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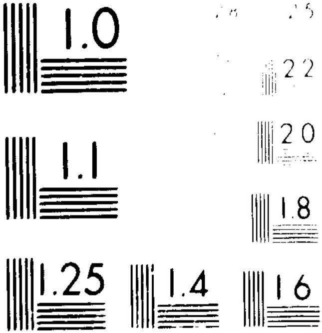
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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

MONOGRAPHS ON APPROPRIATE INDUSTRIAL TECHNOLOGY

# Heat Treatment of Castings and Forgings

prepared by

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# I N D E X

FOREWORD

Heat treatment is known practically as long time as a metal arms manufacturing. In Asia and Africa already in 7-8th century it raised to such perfection that the date back to this period name of the excellent steel - damasence steel - is used up today. Up to end of the last century the heat treatment was made on a base of practical experiences only. The development of the science and engineering in the last few tens of years enabled the working out the research base and explained the events occured in metals and their alloys during the heating and quenching in various media.

In the world economy over half million various metal alloys is at present used. The most wide application has iron alloys with carbon and other additions, which give for alloys a special, sometimes very sophistical properties.

The heat treatment secures the optimal, sometimes extreme, exploitation of utilitarian properties. It allows for the increasing of an exploitation durability of tools and machine parts as well as a reliability of their functioning by the increase of a strength and wear resistance at a simultaneous reducing of their mass.

The heat treatment is a single technology improving of the cast iron properties and plastic working products. It is not only a chipless technology, but it is simultaneously a material-saving technology. The mass reducing of the heat treated products in relation to the non-treated one is estimated at average about 25-30%. The thermo-chemical treatment additionally allows to use the cheaper steel grades and to enrich their surface layers with expensive alloy elements.

For heat treatment is average used about 3 times less heat energy than for producing of the material which was saved as a result of this treatment.

This is why a development of heat treatment is in the world an universal and very fast process: th mass of the heat treated products increases average 2-3 times faster than the mass of the produced raw steel. It concerns in particular the developing countries.

NO MODERN PRODUCTS WITHOUT HEAT TREATMENT !

HEAT TREATMENT ALLOWS TO IMPROVE POSSIBILITIES FOR INCREASING OF THE STRENGTH AND DURABILITY HIDDEN IN METAL !

HEAT TREATMENT IS A TECHNOLOGY WHICH SAVES MATERIALS AND ENERGY !

# 1. Foundations of heat treatment

## 1.1. Heat treatment basic terms

Heat treatment - a technological process which causes the changes of mechanical and physic-chemical properties of metals and alloys in a solid state. These effects are evoked first of all by making structural changes which are mainly a function of temperature, time and medium actions.

Simple heat treatment /called briefly heat treatment, too/ - a technological process which causes the changes of metal and alloy properties. These changes are mainly the function of temperature and time.

Typical heat treatment processes are involved in the range from about 400°C to about 1300°C. The range of the wide noted heat treatment is much more and is comprised in frames from -150°C up to +2000°C.

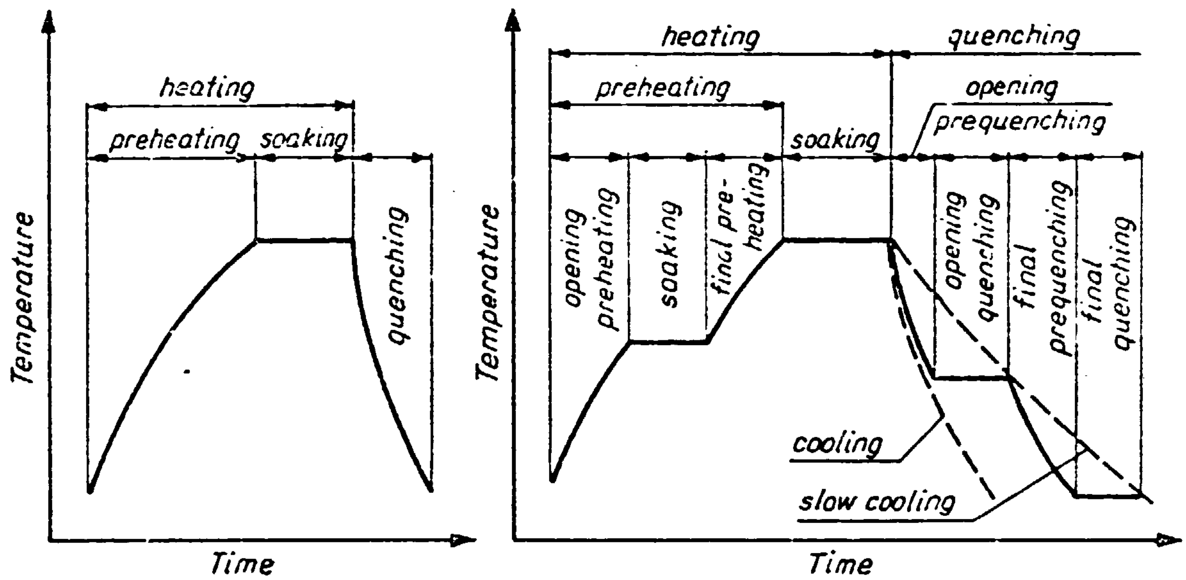
Work-pieces are heat treated in the time range from a few seconds up to several tens of hours. Sometimes it exists even monthes.

