Ministry of Education and Science of Ukraine
Vinnytsia National Technical University

Instructions
for laboratory works in discipline
"Biochemistry"
Module "Biomaterials"
for applicants for higher education in the specialty
163 – Biomedical Engineering





Developed in the frame of project "Erasmus+ (CBHE) BioArt "Innovative Multidisci-plinary Curriculum in Artificial Implants for Bio-Engineering BSc / MSc Degrees" (586114-EPP-1-2017-1-ES-EPPKA2-CBHE-JP).

Vinnytsia
VNTU
2020

Laboratoty work № 1
Determination of the contact angle of the bioceramic material surface and biological fluid

The aim of the work is to investigate the wetting characteristics of the biomaterial and its interaction with the liquid.

Tasks of work:

1) to process theoretical information on the topic of work;

2) conduct appropriate experiments and appropriate measurements;

3) draw conclusions based on the results of work and draw up a report.

Theoretical information and guidelines

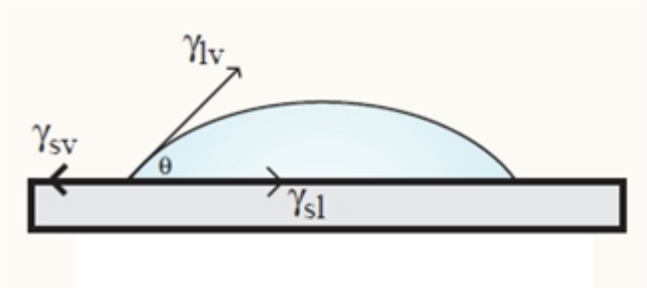
The angle of contact (***θ***) – is the angle formed between a drop of liquid and solid surfaces or other phases.

The balance of forces that affect the contact angle (θ), is described with the equilibrium equation: $\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \cos\theta$

γ_{lv} – is the equilibrium state between the liquid and the gas phase;

γ_{sv} – is the equilibrium state between the solid phase and the gas phase;

γ_{sl} – is the equilibrium state between the solid and liquid phases.



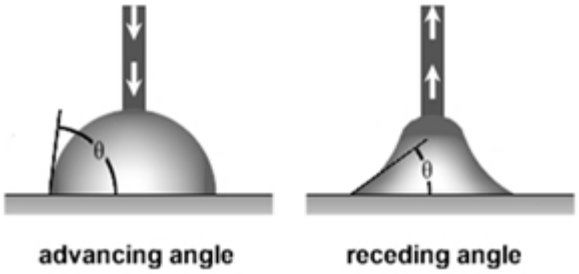
STATIC CONTACT ANGLE

The static contact angle is measured when a drop of liquid is stationary on a solid surface.

DYNAMIC CONTACT ANGLE

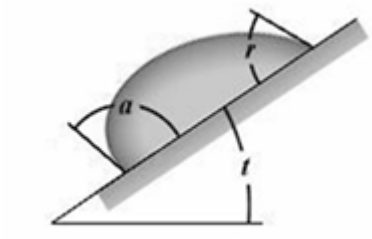
The dynamic contact angle is determined when the phase boundary moves and the static contact angle changes over time. There are two types of dynamic contact angle - advancing and receding. The measurement can be performed using two methods - the drop volume measurement method and the surface tilt method.

Advancing wetting angle θ_a : the largest contact angle is achieved by increasing the interfacial surface with the addition of additional liquid.



Receding wetting angle θ_r: occurs when the volume of a liquid drop decreases.

Hysteresis angle θ_H: is the difference between the advancing and receding angle $\theta_H = \theta_a - \theta_r$



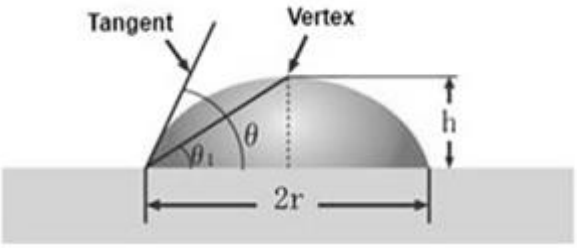
Tilt method: combines both offensive and receding contact angles in one drop. The drop is placed on a desk, which is gradually tilted. The offensive angle is measured at the bottom of the drop (left in the figure) as it begins to move. The receding contact angle is measured at the top of the drop (pictured right).

Method and measurement and calculation of the wetting angle of the lying drop

There are 4 methods of measuring and calculating the wetting angle of a lying drop:

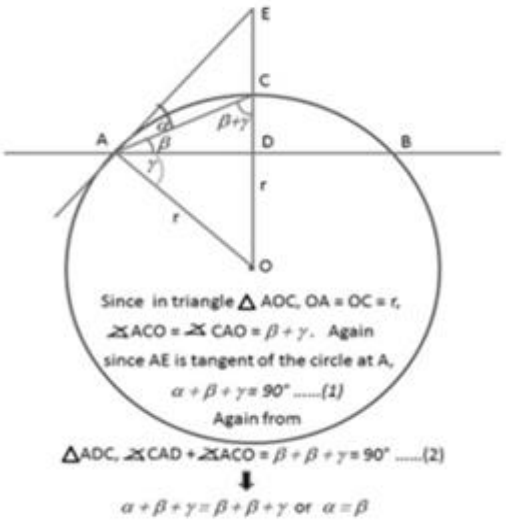
1. Semicircular method
2. Circular method
3. Elliptical method
4. Tangential method

SEMICIRCULAR METHOD



If the size of the drop is small, it can be represented as part of the sphere and the profile of the drop in two dimensions, ie in the form of a semicircle.

