MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Aviation University

MATERIALS SCIENCE

Laboratory works manual
for students of Field of Study 27 "Transport",
Speciality 272 “Aviation transport”

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LABORATORY WORK 1

THE INVESTIGATION OF METAL AND ALLOY STRUCTURE

The purpose of the work: to get acquainted with the main concept of microanalysis; to study a process of microscopic section preparation; to study a microscope construction and its adjustment; to master some methods of grain size measuring;

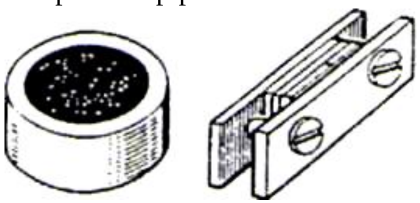
The task of the work: to determine the grain size of commercially pure iron by the method of eyepiece and objective micrometers.

Theoretical Information: microanalysis is investigation of metal and alloy structure by metallographic microscope with magnification from 50 to2000. Microanalysis is used for investigation of:

- a shape and a size of the crystalline grains in metals and alloy;
- changing metal and alloy microstructure after different types of heattreatment;
- microdefects in metals and alloys, for example, microcracks;
- nonmetallic inclusions, such as sulphides, oxides.

The main stages of microanalysis are preparation of microscopic section and its investigation by metallographic microscope.

A metal specimen, which surface is specially processed for microanalysis, is called microscopic section. It is removed from investigated part by cutting off. The most comfortable shape of microscopic section is cylinder with 10-12 mm in a diameter (Fig.la) and 12-10mm in a height or parallelepiped with area of cross-



section 12x12mm and 10mm in height (Fig.lb).

a) b) a) b)

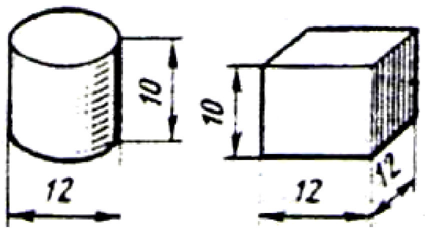


Fig. 1 The most comfortable shape and size of microscopic section:
a) cylinder; b)parallelepiped

Fig. 2 Fixing mechanisms for microscopic section:
a) a pattern; b) a cramp

If an investigated specimen is very small, for example, wire or thin metal sheet, it will be fixed in a special cramp (Fig.2b) or pressed into plastic, such as polystyrene or bakelite. Sometimes a small specimen is mounted in pattern of comfortable shape and size, and is run with a material with low melting point, for example, sulphur or compound.(Fig.2a)

Next stage is facing, because of an investigated surface of microscopic section must be flat plane. This flat plane is obtained by filing (for soft materials) or by abrasive wheel working (for hard materials).

After that, a flat plane is grinded by emery clothes with the different grit (grain) size, at first with coarse grains and then little by little with more fine grains. Grinding may be carried out manually or by grinding machine (grinder). For manual grinding an emery cloth or emery paper is placed on a thick glass or special lapping plate. A specimen flat plane is pressed to grinding material and moved on it in directions perpendicular to the marks, which are formed after filing (previous stage). Grinding is carried out until complete disappearing marks after previous processing. After this stage a microscopic section is washed and wiped by cotton wool. Then a specimen is turned at ∠90° and again grinded by emery cloth with more **fine** grains. This operation is repeated to high surface finish.

Next stage is polishing, which also may be manual or machined. For polishing diamond powder or chromium oxide or alumina is suspended in water and applied on cloth or felt. A microscopic section is slightly pressed and chaotically moved on these materials. As result, a microscopic section surface will be very smooth. Then after washing and wiping, a microscopic section is etched. The main idea of etching is the different solution or different interaction of metal structural components or phases by action of etching reactants, such as acids, alkalis, their solutions or mixtures. For, example, carbon steels and pure iron are etched by water solution of nitric acid. After etching, the more soluble phases are more deep and look like valleys, but less soluble phases are less deep and look like hills. This is the reason of different light reflection and under microscope we can see the valleys as dark and hills as light fields (Fig.3).

Metals commonly used for manufacturing various products are polycrystalline materials and composed of many individual, small randomly oriented crystals with irregular shape, which are called grains. Grain size significantly influences the mechanical properties of metals. At room temperature, a large grain size is generally associated with low strength, hardness and ductility, but fine grains influence oppositely.

Each grain has spherical shape and its main dimension is diameter. There are fourteen numbers or balls of grains by their diameter or area. Grain sizes between 5 and 8 are generally considered fine grains. A grain size of 7 is generally acceptable for sheet metals for making car bodies and other products. It is known several methods of grain size measuring.

1. The method of area: we count the quantity of grain in a given area, then divide this area by the quantity of grains and take an area of one grain. A grain number (or grain ball) is found by special table.
2. The method of secant: grain size is measured by counting the quantity of the grains, that intersects a given length of a line, randomly drown on an enlarged photograph of the grains, taken under a microscope on a polished and etched microscopic section.
3. The method of comparison: grain size may be determined by comparing it to a standard chart.
4. Next technique by which grain size is specified is ASTM grain size number. (ASTM means American Society for Testing and Materials).

The number of grains per square inch is determined from a photograph of the metal taken at metal magnification x100. The number of grains per square inch **N** is entered into formula and the ASTM grain size number **n** is calculated.

$$N = 2^{n-1}$$

A large ASTM number indicated many grains or a fine grain size correlates with high strength.

If the magnification is more or less than x100, the formula is used

$$\left(\frac{G}{100}\right)^2 \cdot N = 2^{n-1}$$

where **G** is a real magnification.

5. Methods of eyepiece and objective micrometers.

The equipment and tools: Metallographic vertical microscope MIM7, object micrometer, a set of microscopic sections.

The concept of microscope action: metallographic vertical microscope with magnification **x50÷x2000** operates by phase-contrast method. The magnifying parts are eyepiece and objective. The complete microscope magnification is a product of eyepiece and objective magnifications, shown on their cases. The light ray moves from the electric lamp, through a set of the mirrors and lenses to the objective, after that it is reflected from microscopic section surface and directed to the eyepiece by a set lenses and reflecting plates. A specimen is placed over the hole of table, which may be moved in two perpendicular directions by screws. The microscope is focused by two screws of coarse adjustment and a screw of fine adjustment.

Executing the work:

The eyepiece micrometer is the usual eyepiece with very thin glass plate between its lenses. There is a scale on this glass plate, similar to the usual rule, but its value of the smallest division is unknown. The objective micrometer is a glass or metallic plate with the scale, which value of the smallest division is 0.01mm. For determining the value of the smallest division of eyepiece scale we place the objective micrometer on a microscope table and adjust its clear image, then combine it with eyepiece scale and count the number of both scale divisions, which completely coincide.

$$\mathbf{C_{eyepiece}=A_{ob}.x0.01/A_{eyepiece}}$$

Where $\mathbf{C_{eyepiece}}$ is a value of the smallest division of eyepiece scale. $\mathbf{A_{ob}}$.- the number of objective scale divisions, which completely coincide with $\mathbf{A_{eyepiece}}$ - the number of division of eyepiece scale. Then we place an investigated microscopic section on the microscope table instead of objective micrometer and measure a grain diameter by eyepiece micrometer scale in two perpendicular directions, that is, vertical and horizontal diameters calculate average value of diameter and determine grain size number (or ball) by table or chart.

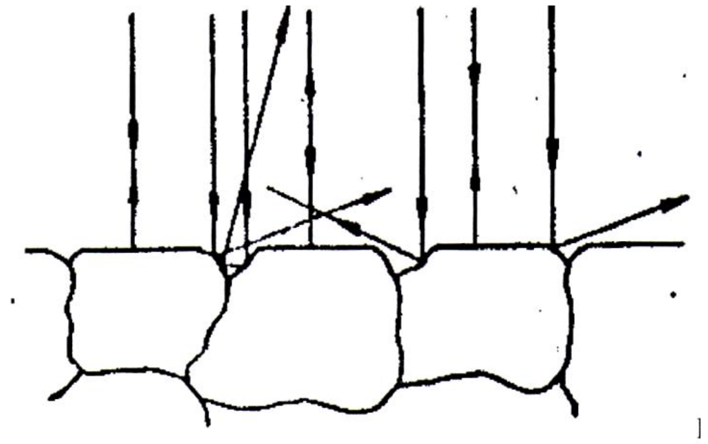


Fig 3 The scheme of light ray reflection from grain plane and grain boundaries

The report: the account must contain the calculations of the grain size number for pure iron and steel 45 microscopic sections.