Thermo-chemical treatment /thermo-diffusion treatment, diffusion treatment/ - a technological process which causes the changes of metal and alloy properties being mainly the function of temperature, time and a chemical action of medium, mostly:

- gases: oxygen, nitrogen, argon, hydrogen;
- metals /or their compounds /: chromium, titanium, niobium, wanadium, silicon, boron, aluminium and carbon, sulphur and others;
- the compositions of various metals and non-metals.

The main purpose of the thermo-chemical treatment is a surface hardening /carbirizing, nitriding, carbo-nitriding, boriding/ or an increasing of the corrosion resistance /aluminizing, chromizing/. A change of the steel structure and connected with it the change of the physical and chemical properties is a result of an adsorbtion from the grounding environment the factor or factors having an influence on the surface layer properties and next on a diffusion of these factors inside the charge.

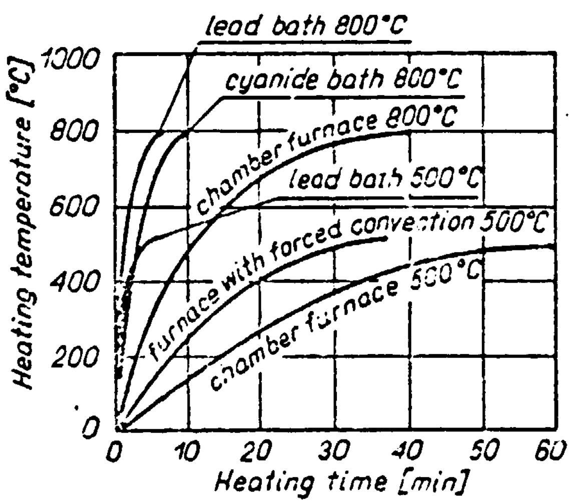
Heating - a general name of operation depends on an increasing and eventual a keeping of the temperature /fig. 1.1/.




a b

Fig. 1.1. Heating and quenching: a - permanent, b - graduated.

Upheating - permanent or graduated increasing of the charge temperature. The rate of upheating depends on power and a heating method of the heating equipment, a shape and size of a charge, kind of the material and a heat medium /fig. 1.2/.




a

| Kind of furnace | Relative heating rate |
|---|---|
| Muffle | 0,6 |
| Chamber resistance | 0,9 |
| Chamber flame | 1,0 |
| Gases convection | 1,5 |
| Salt bath | 4 - 5 |
| Metal bath | 6 - 8 |

b

Fig. 1.2. Influence the kind of the furnace, temperature and heating medium on time /a/ and charge preheating rate /b/.

As thicker is a object, than the heating time is longer. The objects with very surface are upheated faster than the solid shape objects or the objects layed close one to another /fig. 1.3/.

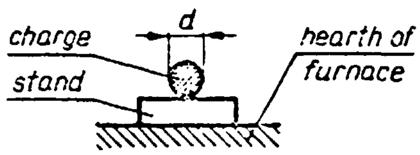
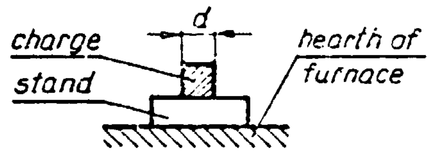
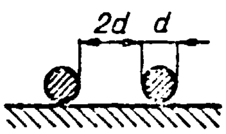
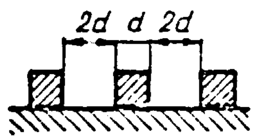
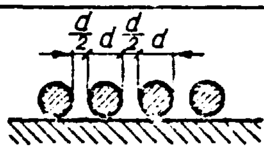
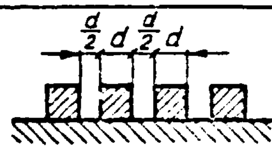
| Loading method | Relative preheating time | | Loading method |
|---|---|---|---|
|  | 1 | 1 |  |
|  | 1 | 1,3 |  |
|  | 1,3 | 1,3 |  |
|  | 1,5 | 2,2 |  |
|  | 2 | 4 |  |

**Fig. 1.3. Relative preheating time of the charge in dependence on a loading method of the furnace.**

Steels with high contents of carbon and alloy steels should be slow upheated, because they are brittle and have a wrong thermal conductivity; at fast upheating the particular parts of the charge are unequal upheated, which causes internal stresses in the charge. These stresses can cause deformations and crackings.

Steels with low contents of carbon and non-ferrous alloys can be upheated faster without any worry about crackings. The most slow is upheated an object loaded into the cold furnace and upheated along with the furnace. It is the method for upheating of the very big objects. The small objects are slow upheated successively in 2 or 3 furnaces /e.g the first upheating 550°C, the second 850°C and final upheating up to 1300°C/.

The fast upheating can be achieved by loading the charge into the furnace, which was previously upheated up to the treatment temperature; The faster upheating, when the charge is put into the furnace upheated up to temperature 100-200°C higher than the treatment temperature, which later is reduced to a proper level.

In practice the upheating time needed for the heat treatment is calculated on the base of section thicknesses, depending from a kind of the machining /table 1.1/, kind of the material /table 1.2/ and a heat medium of the furnace /see fig. 1.2/.

Soaking /holding at temaperature/ - holding the charge at the temperature corresponding to the heat treatment in the time needed for:

- leveling of the temperature in the whole section of the charge
- transition of the harder soluble components into a solution on a purpose to obtain the desirable alloy structure

/at events of the thermo-chemical treatments - as above and:/

- completing diffusion effects.

Austenitising - a soaking on the purpose to obtain the austenite structure before quenching.

Quenching - a permanent or graduatedreducing of the charge temperature up to the ambient temperature or another one through taking the heat away the charge with liquids, gases or solid bodies. The liquids are used the most often.

