which can be carried out by different laboratories, types and sizes of samples are established by GOST 1479-73.

Usually at tests the sample which design length equals $10d_0$ (where d_0 – diameter of a working part of a sample, fig. 2.1) is applied.



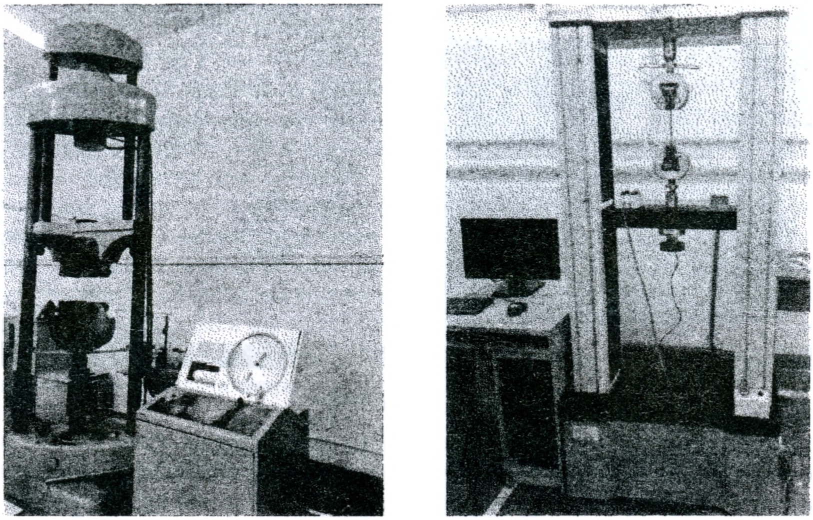
a) sample for testing of metals at stretching; b) the shape of destruction of a ductile material sample
Fig. 2.1. Specimens for stretching tests

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 testing machines «УММ–100» and/or Kason WDW-50 (fig. 2.2). «УММ-100» equipped with the self-recording device which automatically draws the diagram of stretching in a certain scale in coordinates F–Δl. At static tests on stretching the sample at smoothly increasing loading up to a rupture is deformed. The diagram shows functional dependence between force of F acting on a sample, and the deformation of Δl (fig. 2.3a).

It should be noted that diagram (fig. 2.3a) characterizes not properties of material, but property of a sample. To get the material properties characteristic, it is necessary to reconstruct the diagram of stretching F–Δl 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 an apparent stress-strain diagram is called.

At the beginning of testing on the diagram can be observed horizontal and curvilinear sites which due to elimination of gaps both in the machine mechanism, and between heads of a sample and capture devices of the machine are explained. On the diagram the direct line OA corresponding to proportional dependence between loading and lengthening of a sample is drawn. To exclude the curvilinear site arising at elimination of gaps 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*, it is a real initial point of stretching diagram.



«УММ-100» *Kason WDW-50*

Fig. 2.2. Universal testing machines

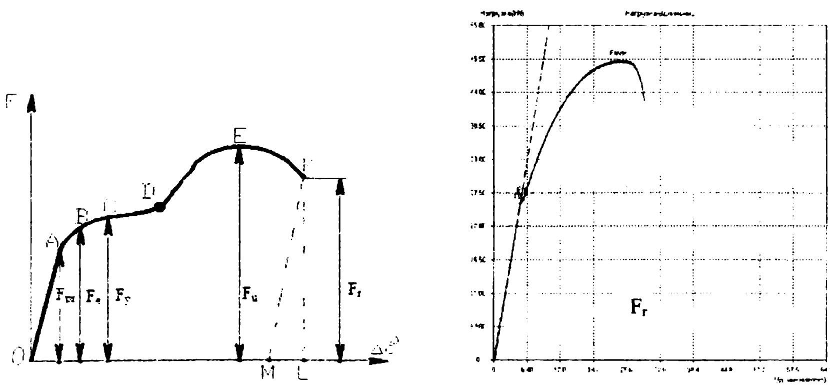


Fig. 2.3. Diagram of stretching

The Kason WDW-50 machine is controlled by a computer. The dialog window is shown in fig. 2.4. The machine allows us to set different loading speed, type of sample and its material, to obtain various types of diagrams (load-displacement, load-extension, stress-extension, etc.)

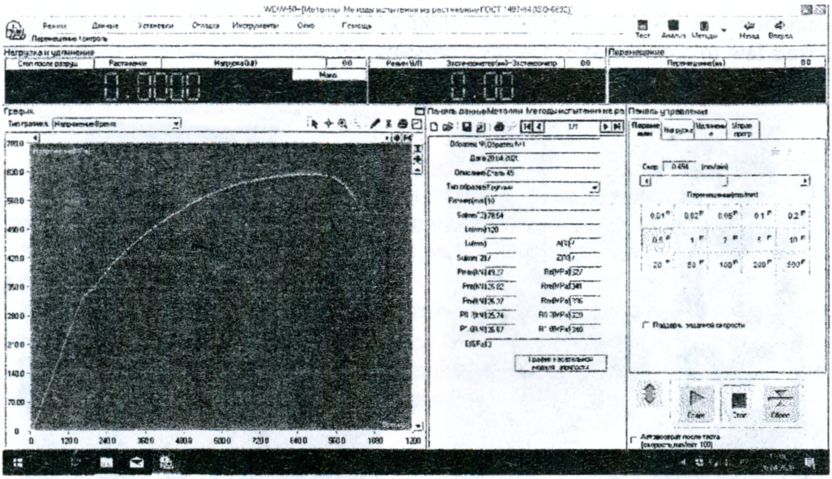


Fig. 2.4. Dialog window

The straight line 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*. Limit of proportionality is called the maximum stress up to which the law of proportionality between stress and deformations is carried out.