The questions for self- checking:

1. What is it microanalysis?
2. What is it microscopic section?
3. What shape and size are more comfortable for microscopic section?
4. Explain the main stages of mechanical preparing microscopic section?
5. What is the main concept of etching?
6. What methods of grain size measuring are known?
7. Explain the method of grain size measuring with the help of eyepiece and objective micrometers?

VOCABULARY:

microanalysis – мікроаналіз
microscopic section – мікрошліф
specimen – зразок
pattern – форма, зразок
cramp – струбцина
filling – обробка напилком
grinding – шліфування
polishing – полірування
etching – травління
emery cloth – наждачна шкурка
emery paper – наждачний папір
felt – фетр, войлок
secant – січна
eyepiece – окуляр
objective – об’єктів

LABORATORY WORK 2

HARDNESS MEASURING

The purpose of the work: to get acquainted with different methods of hardness measuring.

The task of the work: to get acquainted with Rockwell machine construction; to study Rockwell test; to measure hardness of commercially pure iron and steel 45 by Rockwell test.

Theoretical Information: hardness is commonly used quantity and gives a general indication of the strength of the material, as well as its resistance to wear and scratching. More specifically, hardness is usually defined as resistance to permanent indentation. Thus, for example, steel is harder than lead.

Hardness, however, is not a fundamental property because the resistance to indentation depends on the shape of the indenter and the load applied.

Brinell test. Introduced by G.A. Brinell in 1900, this test involves pressing a steel ball (sometimes tungsten carbide ball) 10 mm in diameter against a surface with a load of 500 kg, 1500 kg and 3000 kg.

The Brinell hardness number HB is defined as the ratio of the load P to the curved surface area of the impression and given in kg/cm².

$$\mathbf{HB = 2P/\pi D\left[D - \sqrt{D^2 - d^2}\right]} \ \textbf{kg/cm}^2$$

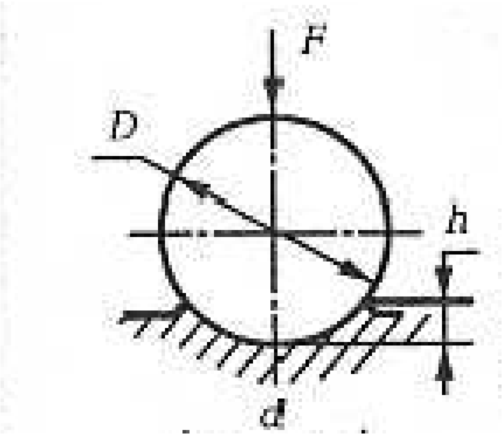


Fig.1. A diagram of Brinell test

Where **D**-is indenter (ball) diameter, **d**-impression diameter, which is measured by microscope.

Brinell test is used for measuring hardness of large parts, of inhomogeneous materials and polymers.

Rockwell test. Developed by S.P. Rockwell in 1922. This test measures the depth of penetration instead of the diameter of the impression, as the Brinell test does.

The indenter (steel ball or diamond cone) is pressed against the surface, first with a minor load of 10 kg for) removing roughness influence and then with a major load of 60kg or 100kg or 150kg depending on the shape of the indenter and the type of investigated materials.

The steel ball and the load of 60kg are used for measuring hardness of soft metals and annealed alloys. Rockwell hardness number is designated **HRB**.

The diamond cone and the load of 60 kg are used for measuring hardness of thin hard layer (for example, after carburizing or nitriding) and the diamond cone and the load of 150 kg **-** for hard metals and quenched steels. Rockwell hardness numbers are designated **HRA** and **HRC**, accordingly.

The difference in the depths of penetration is a measure of material hardness.

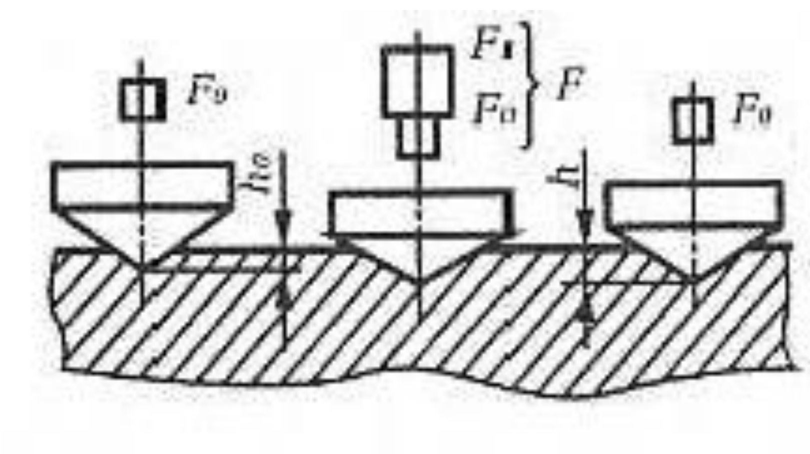


Fig.2. A diagram of Rockwell test

Rockwell hardness numbers are unit less. The unit of hardness is a value, corresponding to indenter axial displacement on 0.002mm. Rockwell hardness number is defined by formulas:

for scale B **HR=130-e**

for scale A and C **HR=100-e**, where **e=** $\frac{h-h_0}{0.002}$; **h**-the depth of indenter penetration into investigated material by action of total load **P**, measured after taking away the major load P_1, but by acting the minor load P_0; h_0-the depths of indenter penetration into investigated material by acting of minor load P_0.

Vickers test. The Vickers hardness test, developed in 1922 and also known as the diamond pyramid hardness test uses regular tetrahedral pyramid as indenter and a load ranges from 1kg to 120kg. The Vickers hardness number is indicated by **HV** and may be determined by formula:

$\mathbf{HV} = \frac{\left(2P\sin\frac{\alpha}{2}\right)}{d^2} = 1.8544$ (P/d^2) kg/mm^2; where **P** is a load; **α** is spatial angle in pyramid top, equal 136^0 ; **d** is an average value of two diagonals of rhombus impression, measured after taking away a load by special microscope.

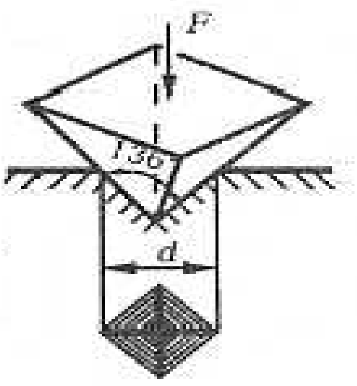


Fig.3. A diagram of Vickers test

The impressions obtained are typically less than 0.5 mm on the essentially the same hardness number regardless of the load and is suitable for testing materials with a wide range of hardness, including heat-treated steels.

A relationship has been established between the ultimate tensile strength (**UTS**) and Brinell hardness (**HB**) for steels:

UTS=3.5 (HB), where **UTS** is in MPa, (in SI units).

The equipment and tools: Rockwell machine, a set of specimens of commercially pure iron and steel 45.

Executing the work.

Put a specimen on the Rockwell machine table and raise it by rotating flywheel clock-wise. When the indentor touches to the specimen, a small indicating hand begins to revolve until its coincidence with red point on the dial-plate. That means, a specimen is pressed by the minor load of 10kg.

Then combine the long indicating hand with “zero” on black scale by the thimble.

Press the specimen by major load pressing treadle.

Obtain Rockwell hardness number on the black scale after the long indicating hand stopping.

Repeat the measurements not less than five times and calculate the average hardness number.

The report: To describe the Rockwell test of hardness measuring and point the hardness number of a set of steel 45 specimens.

The questions for self-checking:

1. What is hardness of material?
2. Explain the Brinell test.
3. Explain the Rockwell test.
4. Explain the Vickers test.
5. What method of hardness measuring is more universal?
6. Show the connection between UTS and HB.