Here ***h*** – is the height, and ***r*** – half the width of the baseline. So, $\theta_1 = tan^{-1}h/r$. And in the case of simple geometry, the wetting angle can be expressed as follows: $\theta = 2\theta_1$. (see Figure). After calculating ***h*** and ***r*** using image analysis, one can then calculate the contact angle θ.



This method is suitable for drops of symmetrical shape and small size. For drops of larger size and weight, the height of its top can be reduced.

CIRCULAR METHOD

Stages of calculating the contact angle by the circular method:

- capture and save the image of the drop;
- baseline recognition;
- selection of 3 or more points on the edge of the curved profile of the drop;
- on the curve with these points you can find the equation of the circle;
- the wetting angle is defined as the angle between the tangent and the baseline.

This method is the most common for determining the contact angle.

ELLIPTICAL METHOD

In the elliptical method, the construction of the curve of the drop profile is used. Therefore, it has something to do with the circular method.

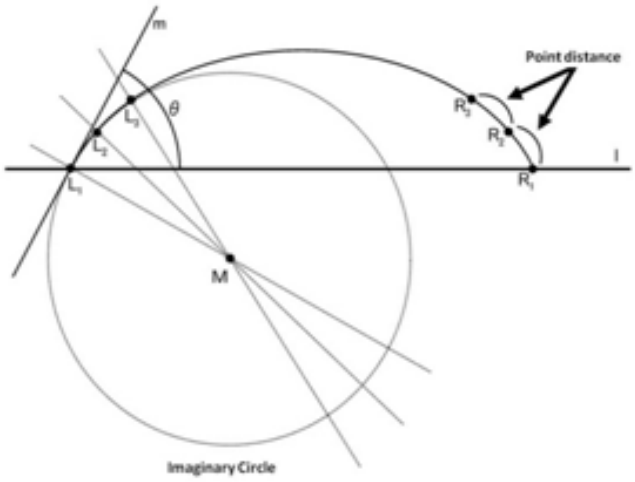
- capture and save the image of the drop;
- baseline recognition;
- selection of 6 base points on the curve;
- calculation of the ellipse equation;
- the wetting angle is defined as the angle between the tangent and the baseline.

Compared to others, this method is quite complex. Therefore, it is used to determine the wetting angle in the range 0–130 °C.

TANGENTIAL METHOD

The shape of the drop is represented as part of the contour of the imaginary circle. This method determines the center of an imaginary circle, and the contact angle is defined as the angle between the tangent and the circle

In this method, the center of the intended circle is determined, and the contact angle is the angle between the tangent and the circle.



Three points L1, L2 and L3 are formed on an imaginary circle. The left contact angle is the angle between the tangent m and the baseline l. The right contact angle can be measured in the same way using the points R1, R2, and R3.

Boundary angle measurement

1. Preparation of a sample of biomaterial

Samples should be prepared in advance and their surfaces should be properly cleaned immediately before measuring the contact angle. The sample should be placed strictly in a horizontal position. The syringe needle must be thoroughly cleaned. This is important because the liquid coming out of the needle may rise slightly up the outer surface of the needle during the experiment. It is desirable to rub the sting of the needle with a non-polar substance (paraffin).

2. Providing humidity / steam conditions

The sample should be placed in a measuring cell filled with working fluid. These operations take place a few minutes before the contact angle is measured. At this stage it is necessary to fix the syringe filled with working liquid, and to align a needle in relation to a sample surface.

3. Measurement of static contact angle

A drop should appear after the liquid comes out of the needle. The diameter of the drop should be 3-4 times the diameter of the needle. The fluid should be supplied until the whole drop comes out of the needle. Next, the needle must be removed. You need to wait 1-3 minutes for the drop to stabilize, after which you can measure the static contact angle.

4. Measurement of the offensive contact angle

The needle should be moved back to the drop and fluid should be added until the base has dissolved. Then the needle is removed and the offensive contact angle is measured. This operation is repeated 3-5 times, after which the average value is taken.

5. Measurement of the receding contact angle

The needle is immersed in the drop in order to begin to draw the liquid into the syringe, reducing the size of the drop. This operation should be performed carefully, without changing the diameter of the drop. After carefully removing the needle, you can measure the receding contact angle. Measurements should be performed 3-5 times, eventually averaging the results.

6. Reproduction of results

The measurement of the contact angle must be repeated either at 3-5 points of the same sample or on other similar samples that have undergone the same stages of purification.

Laboratory work № 2
Testing of polymeric biomaterials

The purpose of the work – is to study biomaterials for hardness by different methods.

Tasks of work:

1) to process theoretical information on the topic of work;

2) conduct appropriate experiments;

3) to draw conclusions based on the results of the work.

Theoretical information and guidelines

Hardness is the property of the surface layer of material to resisting the elastic and plastic deformation or fracture at the local plastic interaction by other, more rigid body (indenter) of specific shapes and sizes.