$$\sigma_{pr} = \frac{F_{pr}}{A_0} \; [MPa]. \tag{2.1}$$

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

$$\sigma_e = \frac{F_e}{A_0} \; [MPa]. \tag{2.2}$$

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 lens 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:

$$\sigma_y = \frac{F_y}{A_o} \quad [MPa]. \tag{2.3}$$

However not all materials have a pronounced 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 *engineering stress* limit of yielding (it is the tension at which relative lengthening reaches *0,2 %* of length of a designed part of a sample). Behind 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 engineering stress σ_u corresponding to this loading is called the *ultimate resistance* or *temporary resistance of material*:

$$\sigma_u = \frac{F_u}{A_o} \quad [MPa]. \tag{2.4}$$

During the test it is possible to observe that behind of *ultimate strength* the deformation in a sample extend not evenly on all length, 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 zone load 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:

$$\sigma_r^t = \frac{F_r}{A_n} \quad [MPa], \tag{2.5}$$

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).

The region ***OB*** diagram – *elastic range of stress* is called, ***BC*** – zone of elasto-plastic strain, ***DE*** – zone of hardening, ***EK*** – zone of local yield.

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. 2.3). To allocate only residual or only elastic deformations, it is enough from a point K the diagram of stretching (fig. 2.3) to plot the straight line parallel to a straight section of the diagram ***OA***. Then the portion of ***OM*** will represent residual deformation of a sample, and portion of ***ML*** – elastic one. Elastic strains disappear at the time of a rupture of a sample, and residual one remain thanks to what the lengthening of a sample corresponds to a part of ***OM*** of the diagram which can be gotten by direct measurement of the broken-off sample.

The diagram of destruction of a sample from ductile material in a fig. 2.1*b* is shown.

In the place of a rupture "a cup" is emerged. Where bottom is perpendicular to a sample axis, and edges at an angle α=45° to its axis are inclined. This comes from the fact that in the plane of transverse section the stresses under the complex parabolic law (with a maximum value close by of axis) are distributed. Therefore the rupture of a sample begins in the central part. Remaining 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 residual lengthening:

$$\delta = \frac{l_1 - l_0}{l_0} \cdot 100\,\%. \tag{2.6}$$

For determination of length of sample after a rupture both of its parts should be densely connected and the measurement is made.

Relative residual narrowing:

$$\delta = \frac{A_0 - A_n}{A_0} \times 100\,\%, \tag{2.7}$$

where A_n – the area of a neck.

For determination of A_n both parts of a sample after a rupture has to be densely connected and the minimum diameter of a neck in two mutually perpendicular directions is measured. Then as an arithmetic average of these two measurements, the area of a neck A_n is calculated. The larger δ and ψ, the more ductile the material is.

3. Order of carrying out of test

1. Measure of 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 A_0.
3. Apply strokes, denoting the design length of a sample $l_0 = 10d_0$.
4. Establish sample in captures of the testing machine.
5. Load sample; loading increases to final rupture of a sample.
6. In the course of loading values of the loading corresponding to characteristic points on the diagram of load-extension or stress-strain in table 2.1 are entered.
7. Measure the sample sizes after a rupture and enter them in to the table.

4. Processing of results of an experiment

1. Note on the diagram the characteristic points corresponding to loadings of F_{pr}, F_y, F_u, F_r. The results in tab. 2.1 are entered (if work was done in machine «УММ-100»).
2. Establish diagram scale (if work was done in machine «УММ-100»).
3. Calculate mechanical characteristics of σ_{pr}, σ_y, σ_u, σ_r, σ'_r. The results in tab. 2.1 are entered (if work was done in machine «УММ-100»).

4. Measure distances between strokes of l_l after rupture the sample and also the diameter of d_n of the neck by densely coincidence of two of its parts.

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

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

7. Plot the diagram of engineering stress (fig. 2.5).

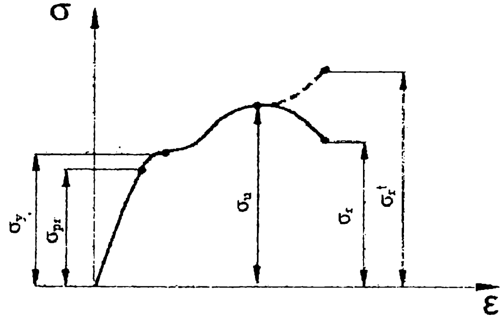


Fig. 2.5. Diagram of engineering stress

Table 2.1.

Material	Sample size						F_{pr}, N	F_y, N	F_u, N	F_r, N	Mechanical characteristics				Characteristics of plasticity	
	Before test			After test							σ_{pr}	σ_y	σ_u	σ^t_r		
	d_o, m	l_o, m	A_o, m^2	d_n, m	l_l, m	A_n, m^2					MPa				δ, %	φ, %
Steel																

By the results received from the test it is possible to judge about the quality of the material. Using help data (table 2.2) of established mechanical characteristics of materials engineer can decide in what designs this material can be applied.

Table 2.2. Typical Mechanical Properties of Metals in Annealed (Soft) Condition

Material	Yield Stress (MPa)	Ultimate Stress (MPa)	Ductility EL%	Elastic Modulus (MPa)	Poisson's Ratio
1040 Steel	350	520	30	207000	0.30
1080 Steel	380	615	25	207000	0.30
2024 Al Alloy	100	200	18	72000	0.33
316 Stainless Steel	210	550	60	195000	0.30
70/30 Brass	75	300	70	110000	0.35
6-4 Ti Alloy	942	1000	14	107000	0.36
AZ80 Mg Alloy	285	340	11	45000	0.29

From the results of the tests, it can be determined whether the material is ductile or brittle. In plastic materials (for example, low carbon steel), residual deformations can reach 25%. In brittle materials (instrument steels, cast iron), residual deformations do not exceed several percent.