VOCABULARY:

annealed alloy – сплав після відпалу;
quenched alloy – загартований сплав;
carburizing – цементування;
nitriding – азотування;
minor load – предварительная нагрузка;
major load – полная нагрузка;
load – навантаження;
roughness – шероховатость

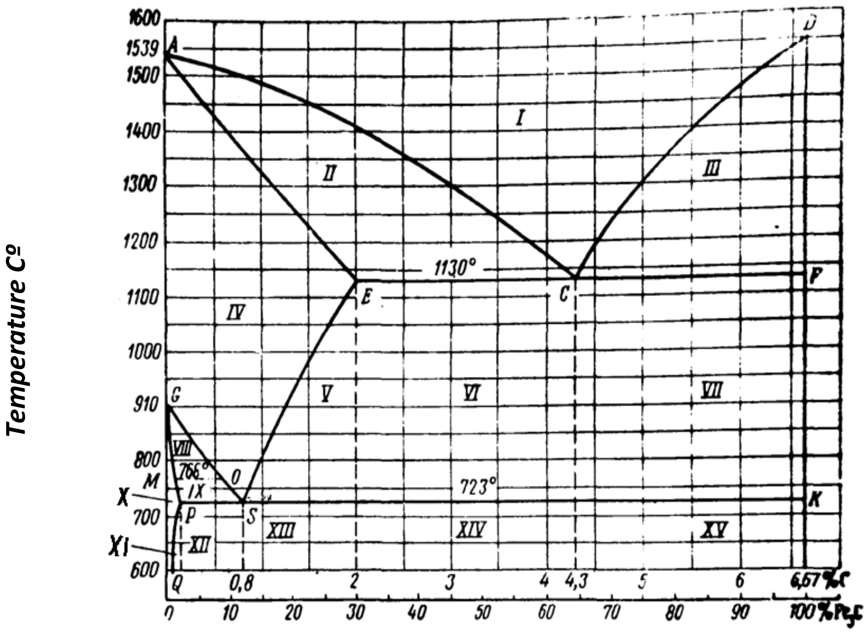
LABORATORY WORK 3

THE INVESTIGATION OF CARBON STEEL STRUCTURES

The purpose of the work: to study the Fe-C phase diagram; the phases and two-phase structures in Fe-C alloys.

The task of the work: to draw the microstructure of a set of carbon steels; to determine the carbon concentration in carbon steels; to get acquainted with the concept of carbon steel designation.

Theoretical information: the phase diagram of Fe-C alloys is shown in fig.3.1



Concentration

Fig.3.1 Phase diagram of Fe-C steels

There are four phases, formed in Fe-C alloys at different temperatures: liquid phase, ferrite, austenite and cementite.

Ferrite is an interstitial solid solution of C into Fe with b.c.c. crystalline lattice. The carbon concentration in it is from 0.01% at room temperature to 0.03% at 723º C.

Austenite is an interstitial solid solution of C into Fe with f.c.c. crystalline structure and ultimate carbon concentration 2.14% at
1147º C.

Cementite is chemical compound-iron carbide with stable carbon concentration 6.67%.

The two-phased structures in Fe-C alloys are ledeburite and pearlite.

Ledeburite is a product of eutectic reaction, formed at 1147º C. It is a mechanical mixture of austenite and cementite with carbon concentration 4.3%

Pearlite is a product of eutectoid reaction, formed at 723º C. It is a mechanical mixture of ferrite and cementite with carbon concentration 0.8%

According to phase diagram of Fe-C alloys

I. liquid phase;
II. liquid phase and austenite;
III. liquid phase and primary cementite;
IV. austenite;
V. austenite and secondary cementite;
VI. austenite and ledeburite, which consists of austenite and cementite;
VII. cementite and ledeburite, which consists of austenite and cementite;
VIII. austenite and ferrite, which is nonmagnetic above 768º C;
IX. austenite and magnetic ferrite;
X. ferrite;
XI. ferrite and tertiary cementite;
XII. ferrite and pearlite;
XIII. pearlite and secondary cementite;
XIV. pearlite and ledeburite, which consists of pearlite and cementite;
XV. ledeburite which consists of pearlite and cementite and primary cementite.

The iron-carbon alloys with carbon concentration up to 0.03% are called commercially pure iron, fig.3.2 and fig 3.3

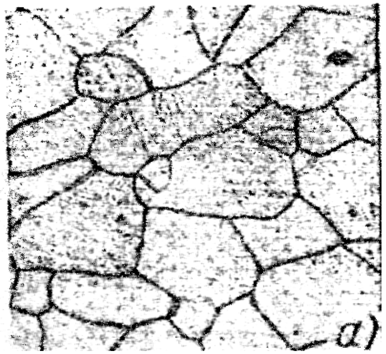


Fig 3.2 Commercially pure iron: ferrite
Microstructure(x500)

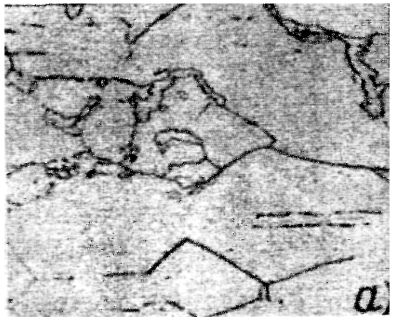


Fig 3.3 Steel with 0.015% C: ferrite and tertiary cementite
Microstructure

The iron-carbon alloys, which contain less than 2.14% of carbon are called steels, and more than 2.14%-cast irons.

By structure the steels are classified into three groups:

-hypoeutectoid steels (less than 0.8% of carbon) consist of ferrite and pearlite, fig3.4

Fig 3.4 *Hypoeutectoid steel* with 0.3% C – ferrite and pearlite
Microstructure(x500)

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-eutectoid steel (0.8% of carbon) consists of pearlite, fig 3.5

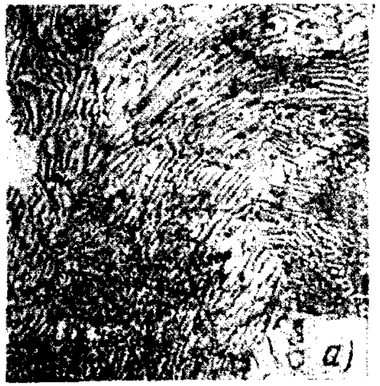


Fig 3.5 *Eutectoid steel* with 0.8% C-pearlite:
Microstructure(x500)

-hypereutectoid steels (from 0.8% to 2.14% of carbon) consist of pearlite and secondary cementite, fig 3.6

Fig 3.6 *Hypereutectoid steel* with 1.2% C – pearlite + cementite Microstructure(x500)

By application the steels may be structural and tool. The structural steels are designated by digits, which show the carbon concentration in hundredth parts of percent, for example, steel 25 (0.25%C), steel 45 (0.45% C), steel 70 (0.7%C) and so on.

The tool steels are designated by Russian letter У and digits, which show the carbon concentration in tenth parts of percent, for example, У7 (0.7% C), У11(1.1% C), У13 (1.3% C) and so on.

The equipment and tools: a set of specimens of carbon steels with different carbon concentration and metallographic vertical microscope.

Executing the work:

To assume, that the area of microstructure on the photograph is 100%. Then, let's determine by eye the area of pearlite on photographs of hypo- and hypereutectoid steels and calculate the carbon concentration in these steels by formulas:

C% (hypoeutectoid steel) = (0.8*Sp)/100%,

Sp – area of pearlite in hypoeutectoid steel; m%0.8 – is carbon concentration (in percent) in pearlite.

C%(hypereutectoid steel)= (0.8 Sp+6.67 Sc)/100%,

Where Sc – area of cementite in hypereutectoid steel, m%6.67% - carbon concentration (in percent) in cementite. Finally, to designate these steels, according to their classification.

The report: to draw the microstructures of commercially pure iron, hypoeutectoid, eutectoid and hypereutectoid steels; to calculate the steel concentration and to designate carbon steels.

The questions for self- checking:

1. What alloys are called steels?
2. What alloys are called cast irons?
3. What steel is eutectoid?
4. Point the carbon concentration in hypoeutectoid steels.
5. Point the structure of hypereutectoid steels.
6. Point the concept of structural steel designation, give the examples of structural steels.
7. Point the concept of tool steel designation, give the examples of tool steel marks.

VOCABULARY:

steel – сталь
cast iron – чавун
commercially pure iron – технічно чисте залізо
hypoeutectoid steel – доевтиктоїдна сталь
hypereutectoid steel – заевтиктоїдна сталь
eutectoid steel – евтиктоїдна сталь
ferrite – ферит
austenite – аустеніт
cementite – цементит
pearlite – перліт
ledeburite – ледебурит
primary cementite – первинний цементи
secondary cementite – вторинний цементит
tertiary cementite – третинний цементит

LABORATORY WORK 4

THE HEAT TREATMENT OF CARBON STEELS

The purpose of the work: to get acquainted with different types of heat treatment and their conditions; to investigate the hardness dependence on heat treatment conditions: the influence of cooling rates on steel hardness after hardening and the influence of temperature on steel hardness after tempering.