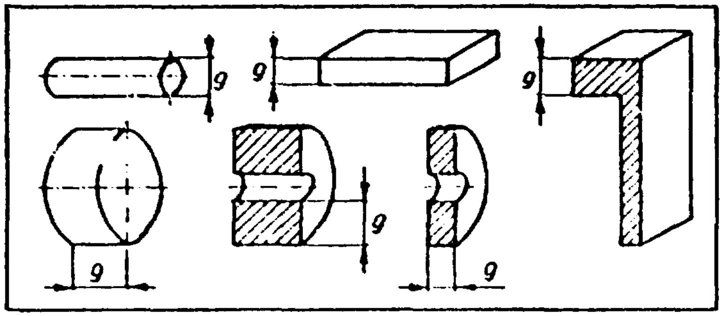
The run of the quenching in liquids is not the uniform one /fir. 1.4/:

- at the first phase a cover of a quenching liquid steam rizes on the surface of the object, creating the heat isulation of the object. In a result of it the quenching of the object runs with not too high rate,
- at the second phase the cover is broken by accumulated steams of the quenching liquid which causes violent boiling of the liquid around the object and quick outflow of steams up; the quenching is at that time the fastest one,
- at the third phase the boiling of the liquid stops, the ob-

Table 1.1.

Approximate heating time of the constructional carbon steel[1/] /0,4% C/ at heat treatment processes - in minutes per 1 mm of section thickness /g/

| Shape of the object | Hardening, normalizing full annealing[2/] | | | | High temperature tempering[3/] | | | |
|---|---|---|---|---|---|---|---|---|
| | Chamber furnace | | Salt bath | | Chamber furnace | | Salt bath | |
| | upheating | soaking /holding/ | upheating | soaking /holding/ | upheating | soaking /holding/ | upheating | soaking /holding/ |
| Round and polygonal steel bars[4/] | 0,8 | 0,2 | 0,35 | 0,17 | 1,0 | 0,25 | 0,45 | 0,12 |
| Sheets and flat objects | 1,2 | 0,3 | 0,50 | 0,25 | 1,5 | 0,37 | 0,70 | 0,18 |
| Tubes, pipes and box shape objects | 1,6 | 0,4 | 0,70 | 0,35 | 2,0 | 0,50 | 0,90 | 0,25 |




1/ For alloy steels the time should be increased about 25-40%

2/ Furnace temperature is about 10-30% higher than the hardening temperature

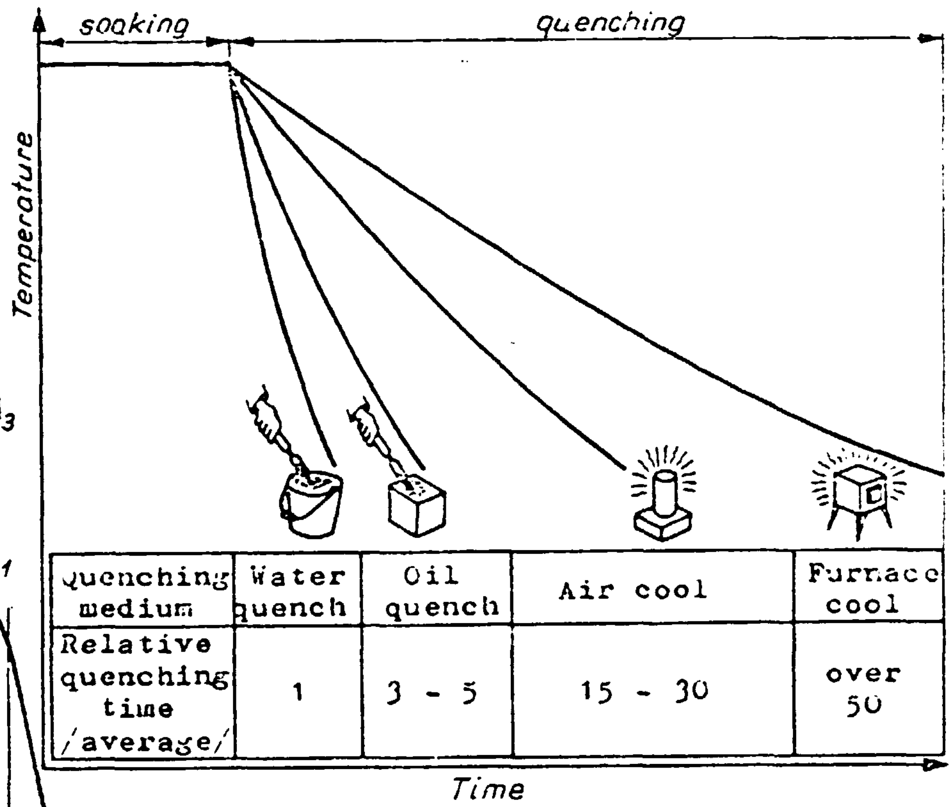
3/ This process time for the alloy steel is usually 1-3 hours

4/ For square bars as a thickness should be taken the square diagonal./i.e 1,4 of one side/

Table 1.2.