From result which were gotten we can calculate an Allowable Stress or Allowable Stress Design (ASD) as showing in fig 2.5 and 2.6. Allowable Strength Design applies a quasi-safety factor approach to evaluating allowable strength. Ultimate strength of an element or member is determined as we have done recently. ASD are compared to the ultimate strength reduced by a factor (omega) which provides a mathematical form similar to Allowable Stress Design resolved with a safety factor. Necessary to remember that Allowable Strength Design approach does not attempt to relate capacity to elastic stress levels.

Philosophy: Maximum stress must not exceed allowable stress

$$F_{max} \le F_{all} = \frac{F_{lim}}{F.S.}$$

F_{max} : maximum stresses due to working loads
F_{all} : allowable stresses
$F.S.$: Factor of Safety > 1 (understrength)
F_{lim} : Limit of Usefulness (F_y F_u F_{cr} etc)

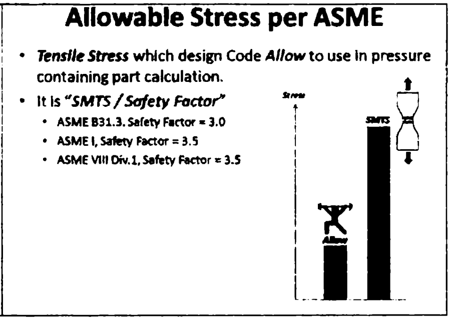


Fig. 2.5. Calculation of Allowable Stress Design (ASD)

- *Tensile Stress* which ASME B31.3 Process Piping Design Code *Allow* to use in pressure containing part calculation usually is *Lower of 1/3 SMTS or 2/3 Yield Strength.*

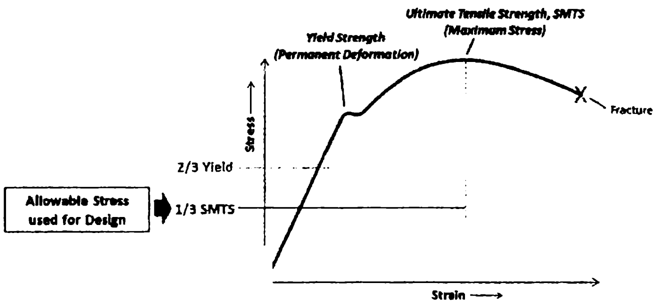


Fig. 2.6. Diagram of Allowable Stress Design (ASD) reckoning

Control questions

1. What requirements to the sizes of an experimental sample are imposed?

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 test?

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 Poisson's coefficient (cross deformation coefficient)».

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

2. 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:

$$\sigma = E\varepsilon. \tag{3.1}$$

The module of elasticity E reflects the material elasticity 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:

$$\Delta l = \frac{F \cdot l}{E \cdot A}. \tag{3.2}$$

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 can be find from dependence:

$$E = \frac{F \cdot l}{\Delta l \cdot A} = \frac{F}{\varepsilon \cdot A}. \tag{3.3}$$

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

$$\nu = \left|\frac{\varepsilon'}{\varepsilon}\right| = \left|\frac{\Delta b \cdot l}{b \cdot \Delta l}\right|, \tag{3.4}$$

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

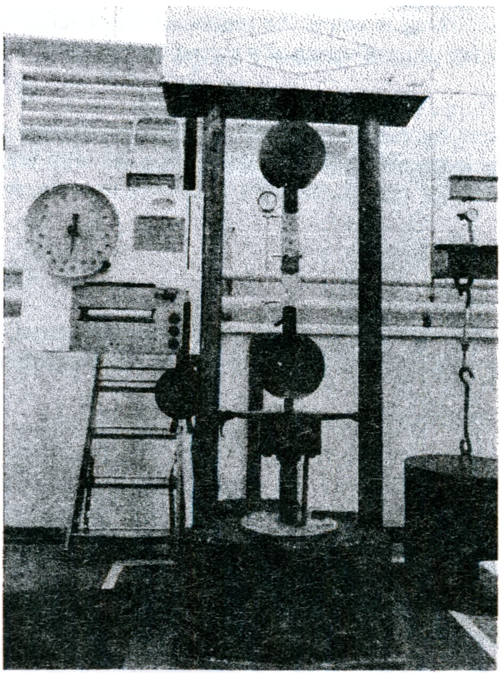
In this work for testing the sample of rectangular cross section is used. The module of elasticity E and Poisson's coefficient ν are kept by the constant values so far Hooke's law is carried out. Then the value of a maximum load is defined from a ratio:

$$F_{\max} < \sigma_{pr} \cdot A. \tag{3.5}$$

Having set of step of loading n, it is possible to count a loading interval

$$\Delta F = \frac{F_{\max}}{n}. \tag{3.6}$$

For determination of the module of elasticity E and Poisson's coefficient of ν the experiment can be used: absolute longitudinal and absolute cross deformations are measured by gauge indicators. At the same time for determination of absolute lateral (cross) deformation which always less than longitudinal, is installed the another indicator with smaller division of scale (*0.001 mm*), than the indicator for measurement of absolute longitudinal deformation with scale of division (*0,002 mm*). The schemes of installation for determination of module of elasticity E and Poisson's coefficient of ν is shown in fig. 3.1.