Task of the work: to draw the diagrams of hardness dependence on quenching rates and tempering temperature by given experimental data.

Theoretical information: the various microstructures and properties of the alloys can be modified by heat treatment techniques, that is, by controlling heating and cooling of the alloys at various rates.

The basic types of heat treatment are annealing, normalizing, hardening (quenching), tempering (ageing). Each type of heat treatment includes three stages:

- heating up the definite temperature;
- holding (or soaking out) at this temperature during definite time;
- cooling with definite rate, cooling rate is the main condition.

The basic conditions of heat treatment may be shown a diagram in coordination's: temperature and time.(Fig.4.1)

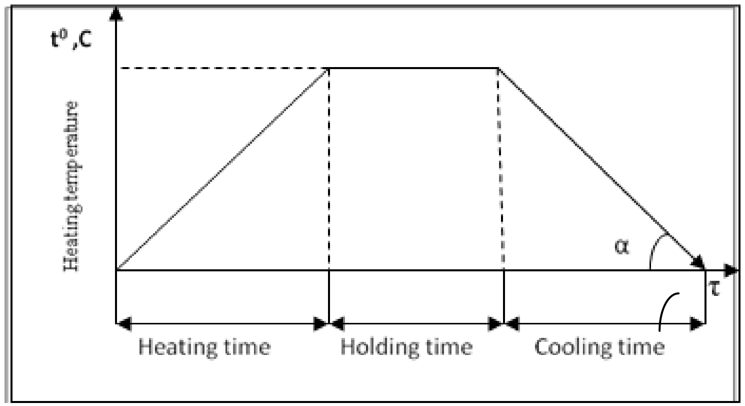


Fig. 4.1 The diagram of heat treatment

$$\tan\alpha = \frac{\text{Hrating temperature}}{\text{Cooling time}} = V_{\text{cooling rate}}$$

Annealing is used for restoration of cold-worked or heat treated metal and alloy to its original properties. The structure, formed after annealing, is equilibrium and corresponds to phase diagrams. The heating temperatures depend on the type of annealing, but cooling is carried out with the slowest rate (annealed metal is cooled together with a furnace).

The types of first kind annealing:

1. Diffusion annealing: is carried out at t°C 1100-1200for 10-15 hours for alloy steels. As result alloy steels obtain homogeneous structure and chemical composition.
2. Recrystallizing annealing: its heating temperature is 0.4 times of melting point after this type of annealing recrystallized metal has a low strength, high ductility.
3. Process annealing: is used to restore metal ductility after cold working. Its heating temperature is always bellow A_1 .

The types of the second kind of annealing:

1. Full annealing. The hypereutectoid steels are heated on 30-50^{0}C above A_3. As a result a coarse pearlite is formed .
2. Nonfull annealing: The hypereutectoid steels are heated on 30-50^{0}C above A_1 for eliminating internal stresses and increasing is ability to be worked by cutting.
3. Spheroidizing: or improving machinability are used for hypereutectoid steels, which contain a large amount of cementite. Steels are heated at t^0 on 30^{0}C above A_1 and held for long time after that, microstructure is continuous matrix of soft machinablle ferrite and spherical particles of cementite.
4. Normalizing: is used to avoid excessive softness of annealed steels. On normalizing hypoeutectoid steels are heated on 30-50^{0}C above A_3 and hypereutectoid steels are heated on 30-50^{0}C above A_{st} .After air cooling sorbite or fine-grained perlite is formed.
5. Hardening: is used to increase hardness of the steels. On hardening the hypoeutectoid steels are heated on 30-50^{0}C above A_3, the hypereutectoid steels on 30-50^{0}C above A_1. Holding time depends on the type of steels, a shape and a size of hardened parts, power and a type of heating furnace. Cooling rates may be ensured by corresponding quenching medium (water, brine, oil, molten salt, polymer solution, air, sprayed water). Cooling rate is picked out to obtain necessary microstructure and properties: air-quenched structure is sorbite, oil-quenched – troostite, water – quenched martensite. Fig.****(Fig.4.2)

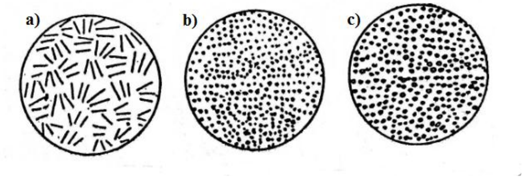
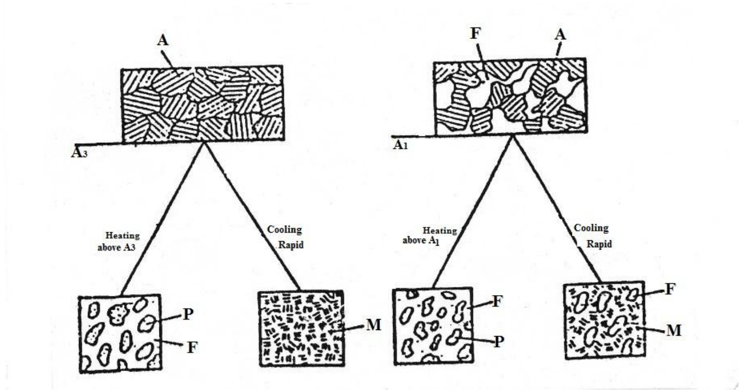


Fig.4.2 The microstructures after hardening

Microstructure of quenched steel: a-martensite (cooling in cold water);b-troostite (cooling in mineral oil);b-sorbite(cooling in quite air).

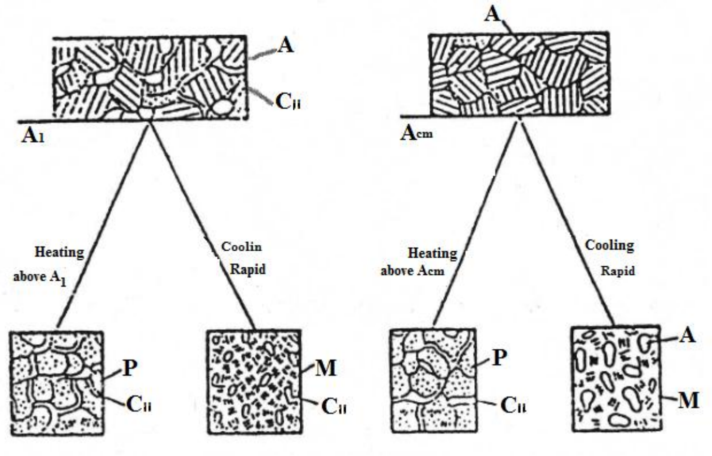
The example of correct and non-correct hardening of hypoeutectoid and hypereutectoid steels are shown in fig.** and fig.***

Fig**



Complete (correct) Noncomplete (noncorrect) quenching process transformation during it in hypoeutectoid steel.

Fig.***



Correct Noncorrect

Quenching process and transformation during it in hypereutectoid steel.

<u>Tempering</u> is used to improve martensite properties – to reduce its hardness and increase its toughness. Three types (or stages) of tempering are:

- low temperature tempering is carried out in temperature range 150-250^{0}C. After it tempered martensite, which is less hard than quenched one, is formed;
- medium temperature tempering is carried out in temperature range 350-500^{0}C. Its product is tempered troostite;
- high temperature tempering is carried out in temperature range 500-700^{0}C and tempered sorbite is formed after it.

The combination of hardening and high tempering is called improvement, because after it a steel receives the best complex of properties: high strength, sufficient hardness and ductility.

<u>The task of the work:</u> to draw the diagrams of hardness dependence on quenching rates and tempering temperature by given experimental data.

<u>The equipment and tools</u>: metallographic vertical microscope; a set a specimens after different types of heat treatment; Rockwell machine.