Approximate heating time in chamber flame furnace in minutes per 1 mm of section thickness

| Upheating temperature /oC/ | | 800 | | | | 750 | | | 500 |
|---|---|---|---|---|---|---|---|---|---|
| Upheated material | | low-carbon steels <0,2% C | constructional carbon steels and low-alloy steels | carbon tool steels | alloy tool steels and high speed steels | brasses | bronzes | copper | aluminium alloys |
| Shape of the object | bars | 0,8 | 1,1-1,2 | 1,6-1,8 | 2,5-3,0 | 0,7 | 0,6 | 0,5 | 0,6-0,7 |
| | plates and box shape objects | 1,6 | 2,2-2,4 | 3,2-3,5 | 5,0-6,0 | 1,41 | 1,2 | 1,0 | 1,2-1,4 |
| The average relative heating rate | | 1,0 | 0,75 | 0,6 - 0,3 | | 1,4 | 1,7 | 2,0 | 2,5 |




| Quenching medium | Water quench | Oil quench | Air cool | Furnace cool |
|---|---|---|---|---|
| Relative quenching time /average/ | 1 | 3 - 5 | 15 - 30 | over 50 |

Fig. 1.5. Relative quenching times in various media.

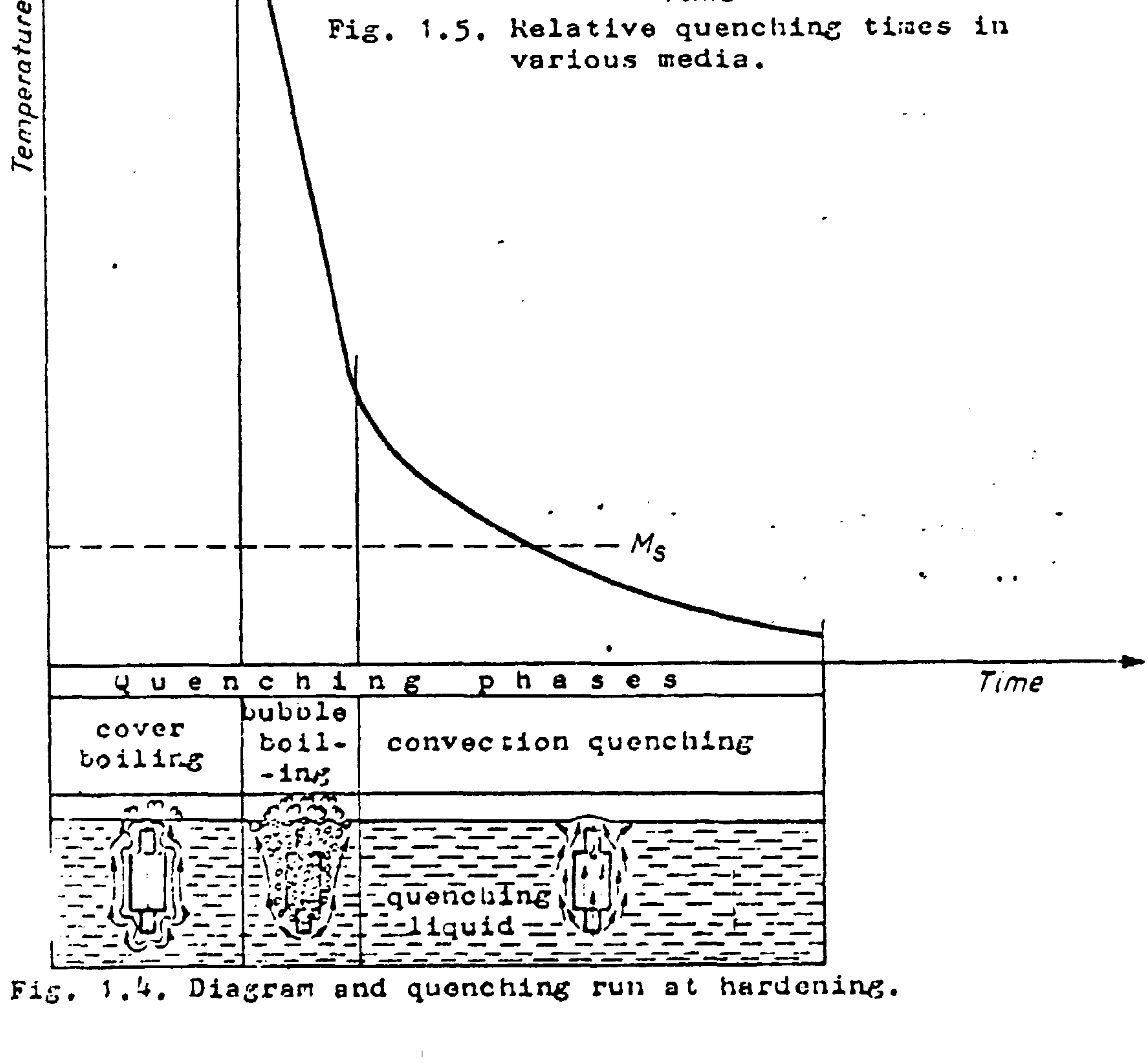



Fig. 1.4. Diagram and quenching run at hardening.

ject is slowly quenched with the liquid freely flowing around the object.

On the fig. 1.5 is shown the quenching rates in various liquids.

On the table 1.3 are given the quenching rates for some applied in practice liquids, gases and solid bodies for two ranges of charge temperatures:

- 650-550°C - the range of the least stability of the austenite; the high quenching rate is desired in order to avoid the desintegration of the austenite in ferrite and camentite /pearlite/;
- 300-200°C - the range of the martensite conversion beginning $M_s$; the slow quenching rate is desired /about 10-30°C/s/ in order to avoid the creating of big internal stresses causing a warpage and cracking of the charge.

On the table 1.4 are given kinds, properties and applications of various quenching media. In many countries the syntetical water quenching media and the hardening oils are produced with different commercial names. Other quenching media the user can make unaided.