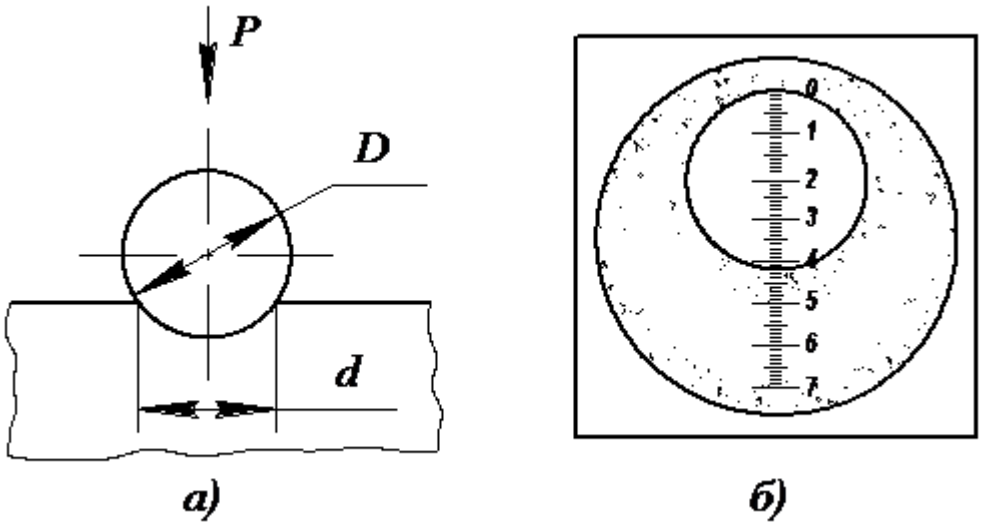


Figure 2.1. Measurement of hardness by the Brinell method:
a - the scheme of imprint formation; b - measurement of the diameter of the imprint

For many alloys there is a clear relationship between hardness, mechanical and technological characteristics (strength, wear resistance, machinability, cutting, pressure, etc.). Therefore, hardness measurement is the most common method of mechanical testing. Methods for determining hardness are divided into static and dynamic depending on the speed of application of the load, and according to the method of its application - on the methods of indentation and scraping. The most common methods use static loading of the indenter perpendicular to the surface of the sample. These are the methods of Brinell, Rockwell and Vickers.

Brinell hardness is determined in accordance with GOST 9012-59. A hardened steel ball with a diameter of 10 is used as an indenter; 5 or 2.5 mm, which is pressed into the surface of the material under load from 153 to 29400 N (from 15.6 to 3000 kg). An imprint (hole) in the form of

a spherical segment with a diameter d is formed on the surface of the sample (Fig. 2.1, a). This diameter is measured using a special microscope, on the eyepiece of which is applied a measuring scale with divisions equal to one tenth of a millimeter. The diameter of the imprint is determined by the average value of its two measurements in mutually perpendicular directions with an accuracy of 0.05 mm (Fig. 2.1, b). The number of Brinell hardness, denoted by the letters HB (H - from the English. Hardness - hardness, B - Brinell), is measured by the ratio of the load P acting on a ball with a diameter of D, to the area of the imprint F:

$$HB = \frac{P}{F} = \frac{2P}{\pi D \cdot (D - \sqrt{D^2 - d^2})}.$$

Brinell hardness unit is - *kg/mm*^{2} or *MPa (MN/m*^{2}*)*. In the first case, the hardness is written as follows: *HB 200, HB 250,* де *200; 250* - the value of hardness in *kg/mm*^{2}. If the hardness is measured in MN/m^2, the record is as follows: *HB* 2000 *MPa*, *HB* 2500 *MPa*. The diameter of the ball, the load and the holding time under load are chosen depending on the expected hardness and thickness of the material (table 3). When measuring the hardness of a ball of a certain diameter with a corresponding load in practice use a standard table, which shows the values of HB depending on the diameter of the hole and the ratio *P/D*^{2} (table 1). When measuring Brinell hardness, the following conditions must be met:

- the surface of the sample must be flat, clean and smooth;

- the sample must lie firmly on the table-stand , so that during the measurement of hardness there is no displacement or bending; the thickness of the sample must be at least ten times the depth of the impression (more than 1 ... 2 *mm*);

- the distance from the center of the impression to the edge of the sample must be not less than 2.5 *d* , and between the centers of two adjacent impressions - not less than *4d;* for metals with *HB* <350, respectively, 3 *d* and 6 *d* .

Table 1 – Brinell hardness when D = 10 мм, P = 29430 N (3000 kg) і P = 30 D^2

d, mm	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.06	0.09
2.90	444	441	438	435	432	429	426	423	420	417
3.00	415	412	409	406	403	401	398	395	393	390
3.10	388	385	383	380	378	375	373	370	368	366
3.20	363	361	359	356	354	352	350	347	345	343
3.30	341	339	337	335	333	331	329	326	325	323
3.40	321	319	317	315	313	311	309	307	306	304
3.50	302	300	298	297	295	293	292	290	288	286
3.60	285	283	282	280	278	277	275	274	272	271
3.70	269	268	266	265	263	262	260	259	257	256
3.80	255	253	252	250	248	248	246	245	244	242
3.90	241	240	239	237	236	235	234	232	231	230
4.00	229	228	226	225	224	223	222	221	219	218
4.10	217	216	215	214	213	212	211	210	209	208

4.20	207	205	204	203	202	201	200	199	198	198
4.30	197	196	195	194	193	192	190	189	188	188
4.40	187	186	185	185	184	183	182	181	180	179
4.50	179	178	177	176	175	174	174	173	172	171
4.60	170	170	169	168	167	167	166	165	164	164
4.70	163	162	161	161	160	159	158	158	157	156
4.80	156	155	154	154	153	152	I52	151	150	150
4.90	149	149	148	147	I46	146	145	144	144	143
5.00	143	142	141	141	140	140	139	138	138	137
5.10	137	136	135	135	134	134	133	133	132	132
5.20	131	130	130	129	129	128	128	127	127	126
5.30	126	125	125	124	124	123	123	122	122	121
5.40	121	120	120	119	119	118	118	117	117	116
5.50	116	115	115	114	114	114	113	113	112	112
5.60	111	111	110	110	110	109	109	108	108	107
5.70	107	107	106	106	105	105	105	104	104	103
5.80	103	103	102	102	101	101	101	100	99.5	99.5
5.90	99.2	98.8	98.4	98.0	97.7	97.3	96.9	96.6	96.2	95.9
6.00	95.5	-	-	-	-	-	-	-	-	-

Rockwell hardness is determined by pressing into a sample indenter in the form of a diamond cone with an angle at the apex of 120 ° or a steel ball with a diameter of 1,568 *mm* (1/16 inch - 1 / 16²). The load on the indenter is carried out sequentially: first, the previous P_0 equal to *100 N* , then the main P_1 . The sum of the previous and main load is the total load *P* , which is selected depending on the indenter and the expected hardness (table 2).