Experimental data Table 4.1

	Quenching			Tempering		
	Water 600^0/s	Oil 150^0/s	Air 30^0/s	200^0	400^0	600^0
	HRC					
	60			58		
		30				
			10			
	60				45	
	60					15

The different structure hardness

Structure	HB, MPa
Ferrite	800-1000
Austenite	1500-1800
Cementite	8000-8500
Pearlite	1900-2300
Sorbite	2500-3000
Troostite	3500-4500
Troostite and martensite	5000-6000
Martesite	6500-7000

<u>Executing the work:</u>

To draw a diagram of hardness dependence on cooling rates of hardening .
To draw a diagram of hardness dependence on temperatures tempering.
To analyse the hardness number of the phases and structures of steels after different types of heat treatment by Table 4.2

The report: the report must contain two diagrams of hardness dependence on cooling rates and tempering temperatures ; explanation of steel structures after different types of heat treatment.

Questions for self-checking:

1. Point the basic types of heat treatment.
2. Point the basic stages of each type of heat treatment.
3. What is the purpose of annealing?
4. What is the heating temperature for hypo eutectoid steel hardening?
5. What is the heating temperature for hypereutectoid steels hardening?
6. What is the cooling rate of hardening ?
7. Point three types of tempering.
8. What heat treatment is called normalizing?

Vocabulary:

Annealing-відпал
Hardening(quenching)-гартування
Tempering- відпуск
Heat temperature- температура нагрівання
Normalizing- нормалізація
Cooling rate- швидкість охолодження
Holding time- час витримки
Sorbite- сорбіт
Troostite- троостит
Martensite- мартенсит

LABORATORY WORK 5

THE INVESTIGATION OF STRUCTURES AND PROPERTIES OF ALLOY STEELS

The purpose of the work: to get acquainted with alloy steel classification and designation; to investigate the microstructure of the basic aircraft alloy steels; to study the properties and application of these steels.

The task of the work: to draw the microstructures of aircraft alloy steels; to point their chemical compositions, properties, heat treatment and applications.

Theoretical information: the steels containing significant amounts of alloying elements (or components) are called alloy steels. These steels are made with more care than carbon steels. They contain less than 0.03% of S and P. Various alloying elements are added to steel to improve their properties:

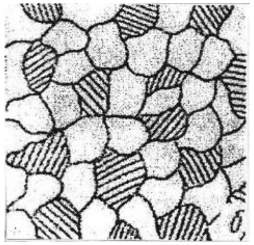
- hardenability by B, Ti, Cr, Mn, Mo;
- strength by Mn, Si, V;
- hardness by Si, W;
- hardness at elevated temperatures W, Mo, V;
- elevated temperature strength – Cr, Ni, Mo, W, V, Co, B (0.01% – 0.005%);
- toughness – Cr, Mo, V;
- corrosion resistance – Cr, Al, Si, Ni;
- heat resistance – Al, Ni, Cr, Ti;
- wear resistance – Cr, Mn, Mo, V;
- creep resistance – Mo;
- machinability – B, Mn, but Si usually decreases machinability.

The alloy steels are designated by letters and digits. The alloying elements are designated by letters: Cr – X; Ni – H; Mo – M; W – B; N – A; Co – K; Nb – Б; V – Ф; Mn – Г; Si – C; B – P; Al – Ю; Se – E; Zr – Ц; rare earths – Ч; and digits behind them, show their concentration in percents. It their no digit after corresponding letter, its concentration will be less than 1%, for example, the alloy steel 40X15H7Г7Ф2MC consists of 0.4% C, 15% Cr, 7% Ni, 7% Mn, 2% V, 1% Mo, 1% Si.

The alloy steels are classified by quantity of alloying elements, equilibrium structure (after annealing), air-cooled structure (after normalizing) and application.

By quantity (summary concentration) of alloying elements the alloy steels may be low alloy (less then 5%), medium alloy (from 5% to 10%), high alloy (more than 10%).

By equilibrium structure the alloy steels are classified into hypoeutectoid (30XГCA, 40XHMA, 38XMЮA), eutectoid (8X3, 8XC), hypereutectoid (9XФ, XBГ) and ledeburite (which contain primary cementite).



By air-cooled structure the alloy steels belong to pearlitic (low-alloy steels), martensitic (medium-alloy steels), austenitic (high alloy steels) groups.

By application the alloy steels may be structural, tool and special (elevated temperature strength, heat resistant, wear resistant, stainless steels).

The basic aircraft alloy steels are shown in tables.

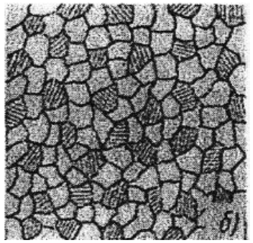
Steel 30XГCA

Steel 30XГCA is applied in aircraft for landing gears, spars, frames, critical units of aircraft, bolts and many other parts.

After normalizing its structure is alloyed ferrite and alloyed pearlite. Steel 30 XГCA has good machinability, weldability, high strength and toughness. It may be heat treated. For hardening 30XГCA is heated up to 860°C and cooled in water. After tempering in temperature range 480-550°C, steel obtains high strength, and impact resistence. Its structure is sorbite with martensite orientation of grains.

The new structural steel 30XГCHA with addition of Ni has ductility, toughness more than steel 30XГCA. It is very important for applying this steel in landing gears.

Steel 38 XMЮA

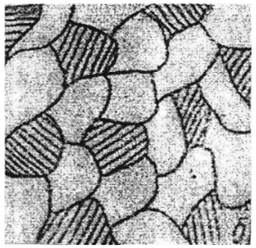


Steel 38XMЮA is applied for some units of jet and piston engines, which are worked in conditions of wear. These units are cylinder surface of piston engine, pins of connecting rod, piston rods of valves, critical pinions of gear unit.

The parts from steel 38XMЮA may work at 400-500°C after nitriding without changing their hardness. On hardening steel 38XMЮA is heated up to 950°C and cooled in mineral oil, after that it is tempered at temperatures 625-650°C. Quenched steel is nitrited at temperatures 500-560°C. Aircraft parts of this steel may be nitrited on 0,5mm in depth.

After normalizing steel 38ХМЮА structure is alloyed ferrite and alloyed pearlite. After hardening, tempering and nitriding its structure consists of tempered sorbite in the center of microscopic section and nitrides, situated on grain boundaries near microscopic section surface.

Steel 40ХНМА

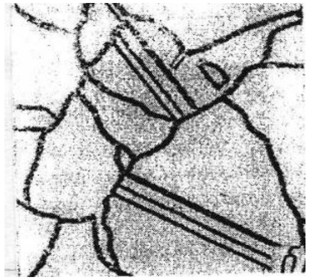


Steel 40ХНМА is used for critical units of aircraft engines, which worked under conditions of high alternating and impact loads. Turbine shafts, critical reducer and impeller shafts, crankshafts, critical bolts, connecting rods of piston engines are made from this steel.

After normalizing its structure is alloyed ferrite and alloyed pearlite, which is very fine-grained.

Alloying this steel by Mo increases its strength at high temperatures (to 500°C). The parts of steel 40ХНМА may be improved to obtain high strength, toughness and fatique.

Steel Х18Н10Т



Х18Н10Т is stainless steel of austenitic class, therefore this steel after heating and cooling in water or in air will have austenitic structure, because it is alloyed by Ni (7-9%) and Cr (17-18%). Х18Н10Т structure consists of austenitic grains with twins and some amount carbides TiC.

Cr, present in Х18Н10Т composition, increases its corrosion resistance, because Cr interacts with O_2 and forms very hard and strength film of oxide on the steel surface.

Ni is added to steel to form austenitic structure, which has more elevated temperature strength than ferrite.

Ti prevents steel from intergrained corrosion, which destroys the connection between grains and is the reason of part destruction.

Corrosion resistance of steel may be decreased at 500-700°C, because of carbon interaction with chromium and complex carbide $(CrFe)_{23}C_6$ formation, which depletes solid solution if there is no titanium in steel. Titanium forms carbide, and therefore titanium concentration must be in 5 times more (niobium – in 8 times more) then carbon concentration.

Steel Х18Н10Т is applied in aircraft for welden structures, which work at abnormally high temperatures and low stresses. It is used for burner casing of jet engine, outer casing of exhaust nozzle, turbine casing and so on.

Nickel-based alloys

Nickel-based alloys are also used as elevated temperature strength and heat resistant materials.

The steels and alloys will be called elevated temperature strength, if they resist the start and the development of plastic deformation, and also destruction by long-duration mechanical loads. The refractory elements, such as tungsten, molibdenium and niobium increase elevated temperature strength, because they suppress diffusion, increase recrystallizing temperature and hold back coagulation of strengthening phases.

The steels and alloys will be called heat resistant, if they resist oxidation for long time at high temperature.