The quenching rate of the whole object or its particular parts can be in considerable degree controlled by using of the proper way of an immersion in the quenching liquid /an immersion rate and a location at the immersion/, the object move in relation to the liquid /or inversely/ and a staying time of the object in the liquid. It allows to reduce the deformations and to obtain higher and more uniform hardness.

Charge - the object or objects which are the subject to heat treatment /e.g. the ones loaded into a furnace or into a quenching bath/.

## 1.2. Structure of metals and alloys

Allotropy - the ability of some elements existing in the same agglomeration state for creating crystallographically different forms at a definited temperature depending on pressure by means of the change from one crystal system to another one. For example: an iron exists in two allotropic forms - an

Table 1.3.

Quenching rate of steel in different media

| Quenching medium | Quenching rate /°C/sec/ in following temperature ranges | |
|---|---|---|
| | 550-650 | 200-300 |
| Water at temperature 18°C | 600 | 270 |
| Water at temperature 28°C | 500 | 270 |
| Water at temperature 50°C | 100 | 270 |
| Water at temperature 74°C | 30 | 200 |
| 10% solution of soda lye at temperature 18°C | 1200 | 300 |
| 10% solution of domestic salt at temperature 18°C | 1100 | 300 |
| Soap water at temperature 20°C | 30 | 200 |
| 10% emulsion of oil with water at temperature 20°C | 60 | 200 |
| Machine oil - 20°C | 150 | 30 |
| Transformer oil - 20°C | 120 | 25 |
| Glycerine - 20°C | 130 | 240 |
| 35% NaOH + 65% KOH - 300°C | 180 | - |
| Alloy of 70% Cd, 30% Sn at temperature 180°C | 450 | 25 |
| Copper plates | 60 | 30 |
| Steel plates | 35 | 15 |
| Liquid glass solution with density 5°Be | 200 | 100 |
| Liquid glass solution with density 15°Be | 100 | 60 |
| Compressed air | 70 | 8 |
| Quiet air | 18 | 2 |

Tablo 1.4

Kinds, properties and applications of different quenching media

| Namo | | Proportios | Application |
|---|---|---|---|
| Water | | quenching: I - very slowly<br>II- very quickly /it can cause deformations and crackings. To use the boiled water | for carbon stoels, low-alloy stoels /to 0,5% Cr or to 3% Ni/, some austenitic stoels, aluminium copper and alloys |
| Water solutions of: | 5-10% of domestic salt /NaCl/ or soda lye /NaOH/ | quenching rate in I and III step higher than in water | for hardening of stools which are the low tendency to deformations - when the high hardness is required |
| | 10-90% of glycerine | soft quenching in I step | hardening of developed shape tools |
| | liquid glass | quenching run more closed to oil | |
| | alcohol or organic compounds | they are produced as the concentrates with different trade names on the base of polivinyl alcohol or poliethylene glicols. Depend on the concentrate strength the quenching powe[illegible] closed to water or oil. They [illegible] edge the oils out of uso | for carbon, low-alloy, middle-alloy and high-alloy stoels |

Table 1.4 /continued/

Kinds, properties and applications of different quenching media

| | | | |
|---|---|---|---|
| solid substance | powdering | there are fluidized beds /corundum, electrocorundum/ putting into movement with air or another gas: ash, sand, lime or mica. The charge is immersed or covered with these substances. Very slow cooling /instead of a furnace cooling/ | |
| | steel or copper plates cooled with water | the charge is located between the plates | high-carbon or alloy steels |
| furnace quenching | | soaked charge remains inside the switch-off or poorly heated furnace. Very slow quenching | annealing of constructional steels: carbon alloy, chromium-nickel steels; tool steels: carbon, alloy, high speed steels; heavy cast steel castings and others |

Table 1.4 /continued/

Kinds, properties and applications of different quenching media

| | | | |
|---|---|---|---|
| Water fog | | slow quenching | for non-ferrous metals instead of oil |
| Hardening oils | | mineral, vegetable and animal oils as well as quick quenching oils /mixtures of the first three + fatty acids/. Much less quenching rate than in water results the less stresses and deformations of the charge and a low hardness. Oil temperature: 20-200°C | quenching of alloy steels, seldom aluminium alloys |
| Metal bathes /lead, seldom lead with tin or zinc/ and salt bathes | | profitable quenching run, minimal deformations. For step and isothermal hardening | most often: quenching of alloy tool steels and high speed steels |
| air /controlled atmospheres | quiet air | slow quenching, it causes very low stresses inside the charge, mostly don't resulting of deformations | normalizing, tempering, softening of the most steels and non-ferrous metals; hardening of some alloy steels |
| | air pressed blast | | hardening of high-alloy and high speed steels |

:siron α existing in two temperature ranges below 910°C and over 1400°C, and an iron γ existing in the temperature range 910-1400°C. The change from one crystal structure to another /e.g. the change of the iron α in the iron γ under an influence of the heating/ is named the allotropic transformation /see fig. 1.5 /.

Blue brittleness - reducing of a steel ductility and increasing of a tensile strength in the temperature range 200-300°C.

Casting - producing of objects by pouring the liquid metal or alloy into sand forms or metal moulds /chills/.

Casting - a object, which was shaped by pouring a liquid metal or alloy into the previous prepared casting forms - and next their solidification. There are distinguished s a n d and c h i l l castings as well as cored and coreless castings. The castings are made of cast irons, cast steels, nonferrous metals or alloys. The castings are mostly heat treated.