According to the difference in indentation depths of the indenter under the action of two consecutive loads P_0 and P_1 conclude the hardness of the material. The arrow of the Rockwell instrument indicator shows not this difference, but the value (100 - *c*) on the black scale *C* or *A* and (130 - *c*) on the red scale *B* , where $b = (h_1 - h_0) / 0{,}002$; h_1 and $h_{0\,the}$ depth of indentation of the indenter when applying, respectively, full and preload; 0.002 - conventional unit of hardness (the price of dividing the scale of the indicator of the device).

The Rockwell hardness unit is a dimensionless quantity that corresponds to the axial displacement of the indenter by 0.002 mm. Hardness on Rockwell indicated as follows: *NRV* 30 *NRS* 60 *NRA* 80, ie 30 per hardness scale *in* 60 - on scale C, 80 - A. The numbers on a scale *NRA* can be translated into numbers *NRS* formula *NRS* = 2 *NRA* - 104.

The scheme of measuring Rockwell hardness is shown in Fig. 2.2.

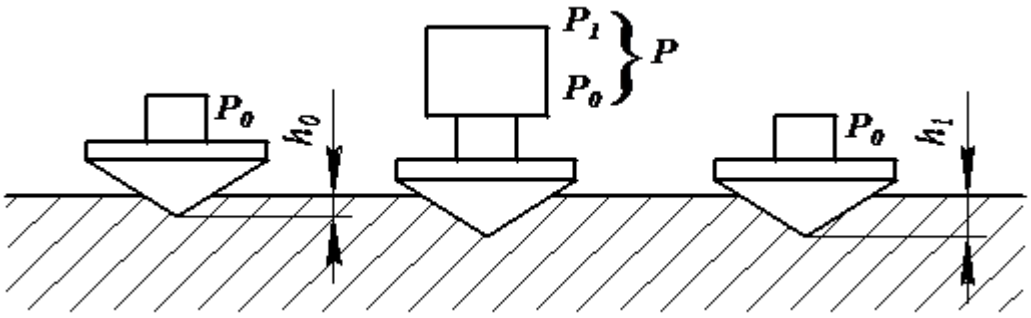


Fig. 2.2. Rockwell hardness measurement scheme

The value of Vickers hardness *HB is* determined by dividing the load P by the area of the side surface of the obtained pyramidal imprint F:

$$HV = 2\ P\ sin\ (a / 2) / d^2 = 1.854\ P / d^2,$$

where *d* - is the arithmetic mean of the two diagonals of the imprint;

$a = 136°$ - the angle at the top of the pyramid.

Hardness is measured in kg / mm^2 and recorded *HB* 200 without unit of measurement or in N / m^2 and recorded with unit of measurement, for example, *HB* 2000 *MPa* .

Numbers *NV* and *NV* are close in magnitude, but only to a value of about *HB* 400. Above these values method Brinellya gives distorted results due to permanent deformation of steel balls. The diamond pyramid in the Vickers method allows to determine the hardness of almost any metallic material. An even more important advantage of this method is the strict comparison of the hardness numbers HB of any materials tested at different loads.

Table 2 - Conditions for measuring Rockwell hardness

Approximate Brinell hardness, kg/mm^2	Scope of application	Rockwell instrument scale	Indentor type	Load *P, N*	Limits of measuring hardness on a Rockwell scale
More then 700	Superhard materials, cemented steels	*A* black	Diamond cone	600	70 ... 90
230 ... 700	Solid and heat-treated steels	*C* blazk	Diamond cone	1500	20 ... 67
60 ... 230	Soft materials	*B* red	Steel ball	1000	25 ... 100

Other methods of determining hardness . To measure the hardness of massive parts and structures, when the described methods can not be used, the method of impact printing (GOST 18661-73). The device for this purpose consists of the case, a fight, balls, springs. A reference sample, the hardness of which is known, is inserted into the slot of the housing. To measure the hardness of the product, the device is placed with a ball on its surface and the hammer is struck with a hammer. In this case, the ball simultaneously forms impressions (holes) in the tested part

and in the standard, the surfaces of which are proportional to the hardness of these materials. The number of hardness of the test material is determined in Brinell units

$$HB = HB_e \times F_e / F_д ,$$

where HB_e - is the hardness of the standard in Brinell units;

F_e - surface area of the impression on the standard, mm^2;

$F_д$ - surface area of the imprint on the part, mm^2.

Of the other dynamic methods of hardness assessment should be noted the method of impact rebound (Shore method) - GOST 23273-78. Hardness is determined using diamond tipped hammer falling from a fixed height H . When a striker weighing q falls from a height H, the impact energy is expended on the irreversible process of plastic deformation and on the elastic deformation, which returns to the stride in the form of the energy of the elastic rebound $A_2 = h \times q$. The total impact energy will be $A_1 = H \times q$. The energy that went to the residual deformation will be $A = A_1 - A_2 = q (H - h)$. Thus, the more energy went to the residual deformation, the softer the material and the lower the bounce height of the striker h .