Chromium, aluminium, silicon form continuous tight oxide films, which protect surface of parts and influence high heat resistance.

Following Nickel alloys ЭИ437Б, ЭИ617, ЖС6-КП are used for critical units of gas turbine engines (turbine vanes and disks).

ЭИ437Б (ХН77ТЮР) consists of 0,06% C, 20% Cr, 2,5% Ti, 0,75% Al, 0,01% B and is used after heat treatment: air-quenching from 1080°C and stabilizing tempering on 700-750°C for 16 hours.

ЭИ617 consists of C≤0,12%, 15% Cr, 6% W, 3% Mo, 2% Ti, 2% Al, B≤0,02%, Fe≤5% and is used for turbine vanes.

ЖС6-КП consists of 0,13% C, 10,5% Cr, 4% W, 5% Mo, 3% Ti, 4,6% Al, B≤0,03%, 6,5% Co, Fe≤2,0%, Ce≤0.015% is used for nozzle bucket and nozzle vanes of gas turbine engines.

Group	Bearing steel	Stainless steel				Heat-resistant steel	High strength steel
Grade	ШХ15	12Х18Н10Т	09Х15Н8Ю	12Х13	30Х13	20Х17Н2	03Н18К9М5Т
Chemical composition	1% C 15% Cr	0.12% C 18% Cr 10% Ni 1% Ti	0.09% C 15% Cr 8% Ni 1% Al	0.12% C 13% Cr	0.3% C 13% Cr	0.2% C 17% Cr 2% Ni	0.03% C 18% Ni 9% Co 5% Mo 1% Ti
Heat treatment	Hardening in oil, low tempering.	Hardening in water or air.	Normalizing or hardening, ageing at 500°C	Hardening in oil, high tempering.	Hardening in oil, middle tempering.	Hardening in oil, zero-treatment, middle tempering.	Hardening in air, ageing at 500°C
Properties	HRC 60 - 65	Corrosion-resistant, ductile, heat-resistant.	Corrosion-resistant strength.	Ductile welded, corrosion resistant.	HRC 48-55 badly welded, wear-resistant	Heat resistant, may be welded.	High strength
Application	Bearings.	The part of gas turbine engine, exhaust nozzle; jet pipes, other parts worked at 800°C	Skin, strong elements, the parts worked at 500°C	Bolts, nuts, aircraft device parts, compressor buckets, worked at 500°C	The parts of fuel system, worked in conditions of wear and corrosion.	Compressor discs and buckets; case and combustor; compressor case.	Landing gear parts, fasteners.

Group	Carburized steels		Improved steels		Nitrided steel	Spring steel	Highstrength steel
Grade	12ХН3А	12Х2Н4А	30ХГСА	40ХНМА	38ХМЮА	50ХФА	40ХН2СВА
Chemical composition	0.12% C 1% Cr 3% Ni	0.12% C 2% Cr 4% Ni	0.30% C 1% Cr 1% Mn 1% Si	0.4 % C 1% Cr 1% Ni 1% Mo	0.38% C 1%Cr 1% Mo 1%Al	0.5% C 1% Cr 1% V	0.4% C 1% Cr 2% Ni 1% Si 1% W
Heat treatment	Hardening in oil, low tempering – after carburizing at 900°C	Hardening in oil, low tempering – after carburizing at 900°C	Hardening in oil, middle tempering	Hardening in oil, high tempering	Hardening and high tempering before nitriding.	Hardening in oil, middle tempering.	Hardening in salt.
Properties	HRC 50…60	HRC 58	May be welded		HV > 1000 wear. resistant.	HRC 44	May be welded
Application	Pinious; pins; piston rings, axles and other, worked at 150 °C	Pins, axles, pinious, collar pins, worked at 150 °C	Bolts; landing gear parts; wing stub; spars; booms.	Turbine shaft; reduction gear shafts; link rods of piston engine.	Years, stud-bolts; pins; parts of turbojet engine worked at 500°C	Springs, worked at 180 °C	Landing parts, stud – bolts, worked at 250°C

The equipment and tools: metallographic vertical microscopes, a set of aircraft alloy steel microscopic sections.

Executing the work: to get acquainted with different groups of alloy steels, given tables 5.1 and 5.2; to draw the microstructures of steels 30ХГСА, 38ХМЮА, 40ХНМА, Х18Н9Т and nickel-based alloy ХН77ТЮР; point basic properties of these alloys.

The report: it must contain the microstructures and description of chemical compositions, properties and applications of the different aircraft alloy steels.

Questions for self-checking:

1. What steels are called alloy?
2. Point the alloy steel classification by equilibrium structure.
3. Point the alloy steel classification by air-cooled structure.
4. Point the alloy steel classification by summary concentration of alloying elements.
5. Point alloy steel classification by applications.
6. What is the concept of alloy steel designation?

VOCABULARY:

alloy steel **-** легована сталь

alloying elements – легуючі елементи

structural steel – конструкційна сталь

tool steel – інструментальні сталі

elevated temperature strength steel – жароміцна сталь

heat resistant steel – жростійка сталь

wear resistant steel – зносостійка сталь

stainless steel – нержавіюча сталь

LABORATORY WORK 6

THE INVESTIGATION OF STRUCTURES AND PROPERTIES OF ALUMINIUM ALLOYS

The purpose of the work: to get acquainted with aluminium alloys classification; to investigate the microstructures of the basic aircraft aluminium alloys; to study the properties and application of these alloys.

Task of the work: to investigate the microstructures and properties of basic aircraft aluminium alloys: to get with their application.

Theoretical information: the main alloying elements in aluminium alloys are copper, manganese, magnesium, zinc, silicon, titanium and some other.

The aluminium alloys are classified by 3 groups: wrought, casting and sintered.

The group of wrought aluminium alloys is subdivided by two subgroups: non heat treatable and heat treatable.

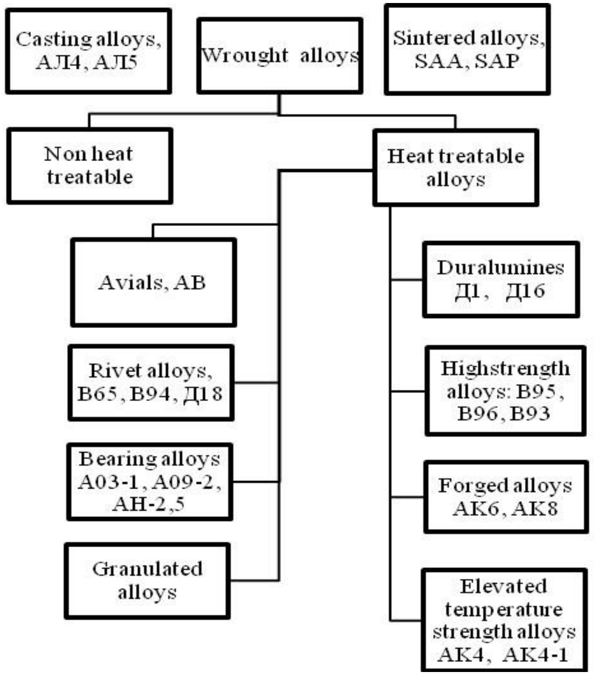
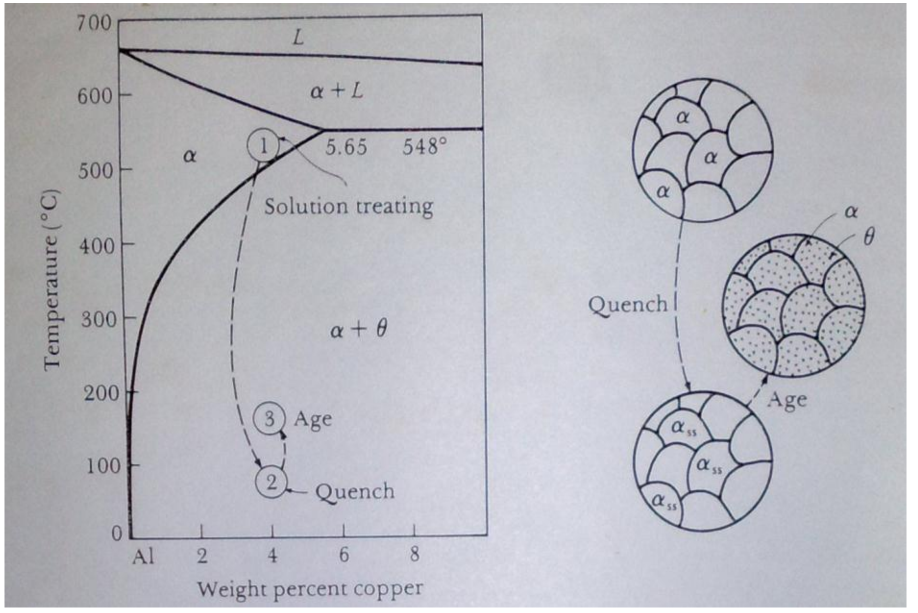


Fig.6.1 **The aluminum alloy classification**

The peculiarity of aluminium alloy heat treatment is precipitation hardening or ageing.