a)

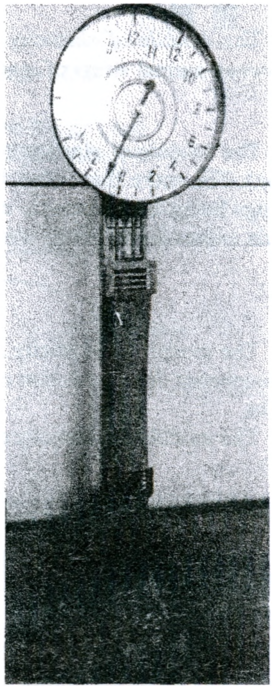

b)

Fig. 3.1. Schemes of installation for determination of the module of elasticity and Poisson's coefficient

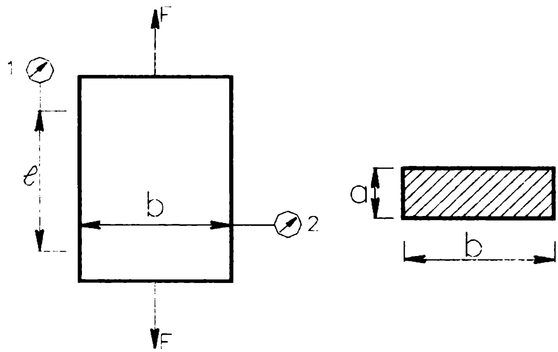


Fig. 3.2. Sizes of a sample

3. Sequence of carrying out of experiment

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

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

At initial loading the first counting on indicators *1* and *2* (fig. 3.2) is made. By the indicator *1* absolute longitudinal lengthening of Δl are determined, and by the indicator *2* – absolute lateral (cross) shortening of Δb. Then loading is increased by equal steps so that the number of steps of loading will equal n. For each step of loading the counting of indicators are made and the results are registered in the list of observations (table 3.1).

4. Processing of results of an experiment

According to experiments which visually illustrates direct proportionality between loading and deformation of a sample the graphs are drawn: $F=f(\Delta l)$.

For each step of loading we determine both the module of elasticity E (by formula 3.3) and Poisson's coefficient of ν (by formula 3.4) and the results in table 3.1 are entered.

Control questions

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

Table 3.1.

Material	Sample sizes			A, m^2	F, N	Absolute deformation		E, MPa	ν	E_{av}, 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	$d =$		$l =$								

LABORATORY WORK № 4

Subject: «Testing of materials for compression».

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

2. 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 [$l_0=(1\div3)d_0$]. 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 $d_0=(20\div30)$ mm, and height of its $l_0=(1\div3)d_0$ (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.

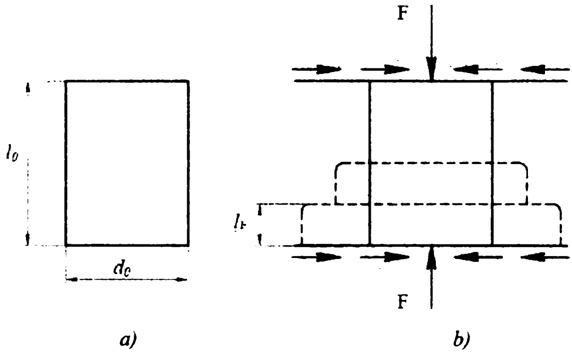


Fig. 4.1. Friction forces at compression of sample

Testing is made on the press machine «ПММ–125» (fig. 4.2). 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 chart-recording instrument of the machine when the sample is loading automatically draws the diagram of compression in coordinates of $F–\Delta l$ (fig. 4.3).

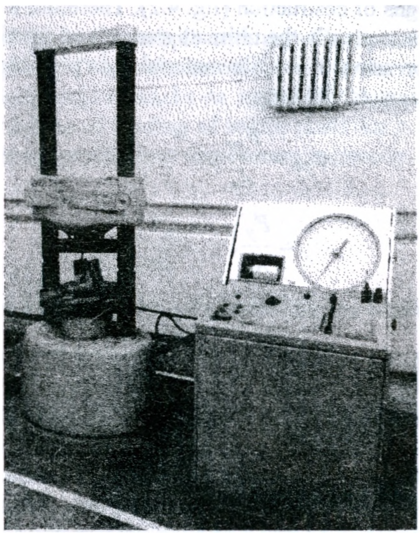


Fig. 4.2. Testing machine «ПММ-125»

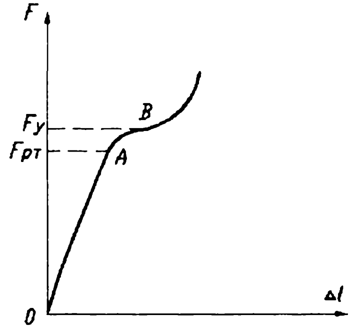


Fig. 4.3.
Diagram of compression of low-carbon steel

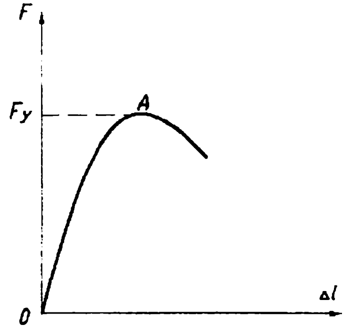


Fig. 4.4.
Diagram of compression of cast iron

To some point A on the diagram, a straight line is observed; there is a proportional dependence between loading and deformation. 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 only appear behind a point B. However the yielding zone under compression of ductile material is weakly identified. Further the falling of loading 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:

$$\sigma_{pr} = \frac{F_{pr}}{A_o}, \tag{4.1}$$

$$\sigma_y = \frac{F_y}{A_o}, \tag{4.2}$$

where A_0 – initial area of a sample.