Cold work - a state of material caused by cold plastic working, resulting the higher strength of metal or alloy. The grain deformation /elongation/ is typical for it.

Crystal - a solid part of structure composed of atoms arranged in a definited pattern, periodic in three dimensions. Free developing crystal creats blocks with regular geometric forms of a polyhedron; in metal alloys the crystals don´t develop free. Physical and chemical properties of the crystal are not uniform in all directions.

Crystallization - the precipitation of a solid phase as the crystals from a liquid phase of the metal alloy resulting its cooling.

Deformation - a change of the object shape or its dimensions without the change of its mass owing to external forces: a p l a s t i c d e f o r m a t i o n - which remains after removal of the stresses, an e l a s t i c d e f o r m a t i o n - which vanishes after the removal of the stresses.

Dendrite - a crystal form or agglomeration of a ramified tree-like structure occuring in castings.

Diffusion - the mass transport of some gases, liquids or

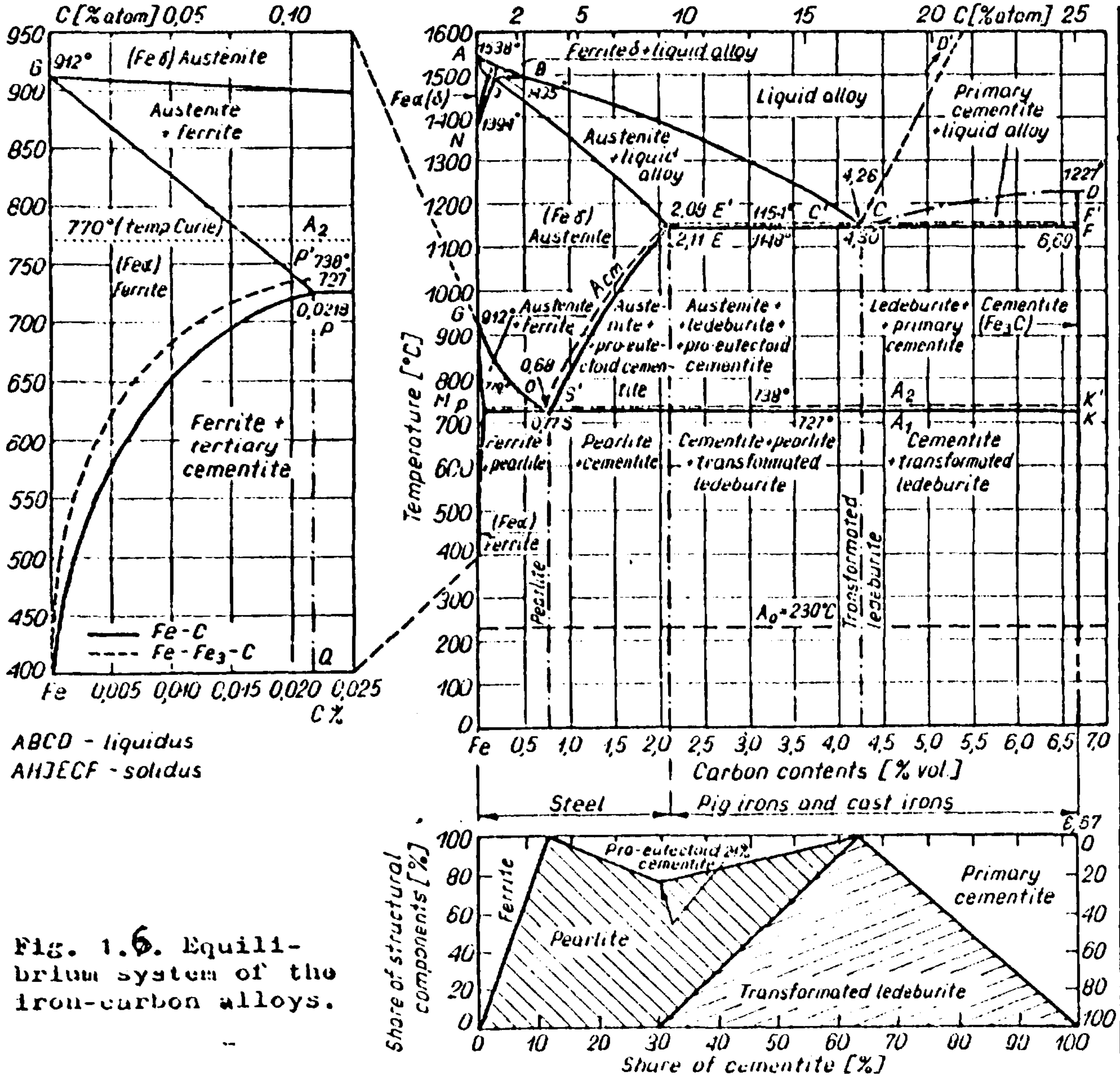



Fig. 1.6. Equilibrium system of the iron-carbon alloys.