The height of the bounce of the striker is fixed by the position of the arrow on the scale of the indicator. The scale has 140 divisions to estimate the rebound height. The rebound in 100 divisions corresponds to the hardness of hardened high - carbon steel. The Shore hardness number is denoted by *HSD* . The advantage of this method is the ability to check the hardness of the polished parts of the bases of the violation of surface quality.

Recently, the ultrasonic method of measuring hardness has been widely implemented.

Laboratory work № 3
Study of the mechanical properties of biomaterials

The purpose of the work is to investigate biomaterials for strength .

Tasks of work:

1) to process theoretical information on the topic of work;

2) to conduct experiments on a bursting machine ;

3) to draw conclusions based on the results of the work.

7.1. The main technical characteristics of the equipment

The universal rupture machine UIT STM-10 provides tensile tests of cylindrical and flat samples according to ISO 6892-84, GOST 1497-84, DSTU EN 10002-1: 2006; compression tests according to GOST 25.503; technological tests of samples (Fig. 3.1).

The main technical data and characteristics are given in table 3.1.

Table 3.1. Basic technical characteristics

The main parameters of the test machine UIT STM-10	**Units**	**Features**
The smallest limit value of the force, no more	kg s	10,00
The largest limit value of the force, not less	kg s	1 000,00
The relative error of the system for measuring, displaying, recording and recording the force, from the value of the measured force, at given elongations and at the time of rupture, not more	%	± 0,5
Range of movement of a traverse (without equipment), not less	mm	1 000,0
The accuracy of the system of measurement, display, registration and recording of movement, not less	mm	± 1,0
Servo drive with built-in function of automatic elimination of low-frequency vibration of the executive mechanism.		+
The high-precision encoder that guarantees stable operation at low speeds with the characteristic, not worse	bit	20
The permissible error of relative elongation readings from the measured value is not more	%	2,0
The smallest value of the speed of the movable clamp , no more	mm/min	0,05
The largest value of the speed of the movable clamp , not less	mm/min	1 000,0
The lower limit of the temperature range of the working space, at which the measurement errors are provided, is not more	ºC	10,0
The upper limit of the temperature range of the working space, at which the measurement errors are provided, is not less	ºC	45,0
Existence of the module of functions of the maintenance of a traverse under static loading for a long time		+

The main parameters of the test machine UIT STM-10	**Units**	**Features**
Supply voltage	-	220 (±10%) В 50±1 Гц
Possibility to install a device for measuring the hardness of large metal products		+
Contact extensometer	mm	Base 50 mm (estimated length), deformation 25 mm (50%)
Software:		
-- load speed task; -- display of parameters on the display in real time; -- test chart analysis (scaling, setting points); -- drawing up test reports and exporting data.		+
Control parameters during the compression test: - plotting the dependence "load - traverse movement".		+



Fig. 3.1. Appearance of the UIT STM-10 universal test machine

Functionalities of the UIT STM-10 test machine:

Formation of the report form according to the Customer's form

Registration function, display; logging of measured and calculated data:

- the value of the tensile speed, mm / min .;
- force, indication in real time, kgf (H);

- force at a given elongation, kgf (H);
- tensile strength, kgf / cm2 (MPa);
- movement, indication in real time, mm;
- relative elongation, indication in real time,%;
- relative elongation at the time of rupture,%;
- stress at a given elongation, kgf / cm2 (MPa);
- plotting in different coordinates

The verified software package is compatible with Microsoft Windows for measuring and evaluating parameters according to GOST 1497:

- limits of proportionality,
- elastic limits,
- limits of physical fluidity,
- conditional fluidity limits,
- temporary resistance,
- relative uniform elongation,
- relative elongation after rupture,
- relative narrowing of the cross section.

Function of data transfer via USB to a personal computer

Overload protection function of the test machine with operator notification

Load or displacement restriction function during compression tests

When testing for tension to fix the sample put special sponges: for round samples – sponges with a relief groove, for flat samples – sponges with a flat surface having a notch.

When tested for compression in the body of the upper clamp is fixed to the support plate, and on the lower – support, which is self-installing. When tested on a bend in the body than upper clamp set, and the lower clamps – table bend (which is a beam with two legs that move).

BRIEF THEORETICAL INFORMATION

The question of safe and reliable operation of artificial implants , modeling the behavior under load of different types of connective tissue is solved mainly on the basis of experimental study of the characteristics of the respective materials under load until their destruction.

Mechanical tests of materials are various. But the main and most common type of tests tensile. The resulting strength and ductility characteristics allow us to assess the strength of the material under static load and use them to calculate artificial implants.

According to the mechanical properties of materials are divided into two main groups: plastic and brittle. The first have a relatively large plastic (residual) deformation, the second is destroyed by a very small residual deformation. To study these properties of materials, special devices are installed on the test machines, which register the deformation of the sample Δl, the tensile force P and cross out the tensile diagram $P = f(\Delta l)$. The dependence curve between the deformation of the sample Δl and the forces that caused it is called the tensile diagram (Fig. 3.2).

At the beginning of the test on the tensile diagram, a small curved section is crossed out due to the elimination of gaps between the contacting parts of the test machine and due to the

compression of the sample heads in the clamps of the machine. When processing experimental data, this area is not considered. With a further increase in load, a rectilinear sloping section of *OA is* observed. In the *OA* region, there is a linear relationship between the elongation of the sample Δl and the tensile force P , ie the sample material is stretched according to Hooke's law.