We will notice that the values of a limit of proportionality and limit of yielding under compression as well as stretching are almost identical for ductile material.

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

<u>Compression of a sample made of cast iron</u>

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: $d_o=10\div25$ *mm*, $l_o=(1\div3)d_o$. 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 chart-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 shortens and gets poorly expressed barrel-shaped form in view of availability of friction between the ends faces and plates of testing machine. 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 – 50° appears. The nature of destruction is shown in fig. 4.5.

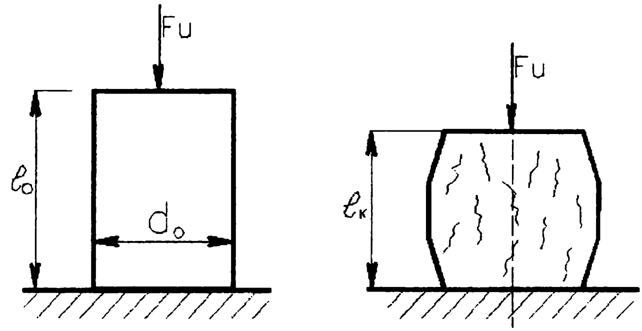


Fig. 4.5. Nature of destruction of a brittle sample

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 of brittle materials is explained by it. Compression test of brittle materials gives the chance to receive ultimate resistance on compression.

$$\sigma_u = \frac{F_u}{A_o}. \tag{4.5}$$

Strength of a brittle material under compression much more, than at stretching.

Timber compression longwise and crosswise

When testing timber samples, sharply different results depending on the direction of the application of loading (with respect 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 *50x50 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 knots changes material work.

When testing the chart-recording instrument of a press plots 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 by formation of cross cracks 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.

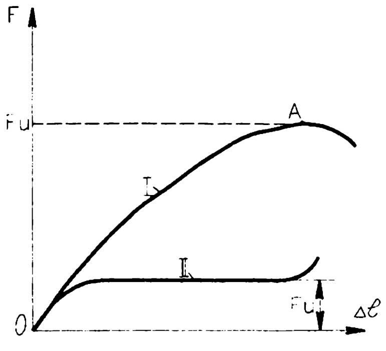


Fig. 4.6. Diagram of compression of a timber

Timber strength (ultimate strength) at compression along fibers is determined by a formula (4.3).

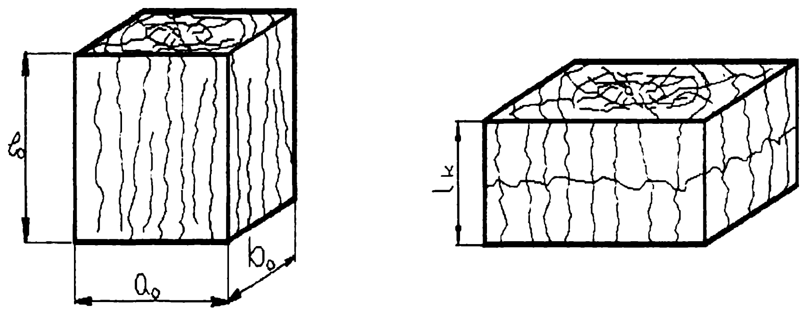


Fig. 4.7. The nature of destruction of a timber cube at compression along fibers

When testing a timber across fibers the picture turns out a bit different. The initial part 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). Significant growth in deformation at weak increase of loading indicates that *load-carrying capability* of a sample is exhausted. Rupture load such at which the cube contracts on 1/3 initial heights are taken for.

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.

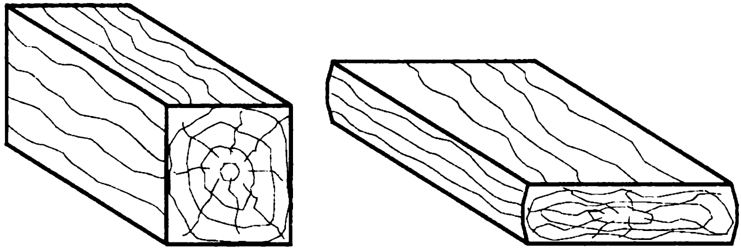


Fig. 4.8. The nature of destruction of a timber cube at compression across fibers

3. 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 sample between plates of a test machine.
4. Load sample and watch the drawn diagram. Load before time point of final fracture of samples.

4. Processing of test results

1. Measure height l_1 of a sample after testing and the result of measurement enter into the table 4.1.
2. For ductile materials determine forces of F_{pr} and F_y (from the diagram), for brittle materials – force of F_u and enter their value into the table 3.
3. On formulas (4.1 – 4.3) define σ_{pr}, σ_y, σ_u and enter results of calculations into the table 4.1.
4. Determine relative deformation by a formula $\varepsilon = \frac{l_o - l_k}{l_o} \cdot 100\,\%$ and results of calculations enter into the table 4.1.
5. Diagrams of engineering stress for steel, cast iron and timber are plotted.

Control questions

1. On what characteristics do materials divide?
2. How does the ductile samples behave under compression and how the brittle?
3. What mechanical characteristics were been defined as a result of compression test of steel samples, cast iron, and timber lengthwise and crosswise of fibers?

4. How did the form of samples of steel and cast iron in the course of testing change? How is it possible to explain?

5. How the cracks formed under testing 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?

Table 4.1.