After heating and water-quenching aluminium alloy (for example, of 95,5% of Al and 4.5% of Cu Fig.6.2.a) is single-phased (α – solid solution) and has moderate strength and considerable ductility. The alloy is stronger after precipitation to hardening. For that, the alloy is reheated to an intermediate temperature and held for a period of time. This process is called ageing. The copper atoms diffuse to nucleation sites, combine with aluminium atoms,



producing new phase, which may be shown as small dots within the grains of original α – phase, Fig.6.2.b.

a b

Fig.6.2 The diagram of aluminium alloy heat treatment; a) Phase diagram for Al – Cu alloy with heating temperature of quenching; b) The stage of precipitation hardening and structures, obtained during them.

The table of basic aircraft aluminium alloys.

Grades	Д16	B95	AK4	АЛ5
Chemical composition	Cu – 4,4% Mg – 1,5% Mn – 0,6%	Zn – 6% Cu – 1,7% Mg – 2,3% Mn – 0,4% Cr – 0,15%	Cu – 2,2% Mg – 1,6% Ni – 1,35% Fe – 1,25%	Si – 5% Cu – 1,2% Mg – 0,5%
Alloying element influence	Cu, Mg increase strength, Mn increases corrosion resistance	Zn, Cu Mg increase strength, Mn, Cr increase corrosion resistance	Cu, Mg increase strength, Ni increases thermal conductivity, Fe increases elevated temperature strength, but decreases corrosion resistance.	Si provides with fluidity, Cu, Mg increase strength.
Heat treatment	Water-quenching from 495 – 505^0 C; natural or artificial ageing.	Water-quenching from 465 - 480^0 C artificial ageing at 120 - 140^0 C for 16 – 24 hours.	Water-quenching from 535^0 C, artificial ageing at 175^0 C	Sand casting.
Applications	Skin, rivets, different units of framework: beams, formers, stringers, ribs.	High loaded units; framework parts.	Disks and buckets of compressor, engine mount units, engine stands.	Engine case, compressor case, the cases of different types of equipment.

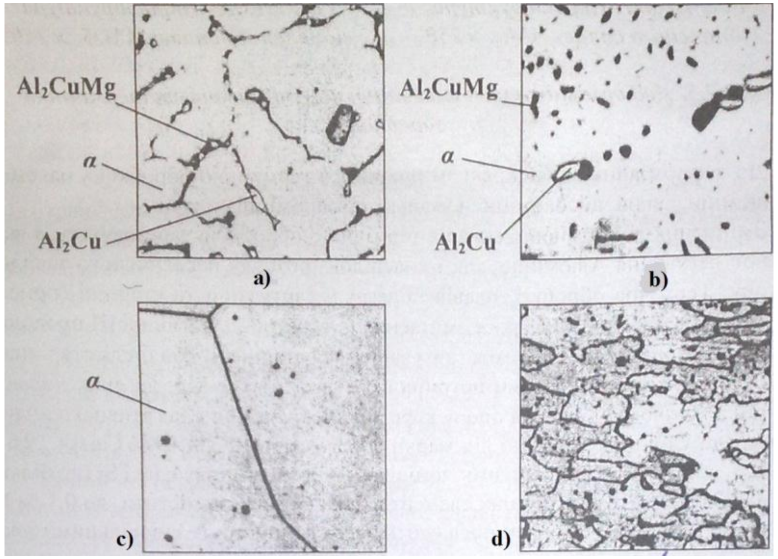


Fig.6.3 Microstructure of D16: a-casting; b-wrought after annealing c-after hardening: d-after deformation and ageing

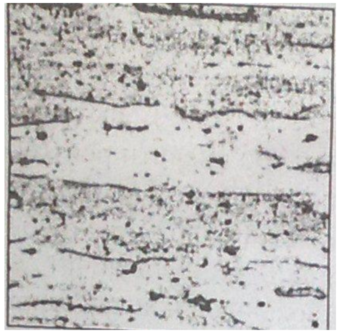


Fig.6.4 Microstructure of B95 after artificial ageing

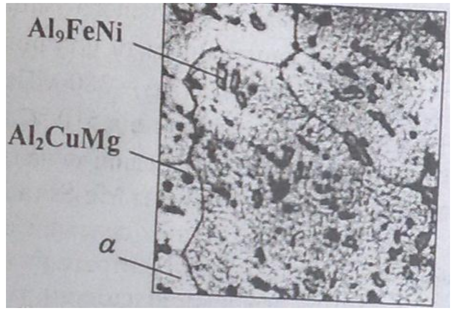
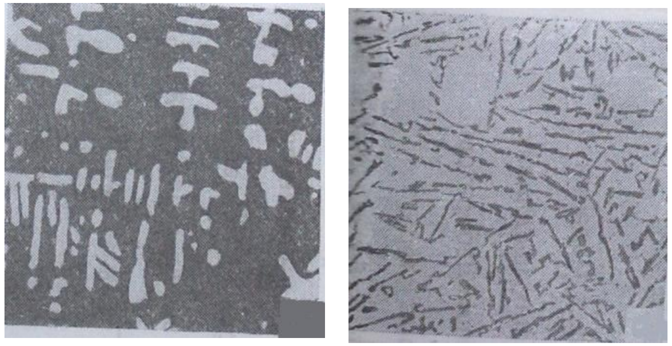


Fig6.5 Microstructure of AK4 after artificial ageing



a)

a b

Fig 6.6 Microstructure of АЛ5 a) before modification b)after modification

The equipment and tools: vertical microscope, a set of aluminium alloy microscopic section.

Executing the work: to investigate the microstructure of basic aluminium alloys B16, B95,AK4, АЛ5 and in the report; to study chemical composition, heat treatment and application of these alloys in aircraft.

The report: it must contain the microstructures and description of the chemical compositions, properties and applications of the basic aircraft aluminium alloys.

Questions for self – checking:

1. Point the basic alloying elements in aluminium alloys.
2. Point the classification of aluminium alloys.
3. Point subdivisions of wrought aluminium alloys.
4. What is peculiarity of aluminium alloy heat treatment ?
5. What is the result of aluminium alloy hardening?
6. Explain the process of precipitation strengthening.

Vocabulary

wrought alloy – деформуємий сплав
casting alloy – ливарний сплав
sintered alloy – спечений сплав
non – heat treatable – сплав, що не зміцнюється термічною обробкою
heat treatable alloy – сплав, що зміцнюється термічною обробкою
precipitation –випадіння фаз

LABORATORY WORK 7

THE INVESTIGATION OF STRUCTURES AND PROPERTIES OFCOPPER ALLOYS

The purpose of the work:to get acquainted with copper alloy classification;to investigate the microstructures of copper alloys; to study the influence of alloying elements on copper properties.

The task of the work:to investigate the microstructures of basic copper alloy; to get acquainted with properties and applications of these copper alloys.

Theoretical information: Copper alloys acquire a wide variety of properties by addition of alloying elements, which improve their characteristics.

The alloying elements are subdivided by three groups:

1 .The elements, which are dissolved in copper and form solid solutions, improve the mechanical properties of copper. They are nickel, zinc, tin, aluminium, phosphorous, antimony.

2. The elements, insoluble in copper, form eutectic microconstituents, which have low melting temperature. They are lead and bismuth.

3. Oxygen and sulpher are nondesirable additions for copper, because they are the reason of copper alloy embrittment.

It is known two types of copper alloys: bronze and brass.

Bronzes are the alloys of copper and different alloying elements, such as tin, lead, aluminium, manganise, phosphorous, antimony, berrilium, nickel, iron and zinc, too.

Brasses are the alloys of copper and zinc with addition of other alloying elements.