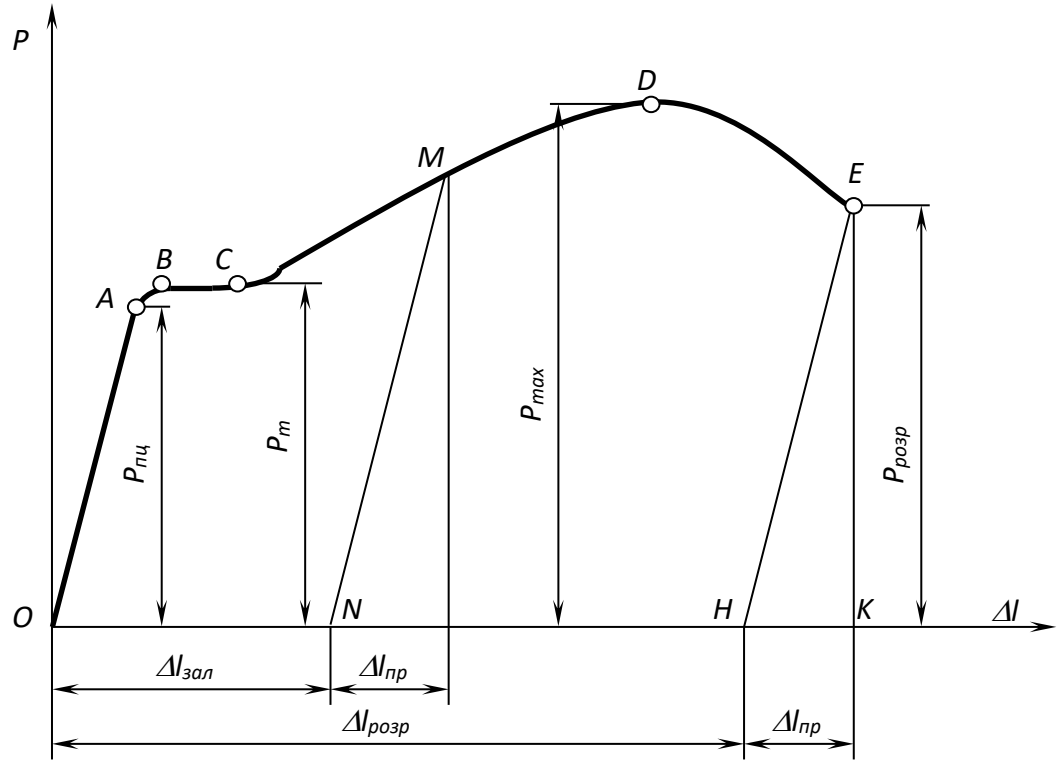


Fig. 3.2. Tensile diagram of low carbon steel in coordinates *P–Δl*

The maximum stress at which the proportional relationship between deformations and loads is still preserved (point A of the diagram) is called the proportionality limit.

$$\sigma_{nц} = \frac{P_{nц}}{F_0}, \tag{3.1}$$

where $P_{nц}$ – is the force corresponding to point *A* on the diagram (see Fig. 3.2);

F_0 – the initial cross-sectional area of the sample.

The transition point for *A* justice law Hooke broken, elongation strength is more intense growth *of P*. The line *OA* passes into the curve *AB* . At point *B, the* curve turns into a horizontal or almost horizontal line *VS* , which indicates an increase in length with a constant or very small increase in force. The material "flows" (fluidity zone).

The stress at which the fluidity of a material is observed is called the yield strength.

$$\sigma_m = \frac{P_m}{F_0}, \tag{3.2}$$

where P_m – is the ordinate of point *B* of the diagram.

At the load corresponding to the σ_m, plastic deformation noticeably increases (there are shifts along the entire volume of the sample and on the polished surface there are lines Chernov - Luders , which make an angle $\alpha \approx 45°$ with the direction of the axis of the sample).

In the area of the *CD* diagram (hardening zone), the sample receives significant residual elongations. If the sample is unloaded at this point in time and then reloaded, the mechanical properties of the sample will be different from its initial properties. The line of unloading *MN* and *reloading NM is* drawn parallel to the segment *OA* . After unloading, the residual deformation remains in the sample $\Delta l_{зал}$, and the elastic part of the total deformation disappears. Hence an important conclusion – elastic deformations occur in the sample and beyond proportionality, and here they still operate according to Hooke's law .

Increasing the boundary of proportionality and reducing the ductility due to the preliminary deformation of the sample beyond the yield strength is called hardening, the effect of which on steel is similar to the action of hardening. The positive effect of hardening used in the preparation of high-wire (cold drawing), pre-extract circuit vantazhopid'yemnyh machines and so on .

Point *D of the* diagram determines the largest value of the force P_{max} for this test . Before loading P_{max} deformations are evenly distributed along the length of the working part of the sample. When the load P_{max} reaches the deformation is localized and the sample appears local narrowing, called the neck. All the deformation of the sample is further concentrated only in the neck and the sample is elongated only due to plastic deformation in the neck. The cross-sectional area of the neck decreases more intensely with increasing force. In the diagram, this circumstance is marked by a decrease in the force *P* (section *DE*).

It should be noted that in the neck there is a volumetric stress (uneven comprehensive stretching). The exact law of stress distribution across the section is not known. Therefore, the practical characteristic of the tensile strength of the material is not the stress corresponding to the fracture, but much less stress, which is called the tensile strength
or temporary resistance of the rupture material:

$$\sigma_в = \frac{P_{max}}{F_0}, \tag{3.3}$$

where P_{max} – is the maximum force that can withstand the sample.