Material	Sizes of samples				F_{pr}, N	F_y, N	F_u, N	σ_{pr}, MPa	σ_y, MPa	σ_u, MPa	δ, %
	Before experience			After experience							
	d_o, m	l_o, m	A_o, m^2	l_1, m							
Steel											
Cast iron											
Timber along fibers											
Timber across fibers											

LABORATORY WORK № 5

Subject: «Testing of materials for a cut».

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

2. 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 only shearing stresses are acted.

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

$$\tau = \frac{F}{A_{av}} \le R_{av}, \tag{5.1}$$

Where R_{av} – the design resistance of material on a cut. Theoretically design resistance of R_{av} depends on the accepted theory of strength.

So according to the theory of the maximum shearing stress:

$$R_{av}^{III} = 0,5 \cdot R_{st};$$

where: R_{st} – the design strength of material at stretching.

According to the energy theory of strength: $R_{av}^{IV} = \dfrac{R_{st}}{\sqrt{3}}$.

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

The sample is put into the device and clamping (fig. 5.1) by help of captures. Then the sample with gradually increasing load loads up to destruction instant. The sample cuts on two platforms:

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

Besides, the sample presses on cylindrical surfaces. Maximum compressive stress:

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

where:

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

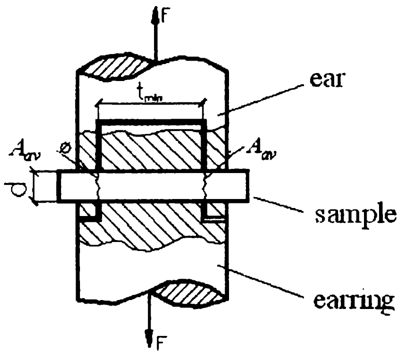


Fig. 5.1. Device for testing of metal for a cut

When testing a timber for shearing the sample in the conductor (fig. 5.2) which locates under plates of a machine (ПММ–125) is established. Then it loads by continuously increasing load up to destruction.

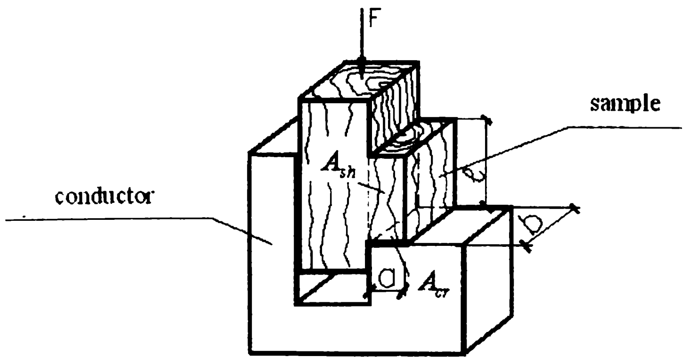


Fig. 5.2. The device and the sample for testing of a timber for shearing

Shearing stress determines by a formula:

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

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

Maximum compressive stress is determined by a formula:

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

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

3. 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 and compression for a metal sample, the area of shearing and compression of a timber sample and the results of calculations enter into the table 5.1.
3. The sample into the captures device in test machine is placed.
4. Make the loading of a sample before destruction and write down values of loadings.

4. 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. Determine compressive stress for metal and timber by formulas (5.2, 5.5).
3. The received strength compare with the strength calculated on one of theories of strength.

Table 5.1.

Material	Sizes of samples, m				A_{av}, m^2	A_{sh}, m^2	A_{cm}, m^2	τ_{av}, MPa	σ_{com}, MPa	τ_{sh}, MPa
	d_o	a	b	l						
Steel										
Timber										

Control questions

1. Describe the scheme of the device which to testing of a steel sample for a cut is used.
2. Show the platforms a cut, shear and compressive stress of samples were.
3. How the values of strength of samples at a cut (shear) in testing were defined?
4. How compressive stress for steel and timber were defined?

LABORATORY WORK № 6

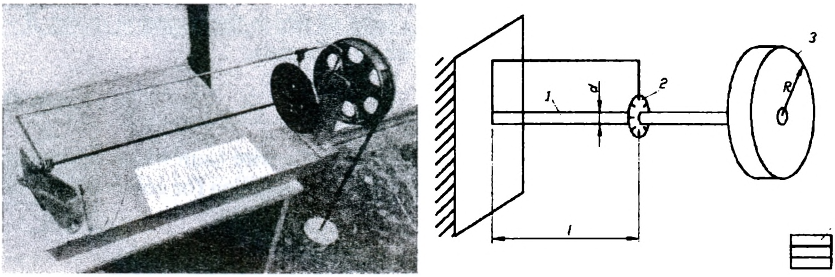
Subject: «Testing of a round steel rod for torsion and screw coil springs with a small step of screws».

1. Work purpose: Determination of the *shear modulus* of steel and its comparison with tabular value.

2. 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 experiment.

For testing of a round steel rod the following installation is made (fig. 6.1).



a) b)

1 Round steel rod, 2 – measuring instrument of an angle of twisting (protractor), 3 - pulley for creation of the twisting moment, 4 – loading

Fig. 6.1. The scheme of installation on torsion

The shear modulus G is defined from a formula:

$$\varphi = \frac{T \cdot L}{G \cdot J_P}, \tag{6.1}$$

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.

In installation the angle of twisting is defined on degrees $\varphi°$. Therefore in a formula the angle of φ has to be recalculated by following way: $\varphi = \varphi° \cdot \frac{\pi}{180°}$.

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

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

1. The load (4) is suspended and the angle of twisting $\varphi°$ not less than three times is measured.
2. Parameters of the sample of L, R, d are measured.

For defining of G obtained data has to be substituted in a formula (6.2).