The bronzes are classified by their main alloying element:

- aluminium bronze – БрАЖН-10-4-4 (10% of Al; 4% of Fe; 4% of Ni);
- БрАЖМц10-3-1,5 (10% of Al; 3% of Fe; 1,5% of Mn) have high strength, corrosion resistance, wear resistance;
- lead bronze БрС30 (30% of Pb), lead-tin bronze БрОС5-25 (5% of Sn, 25% of Pb) are used for bearings;
- berrilium bronze БрБ2 (2% Of Be) is used for springs.

The brasses are designated as Л70 (70% of Cu, 30% of Zn), ЛО70-1 (70% of Cu, 29% of Zn, 1% of Sn), ЛС59-1 (59% of Cu, 40% of Zn, 1% of Pb).

The structure of brasses may be single-phased and two-phased. (Fig.7.1)

The brasses, which contain up to 39% of Zn, are single-phase. The brasses, which contain 39-50% of Zn, are two-phase. The β-phase is ductile at high temperatures, but it is brittle at low temperatures.

Therefore, the single-phase brasses are processed by cold and hot working. The two-phase brasses are processed only by hot working.

The brass ЛЦ36Мц2С2К2 (36% of Zn, 2% of Mn, 2% of Pb, 2% of Si) has high corrosion resistance.

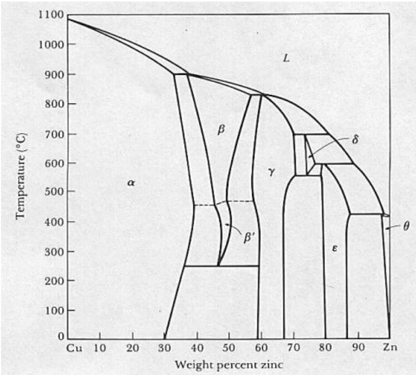


Fig.7.1 Cu-Zn diagram

Alloy's grade	БрАЖН10-4-4	БрОС5-25	ЛС59-1	БрАЖМц10-3-1,5
Chemical composition	Al-10%, Ni-4%, Fe-4%.	Pb-25%, Sn-5%.	Zn-40%, Pb-1%.	Al-10%, Mn-1,5%, Fe-3%.
Alloying element influence	Fe and Ni increase mechanical properties, Ni increases elevated - t° strength and wear resistance.			Fe increases mechanical properties.
Heat treatment	Quenching (heating t° 900-930°C, cooling in water); tempering for 1-2 hours.			Quenching (heating t° 900-930°C, cooling in water); tempering.
Applications	Bushings, (toothed) gears, glands.	Bearings.	Bushings, pipes, nuts, gaskets.	Bushings, gears.

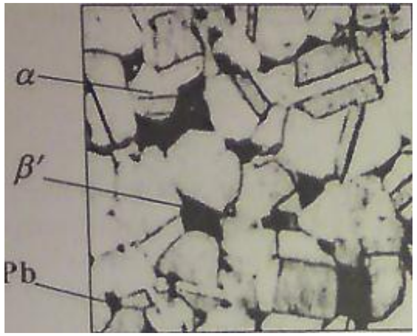


Fig.7.2 Microstructure of ЛС59-1

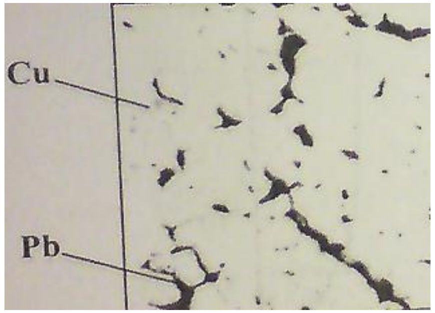
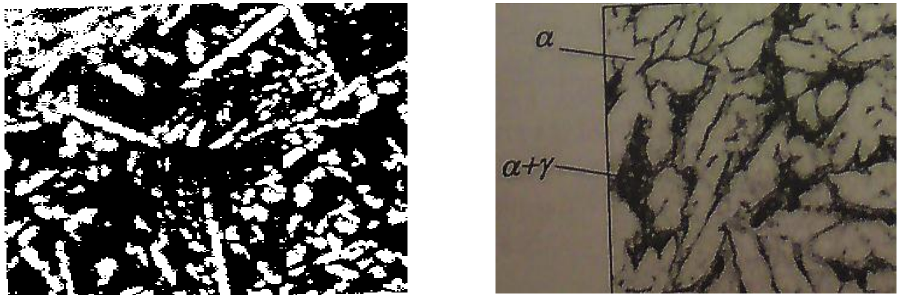


Fig.7.3Microstructure of Брос5-25



a b

Fig.7.4Microstructure of БрАЖН10-4-4, a –casting; b – after hardening

The equipment and tools: metallographic vertical microscope, a set of copper alloy microscopic sections.

Executing the work: to draw microstructures of basic copper alloys; to paint their properties and applications.

The report: it must contain the microstructures and description of the chemical compositions, properties and applications of the different copper alloys.

Questions for self-checking:

1. Point three groups of alloying elements in copper alloys.
2. What elements are nondescrable impurities in copper alloys?
3. What copper alloy is called bronze?
4. What copper alloy is called brass?
5. What is the concept of bronzes classification.
6. What is difference between single-phase and two-phase brasses properties?

VOCABULARY:

bronze – бронза
brass – латунь
single phase – однофазний
two-phase - двофазний

LABORATORY WORK 8

INVESTIGATION OF BASIC PROPERTIES OF AIRCRAFT THERMAL INSULATING

The purpose of work: to get acquainted with structure and properties of thermal insulating materials, applied in aircraft.
The task of the work: to investigate the microstructure of thermal insulating materials: polystyrene and polyvinylchloride foam-plastics;
To determine solid mass, porosity and thermal insulating properties of polystyrene and polyvinylchloride foam plastics.
Theoretical information:the basic properties of thermal foam plastics are solid mass, porosity, density and heat protective properties.
The mass of the volume unit of a porous material is called solid mass. It is calculated by formula

$$\gamma = \frac{Q}{abh}$$, where

Q is the mass of thermal insulating material, kg; ab is the square of specimen, m^2; h is the thickness of a specimen, m.
Porosity of a material is determined by density and solid mass of a material:

$$\omega = 100\left(1 - \frac{\gamma}{d}\right)\%$$, where

γ is solid mass of material, kg/m^3;
d is density of polymer, kg/m^3;
ω is porosity of a material.

Porosity is an air content in a material, given in %.
Density of polymers, which are used in foam plastics, is 1.06×10^3 kg/m^3 for polystyrene and 1.4×10^3 kg/m^3 for polyvinylchloride.
Heat protective properties of a material show its ability to save heat.
The equipment and tools:microscope MBS-2; a set of specimens of polystyrene and polyvinylchloride; calorimeter with a set of foam plastic protective rings; stop-watch; thermometer with the scale to 100°C; electrical furnace; a flask with 1 liter of distilled water; funnel; scales and a set of weights.

Executing the work:to investigate the microstructures of foam plastics under microscope and draw it; to determine solid mass and porosity of a set of foam plastic specimens; to determine thermal insulating property k of foam plastics with a help of calorimeter; to determine thermal insulating property of polystyrene and polyvinylchloride foam plastics by calorimeter method.
Calorimeter is a brass cylindrical vessel, which is placed on a rubber foot and is closed by rubber lid. There is a hole in a rubber lid to pour hot water into calorimeter and to place a thermometer. The concept of calorimeter method is in following. Hot water (95-98°C) is poured into calorimeter with thermal insulating rings as protection by foam plastics and into non-protective one. When water is cooled to 90°C, a stop-watch will be turned in and the temperatures will be again measured over 1 hour duration. The difference between temperatures in non-protective calorimeter and in calorimeter with foam plastic ring protection, divided by solid mass is thermal insulating property of foam plastics.

The report: it must contain the calculations of the basic properties of foam plastics conclusions on the work.
The questions for self-checking:

1. What is it solid mass?
2. What is it porosity?
3. How is solid mass determined?
4. How is porosity determined?
5. Explain the concept of calorimeter method.
6. How is thermal insulating property determined?

Vocabulary:

Foam – піна
Foamplastic – пінопласт
Polystyrene – полістирол
Polyvinylchloride – полівінілхлорид
Calorimeter – калориметр
Vessel – сосуд, ємність
Solidmass – об’ємна маса
Porosity – пористість
Thermal protective property – теплоізоляційна властивість
Stop-watch – секундомір
Scales - ваги