Characteristics of plasticity

The ability of steel to deform plastically without fracture is characterized by a relative residual elongation

$$\varepsilon = \frac{\Delta l_{розр}}{\Delta l_0} 100\% \tag{3.4}$$

and a relative narrowing of the cross-sectional area of the sample after rupture

$$\Psi = \frac{F_0 - F_ш}{F_0} 100\%, \tag{3.5}$$

where $\Delta l_{разр}$ – is the absolute residual elongation of the working part of the sample;

$F_ш$ – cross-sectional area of the neck after rupture. The mechanical characteristics of the material in tension, as experiments show, depend not only on its physical properties and conditions in which the test is performed, but also on the shape and size of the sample. In order to always obtain the same results for the same material, regardless of the size of the sample, it is necessary to observe the following conditions in the manufacture of samples:

$$\frac{\sqrt{F_1}}{l_1} = \frac{\sqrt{F_2}}{l_2} = ... = \frac{\sqrt{F_n}}{l_n} = const. \tag{3.6}$$

According to the norms in force in Ukraine, the main ratios for the selection of samples are:

$$\frac{l_0}{\sqrt{F_0}} = 11{,}3; \tag{3.7}$$

$$\frac{l_0}{\sqrt{F_0}} = 5{,}65; \tag{3.8}$$

The ratio (3.7) corresponds to the so-called ten-fold sample of circular cross-section, in which the calculated length $l_0 = 10\ d_0$; relation (7.8) – fivefold ($l_0 = 5d_0$). Samples with a diameter $d_0 = 20$*мм* are called normal, others are proportional.

In this work, a steel (stainless steel 40X13) or titanium sample of cylindrical shape (Fig. 3.3) with a diameter $d_0 = 3$ *mm* and a length of the working part $l_0 = 30$ *mm is used* . The tests are performed on a universal testing machine .

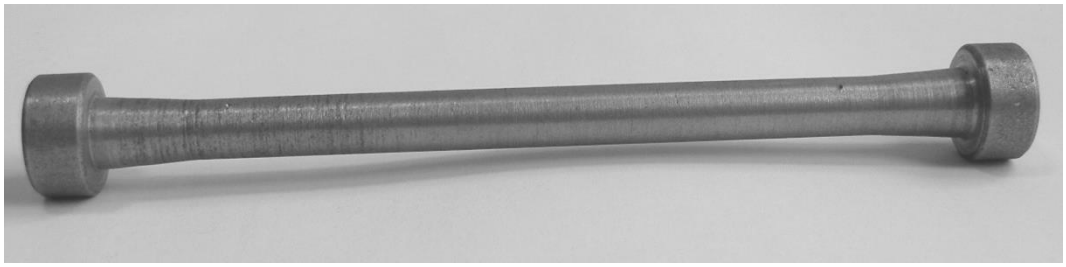


Fig. 3.3. Sample

Test procedure

1. Draw a sketch of the sample (Fig. 3.4):

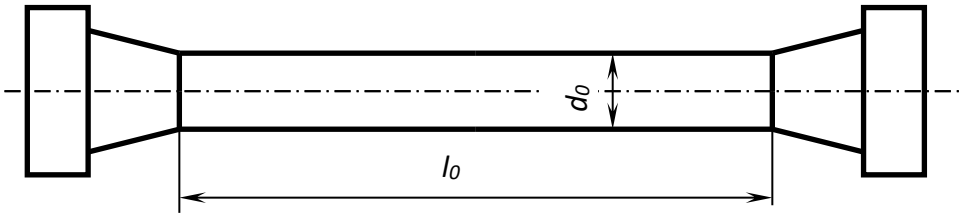


Fig. 3.4. Sketch of the sample

2. Measure the diameter of the sample to the nearest 0,01 *mm* in three places along the length (in the middle and at the edges), in each place in two mutually perpendicular directions. In the smallest cross section, take the arithmetic mean of two mutually perpendicular diameters, which are taken as the calculated value of d_0.

3. For the calculated length of the sample l_0 take the distance between two marks applied to the edges of the working part of the sample. Measure the length l_0 with a caliper to the nearest 0.1 *mm* .

4. Install the sample in the machine and perform the test. In this case, the dependence between the load *P* acting on the sample and its absolute elongation Δl is automatically recorded on the drum of the machine .

5. During the test it is necessary to note on the scale of the force meter load P_t at which the stress in the sample reached the yield strength σ_m (at this time the load growth stops for a while with increasing deformation of the sample), the maximum load P_{max} that can withstand the sample; load at the time of rupture $P_{category}$.

6. After rupture of the sample, measure its diameter d_w at the rupture point (neck).

7. Both of the sample after the break put a one to one which is denser and measure the length *l* of the working part of the sample between the two marks. Record the measurement results in table 3.1.

Table 3.1. Test template

Sample dimensions				Resistance of the sample			
before the test		after testing					
l_0, *mm*	d_0, *mm*	*l*, mm	*d*, *mm*	$P_{пц}$, *N*	P_m , *N*	P_{max} , *N*	$P_{розр}$, *N*

Processing of test results

The value of loads $P_{пц}$,P_m і $P_{розр}$ are taken from the chart recorded on vyprobuvalnыy machine.

За величинами d_0 і l_0 обчислюють початкову площу F_0 і об'єм робочої частини зразка V_0 , а по $d_ш$ – площу перерізу шийки $F_ш$.

За формулами (2.1.1) – (2.1.5) обчислюють характеристики міцності $\sigma_{пц}$, σ_m , $\sigma_в$ і характеристики пластичності ε, ψ.

Результати розрахунків занести в таблицю 7.2.

The value of loads $P_{пц}$,P_m і $P_{розр}$ are taken from the chart recorded on vyprobuvalnыy machine.

The magnitude d_0 and l_0 is calculated starting area F_0 and the volume of the working part of the sample V_0 , and d_w – cross-sectional area of cervical F_w.