**Transformations in the equilibrium system Fe-Fe3C**

| Designation: Upheating | Designation: Quenching | Temperature [°C] | Transformation type |
|---|---|---|---|
| $A_0$ | $A_U$ | 230 | magnetic one of cementite |
| $A_{c1}$ | — | 727 | eutectoidal one - pearlite into austenite |
| — | $A_{r1}$ | | eutectoidal one - austenite into pearlite |
| $A_{c2}$ | $A_{r2}$ | 770-727 | magnetic one of ferrite |
| $A_{c3}$ (GSK) | $A_{r3}$ | 912-727 | alotropic one - Fe$\alpha \rightleftarrows$ Fe$\gamma$ |
| $A_{c4}$ | $A_{r4}$ | 1394-1495 | alotropic one - Fe$\gamma \rightleftarrows$ Fe$\alpha(\delta)$ |
| $A_{ccm}$ (SE) | — | 727-1148 | solution finish of cementite in austenite |
| — | $A_{rcm}$ (SE) | | precipitation start of cementite from austenite |
| — | — | 1495-1148 | melting start of steel at upheating |
| — | — | | solidifying finish of steel at quenching - creating of austenite |
| — | — | 1148 | melting start of cast iron at upheating |
| — | — | | solidifying finish of cast iron at quenching - creating of ledeburite |
| — | — | 1538-1148 | melting finish of alloy Fe-C at upheating |
| — | — | ~1600 | solidifying start of alloy Fe-C at quenching |

solids into other ones, caused by migration of atoms. The diffusion rate depends mainly on temperature and a kind of diffunding substances. The utilizing of the diffusion is a base of thermochemical treatment.

Elongation - the ratio of the increase in the length under a loading, describing the plastic properties of the material; it is marked as a specific elongation on the specimen, which measuring length is usually equal to 5-times or 10-times of the diameter /marked $A_5$ and $A_{10}$/.

Eutectic - an alloy in a fixed chemical composition solidifies at a given temperature like a metal; it forms a mixture of two or more components which doesn't mutually dissolve /solubilize/. Eutectic's composition suits to the lowest melting temperature /or to the solidifying one/ of a two-component alloy; e.g. in the iron-carbon alloy containing 4,3% of carbon - at temperature 1130°C solidifies an eutectic named ledeburite.

Eutectoid - a mixture in fixed proportions which results from an allotropic transformation of the one of compounds and the decomposition of a solid solution in two phases - during a quenching of the already solidified alloy /e.g. pearlite is a mixture of ferrite and cementite occuring in the quenching steel at temperature 723°C/.

Fatigue of a metal - reducing of the metal strength subjected to repeated stress cycles.

Forgeability /malleability/ - the technological property of a metal or alloy to be hot working by forging.

Forging - a hot or cold plastic working when a metal or alloy product is formed from an ingot, billet or bar by striking or pressing. There are distiguished following forgings: h a n d forging /a pressure is done by striking of the hand hammer/ and m a c h i n e forging /die or blacksmith ones/.

Forging - a blank /a semi-finished product/ or a product obtained by the forging. There are distinguished the h a n d forgings and d i e forgings. The forgings are usually heat treated and machined. The forgings are made of steels and non-ferrous metals or alloys.

Fracture - the surface look of a metal object on the breaking place of the object; the fracture character allows to describe a quality of the material and terms which caused its destroying. E.g. a fibrous fracture reflects upon a presence of impurities, a fatigue fracture - about occuring of variable stresses.

Grain /crystallite/ - the crystal which has been hindered in assuming a regular geometrical external shape, as by interference of adjacent growing crystals. It occurs during solidifying of a melting metal or alloy. It is the basic element of metal or alloy structures.

Hardening capacity /hardening power/ - an ability of the steel to become hardened, expressed as the highest possible hardness which can be acquired as a result of the quench hardening.

Hardness - a resistance of the material offered to permanent plastic deformations under the concentrated forces pressing on the small area of the material. Numerical values of the hardness /H/ depends on used measurement methods: Brinnel /HB/, Rockwell /HRC/ and Vickers /HV/ ones. The hardness usually increases after heat treatment.

Hydrogen brittleness - a brittleness of metals resulting from the excessive absorbtion of hydrogen gas, e.g. at an etching /etching brittleness/ or at an electrolitic coating /plating/ of the metallic products.

Impact strength - a resistance of the material against to cracking at striking.

Internal stresses - mutual counterbalance stresses inside a certain region of a body and occuring beside an external loading: c o n s t i t u t i o n a l stresses - occuring at structure changes /e.g. an increase of the specific volume at the transformation of austenite into the formation of martensite/, t h e r m a l stresses - owing to heating or quenching of the metal or alloy and caused by the expanding or shrinking /e.g. quenching, casting, welding stresses/.

Liquid solution - an homogeneous liquid occured as a result of the mutual soluting of melted metals or metals and non-metals.

Liquidus - a solidification start of alloy shown as lines in the system diagram.

Machinability - the property of the material determining its suitability for being machined.

Melting - the passing of a solid body of metals or alloys into a liquid state as a result of the heating.

Overheatness - a susceptibility of steel to overheating - shown by coarsening of the austenite grain /not squashed/ under the influence of an elevated temperature and time.

Phase - an homogeneous part of a system /with uniform physical properties and the same chemical composition/ which can be separated from the remainder with mechanical methods. E.g. water and water solution of juice give one phase; a mixture of water and sand - two phases; allotropic forms of the iron α and γ give two separate phases.

Plasticity /malleability/ - an ability of metals and alloys for extensive permanent deformations under external forces /e.g. a hammer, a press/ without a fracture.

Recrystallization - a replacement of cold worked metal or alloy structure by a new set of strain-free grains. This process occurs during heating. The heating process is named the recrystallization annealing. The lowest temperature at which the process starts is named the recrystallization temperature. The process runs in three periods /fig. 1.7/.