Results enter into the table 6.1.

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

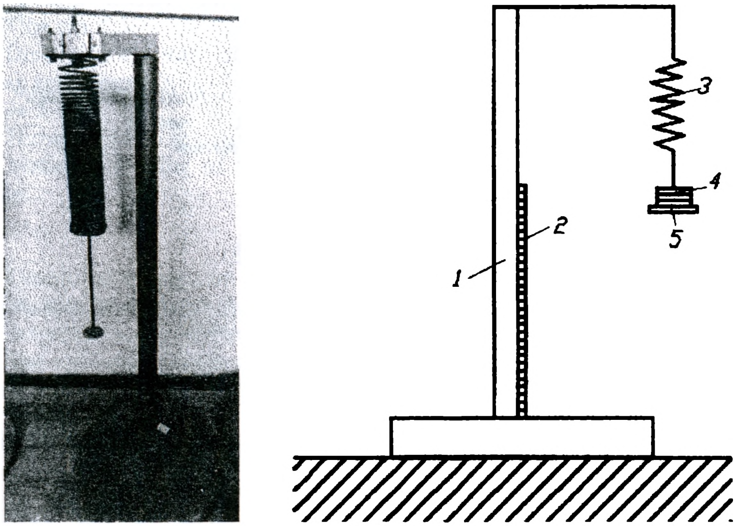
$$\lambda = \frac{4F \cdot R^3 \cdot n}{G \cdot r^4}, \tag{6.3}$$

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 is determined by a formula:

$$R = \frac{D-d}{2}, \tag{6.4}$$

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



a) b)

1 – rack, 2 – ruler, 3 – spring, 4 – loads, 5 – suspender

Fig. 6.2. Experimental installation for experiment with a spring

3.2. Order of carrying out the tests and processing of test results

1. With the help of a caliper the outside diameter of a spring coil of ***D*** and diameter of a wire ***d*** of a coil to within *0,1 mm* is measured.
2. Average radius of a spring coil is determined by a formula (6.4).
3. Beforehand of test necessary to count 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 into the tables are entered.

Table 6.1.

№ of items	R, mm	D, mm	L, mm	F, N	φ^0	G, 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, mm	λ, mm	G, MPa	Note
1									
2									
3									
								G_{av}=	

Conclusions of work:

1. Make a conclusion: whether material submits to Hooke's law.
2. Compare experimental values of the module of ***G*** with tabular data.

Control questions

1. How Hooke's law at shear is formulated?
2. What does mean the angle of twisting?
3. Describe a technique of carrying out of experiments.
4. List elastic constants of materials that are known to you. Name the connections between them.
5. How to determine spring elongation (or compression)?
6. What is the rigidity at torsion?
7. What stress does 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».

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

2. Work content

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

In places of sharp change of cross section of body, at cuts and cracks the concentration of stresses (fig. 7.1) is observed.

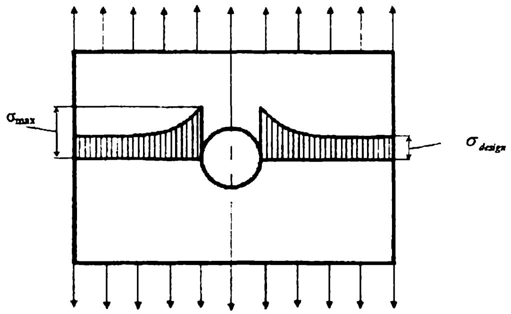


Fig. 7.1. Concentration of stresses

The relation between the maximum stress (calculated with taking into account concentration of stresses in an elastic zone of diagram of deformation of material) and design stress in the same point of section is called – coefficient of concentration of stresses.

$$\alpha = \frac{\sigma_{max}}{\sigma_{design}}. \tag{7.1}$$

The design stress is the stress which is determined by formula of strength of materials without effect of concentration. Usually design stress is determined for the weakened section. For example, for strip is weakened by a hole (fig. 7.1):

$$\sigma_{design} = \frac{F}{A_{net}}. \tag{7.2}$$

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

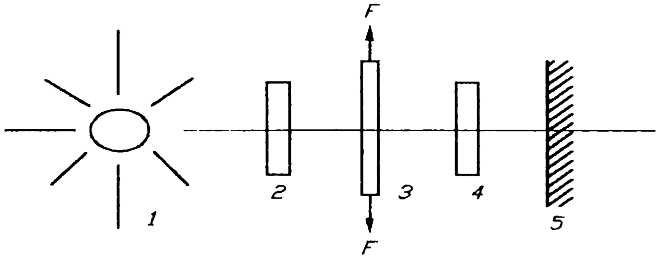
As a rule, the coefficient of concentration of stress is defined experimentally.

The polarizing and optical method bases on the fact that some transparent materials under deformation become statically anisotropic, in the deformed state they acquires property of double refraction (glass, celluloid, bakelite, etc.). In an optical method not the detail itself, but its model from transparent material is made and investigated. The model in the optical installation – polariscope is placed. Then it is irradiated (it is shone through) 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 disposition of the main parts of the polariscope with flat polarization of light is schematically shown.

Main parts of polariscope are polarizer and analyzer. In turn-on-position polarizer and analyzer are mutually perpendicular are turned. In the case when model is absent or doesn't load the ray of light which passes through a polarizer will be liquidated by the analyzer. This position of a polarizer and the analyzer the installation on darkness is called.

By applying load to the model, so that it deforms, material of model will become optically anisotropic, and it will behave as the crystalline body having property of double refraction.