By formulas (3.1)–(3.5) calculate the strength $\sigma_{пц}$, σ_m , $\sigma_в$ characteristics and ductility characteristics ε, ψ.

The results of the calculations are listed in table 3.2.

Table 3.2. Characteristics of strength and ductility

	Material	$\sigma_{пц}$, MPa	σ_m , MPa	$\sigma_в$, MPa	ε %	Ψ %

Experiment						
Reference handbook						

Using the found values of the tensile strength $\sigma_в$, and relative elongation ε, narrowing Ψ, compare the obtained data with the reference data.

Control questions

1. What are the characteristic points of the tensile diagram of the sample?
2. How to determine the limits of proportionality of yield strength and tensile strength?
3. At what load does the neck appear on the sample?
4. How to determine the relative elongation and narrowing of the sample after its rupture?
5. How to determine the proportion of elastic and residual deformations outside the proportionality diagram?

Laboratory work № 4
Determination of the modulus of elasticity of biomedical materials

The purpose of the work is to determine the key mechanical characteristic of biomaterial y - modulus of elasticity .

Tasks of work:

1) to process theoretical information on the topic of work;

2) to conduct experiments on a bursting machine;

3) to draw conclusions based on the results of the work.

Brief theoretical information

In the initial stage of the tensile load –compression within the elasticity for most materials there is a linear relationship between the axial load *P* and elongation Δl :

$$\Delta l = \frac{Pl}{EF}, \tag{4.1}$$

where l – is the initial length of the part of the sample whose elongation varies (for example, the base of the extensometer); F – is the cross-sectional area of the sample.

The value of the force P in expression (4.1) should not exceed $P_{max} = \sigma_{nц} F$, where $\sigma_{nц}$ – is the limit of proportionality of the sample material..

The longitudinal deformation of the sample is characterized by the absolute longitudinal deformation Δl and the relative longitudinal deformation:

$$\varepsilon = \frac{\Delta l}{l_0} \tag{4.2}$$

To determine the values of the elastic constants E and μ of the investigated material, we use formulas (4.1), (4.2), from which we find

$$E = \frac{P}{F \cdot \varepsilon} \tag{4.3}$$

To increase the accuracy of measurements, the sample is loaded in steps, increasing the load each time by the same amount. Small linear deformations are measured with a strain gauge.

Test procedure

1. Draw a sketch of the sample.
2. Attach the sample to the test machine clamp.
3. Install an extensometer on the sample.

4. To eliminate errors at the beginning of the test (elimination of gaps in the components of the test machine, slippage of the sample in the clamps of the machine, etc.), the values of ΔP should be set from the previous load P = 100…200 N.

5. Load the sample in uniform steps to a force of 8… 9 kN .

6. Record the measurement results in table 4.1.

Table 4.1. Results

	Load P, N	Deformation measured by the extensometer, Δl , mm	Relative deformation, ε_i
1			
2			
3			
4			
5			

Processing of test results

The values of relative deformations ε at each load stage are defined as the difference between the values of the end ε_{i+1} and the beginning ε_i of the stages. The average values will be equal to:

$$< \varepsilon >= \frac{\varepsilon_1 + \varepsilon_2 + ... + \varepsilon_k}{K};$$

where K is the number of stages.

The modulus of elasticity according to the experiment is calculated by the formula

$$E = \frac{\Delta P}{< \varepsilon > F},$$

Control questions

1. What is the physical and geometric content of the modulus of elasticity E ?

2. Why in the determination of E stresses should not exceed the limits of proportionality?

3. How does the value of E depend on the grade of steel?

4. What are the ways to increase the accuracy of E determination ?

List of references

1. Da Poian, A. T. Integrative Human Biochemistry: A Textbook for Medical Biochemistry / Andrea T. Da Poian, and Miguel A. R. B. Castanho. – Springer, 2015. – 421 p.
2. Biomedical engineering fundamentals / eds.: Joseph D. Bronzino, and Donald R. Peterson. – CRC press, 2014.
3. Chen, Q. Biomaterials: a basic introduction / Qizhi Chen and George Thouas. – CRC Press, 2014.
4. Biomaterials in artificial organs / ed. John P. Paul. – Springer, 2016.
5. Ducheyne P. Comprehensive biomaterials. Vol. 1 / Paul Ducheyne. – Elsevier, 2015.
6. Molecular, Cellular, and Tissue Engineering / eds.: Bronzino, Joseph D., and Donald R. Peterson.. CRC Press, 2015.
7. Методичні вказівки для самостійної роботи студентів, лабораторні роботи та завдання із курсу біохімії / укл. Будняк О. К.та ін. – Одеса : ОНУ ім. І. І. Мечникова, 2003. – 60 с.
8. Біохімія : підручник / Л. І. Остапченко, Т. Р. Андрійчук, Ю. Д. Бабенюк та ін. ; упоряд. О. В. Скопенко. – К. : Київський університет, 2012. – 695 с.
9. Шевряков М. В. Практикум з біологічної хімії : навчальний посібник / Шевряков М. В., Яковенко Б. В., Явоненко О. Ф. – Суми : Університетська книга, 2003. – 204 с.
10. Явоненко, О. Ф. Біохімія : підручник / О. Ф. Явоненко, Б. В. Яковенко. – Суми : ВТД "Університетська книга", 2002. – 380 с. – ISBN 966-680-039-X.
11. Біохімія : підручник / М.Є.Кучеренко, Ю.Д.Бабенюк, О.М.Васильєв. – К. : Київський університет, 2002. – 480 с. – ISBN 966-594-334-0.

This project has been funded with support from the European Commission. This publication / communication reflects the views only of the author, and the Commission cannot be held responsibility for any use which may be made of the information contained therein