1 – light source; 2 – polarizer; 3 – model; 4 – analyzer; 5 – screen
Fig. 7.2. Scheme of installation

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

3. Order of carrying out the 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. The sample without concentrators of stresses as standard (reference) is accepted. Samples with concentrators – are models.

Fix please a reference sample in captures of the testing machine. Establish a polarizer and analyzer on darkness. Load gradually reference sample and observe the screen. Write down the value of corresponding loading at appearance on the screen the color picture. Having divided the load of a reference sample on the cross-section area of a sample, you can find average stress in reference sample.

The same way the models are tested. In models the color on the screen corresponding to test of a reference sample appears earlier at edges of the concentrator. Having divided the load matching the color of a reference sample on the cross-sectional area of a sample (model with patterns), we find maximum stress in model:

$$\sigma_{ref} = \frac{F_{ref}}{A_{ref}}; \ \sigma_{\max,\mathrm{mod}} = \frac{F_{\mathrm{mod}}}{A_{\mathrm{net,\,mod}}}.$$

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

Control questions

1. Give the definition of theoretical coefficient of stress concentration.
2. Describe the scheme 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 coefficient of stress concentration defined?

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

Table 7.1.

Sketches of holes	A, m^2	F, N	σ, MPa	α
				
				
				
				

LABORATORY WORK № 8

Subject: «Determination of notch impact strength».

1. Work purpose: To determine notch impact strength at a dynamic buckling of a steel sample with a cut.

2. Work content

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

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

For determination of notch impact strength the great propagation has a pendulum impact testing machine (the scheme of installation is shown in fig. 8.1, 8.2).

When testing standard sample (fig. 8.3) pendulum hammer with reserved energy (no exceed than 30 [$\kappa g \cdot m$]) is applied.

In our case on MK-30A – pendulum impact testing machine test is made.

According to GOST 9454-60 sample must have standard size and the cut for a sample is established (fig. 8.3).

If the amount of the energy spent for a break of 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:

$$\alpha = \frac{U}{A}\left[\frac{\kappa g \cdot m}{cm^2}\right]. \tag{8.1}$$

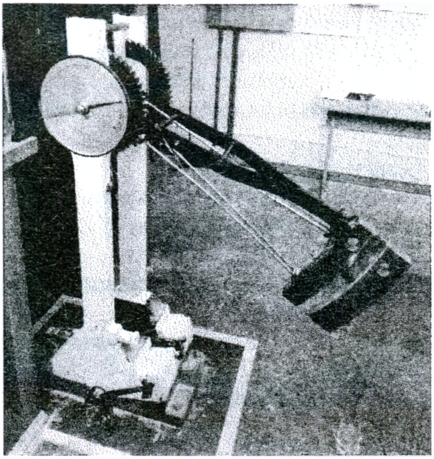
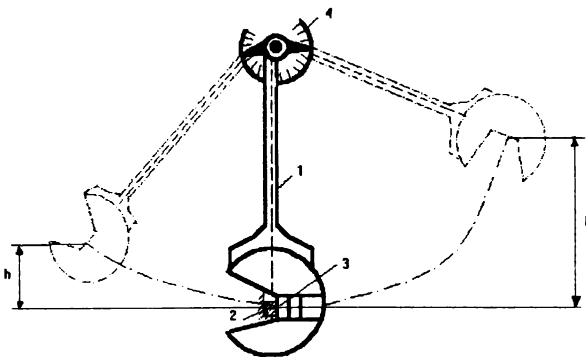


Fig. 8.1. Pendulum impact testing machine



1 – pendulum, 2 – sample, 3 – peen (knife), 4 – scale of measurements
Fig. 8.2. Pendulum hammer

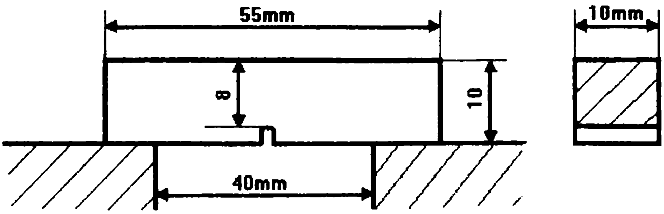


Fig. 8.3. Standard samples for shock test

The sense of a cut is next: material absorbing shock loading try to set the most severe conditions. The local stresses arising herewith represent such system of stresses at which material is in a triaxial (volumetric) stress condition; in this case plastic deformations practically disappear, and material near the bottom of a cut gets a brittle state.

3. Order of carrying out tests

1. Before testing undergo the sample to a careful external examination.
2. Measure the sizes of lateral section in the weakened section of a sample with the help of a caliper.
3. Lift up pendulum hammer on height of ***H*** and fix on measuring instrument scale potential energy an amount of U_0.
4. Established the sample between supports of pendulum impact testing machine a cut aside, opposite of rap.
5. Make a rap and fix amount of potential energy after destruction of a sample – U_1.

4. 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 notch impact strength of material is found.
4. The percentage content of carbon is determined by table 8.1.
5. Conclusion about plastic properties of steel is written down.

Table 8.1.

Characteristics steels and their chemical composition	Heat treatment			
	Annealing		Tempering and issue	
	σ_u, *MPa*	α, $\frac{\kappa g \cdot m}{sm^2}$	σ_u, *MPa*	α, $\frac{\kappa g \cdot m}{sm^2}$
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 notch impact strength of material?
2. What are the features of behavior of materials at impact load?
3. Describe the installation for notch impact strength testing.
4. What does notch impact strength for tested steel characterize?
5. Describe the standard sample and what purpose the cut is made for?
6. What are more dangerous for steel – temperature increase (in the plus side) or lowering below zero from the point of view of the resistance to impact load?

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