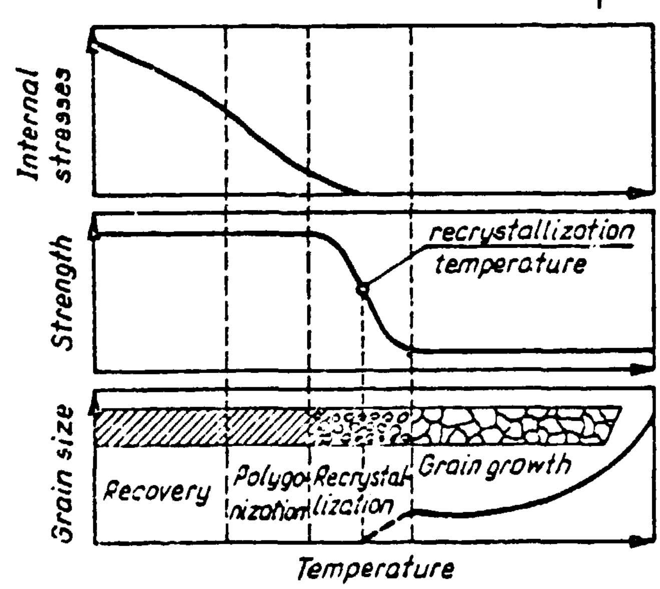



Fig. 1.7. Recrystallization. For example is shown the recrystallization annealing and its influence on changes of some steel properties.

Solid solution - an homogegeous mixture of the mutual soluting of metals or metals and non-metals, e.g. solid solution of carbon and iron $\gamma$ /austenite/.

Solidification - the passing of a metal or alloy from a liquid state into a solid state.

Solidus - a line in the constitutional diagram showing when the alloy solidification is completed.

Strength - a resistance against to destroying dealing of mechanical factors, i.e. different kinds of the loading; the ability of a material to sustain loads. In dependence on the loading kind, the following strengthes can be distinguished: tensile /$R_m$/, torsional, bending, shear, compressive, creep and fatigue one.

Structure - an internal construction of the metal or alloy M a c r o s t r u c t u r e - the structure which may be seen with the naked eye. M i c r o s t r u c t u r e - the structure which may be seen by a microscope only after the surface has been suitable prepared.

Temper brittleness - reducing of an impact strength which occurs when certain costructional steels are cooled slowly after tempering or soaking for long time in the temperature range 450-600°C.

Temperability - the susceptibility of a hardened steel to be tempered shown by reducing of the hardness at increasing of the tempering temperature.

Thermal arrest - a temperature stop at the solidifying or melting of metals and during heating or quenching of the solid alloys - at the moment of the allotropic transformation or a precipitation of the new phase; these temperatures are named the critical temperatures.

Warping - a distortion of a metal object during heat treatment, occuring as a result of internal stresses, the heat treatment process terms and others.

## 1.3. Metals and their alloys

Metals - the chemical elements /e.g. iron, copper, nickel, zinc/ distinguishing themselves with a specific lustre /co called - the metallic lustre/, plasticity /an ability to form the objects by forging, pressing, drawing, bending and other methods/, the good thermal and electrical conductivity. Many of them can be shaped by casting.

Metal alloys - sometimes, in familiar speech, they are named simply: the metals.

Non-ferrous metals - every metal except iron.

Non-metals - chemical elements distinguishing themselves with a lack of the metallic lustre, with the brittleness as well as the bad thermo and electrical conductivities /e.g. carbon, sulphur, phosphorus/.

Alloy - a substance with metallic properties, obtained by melting or mixing up of two or more chemical elements. At least a one among them is the metal and is used in the mostly part. Alloys are usually made for property changes of the main metal in the required direction, e.g. for improving of the mechanical, casting and other properties; in many events the improvement of the mechanical properties is connected with getting worse of the plasticity, thermo and electrical conductivity, corrosion resistance. The most known alloy of the metal and non-metal is the alloy of iron carbon.

Non-ferrous alloys - alloys, where iron isn't the main component and can be, at the most, the one of the alloy components. The most known these alloys are brasses, bronzes and various aluminium alloys.

Steel - the plastic worked and heat treated iron-carbon alloy conaining less than 2% carbon. Every steel contains except of carbon the other admixtures /e.g. manganese, silicon/ and impurities /sulphur, phosphorus and others/.

Carbon steel - a steel which, except of carbon, contains small admixtures of manganese and silicon.

Alloy steel - a steel which, except of admixtures met in the carbon steel, contains intentionally added nickel, manganese, chromium, silicon, wanadium, tungsten and others, in order to give for the steel required properties /table 1.5/. Every steel can be plastic worked /rolling, forging/.

Cast steel - a steel casted into forms and used as a semi-product without the additional plastic working. Alike the

Table 1.5.

Influence of the alloy additions on the steel properties

| Name and symbol of an element - the alloy addition | Overheating sensitivity | Hardenability | Temperatures of annealing normalizing and hardening | Hardness and tensile | Plasticity | Strength at high temperatures | Temper brittleness sensitivity |
|---|---|---|---|---|---|---|---|
| Aluminium Al | --- | -- | ++ | + | + at low contents | = | + |
| Chrominium Cr | -- | ++ | +++ | + | + | ++ | ++ |
| Cobalt Co | = | - | = | + | = | + | 0 |
| Silicon Si | = | ++ | ++ | ++ | -- | ++ | 0 |
| Manganese Mn | + | ++ | -- | ++ | 0 /to 1,5% in low carbon steels/ | = | ++ |
| Molybdenum Mo | = | +++ | ++ | ++ | ++ | ++ | --- |
| Nickel Ni | = | ++ | -- | ++ | + | ++ | 0 |
| Niobium Nb | 0 | 0 | ++ | -- | ++ | 0 | - |
| Titanium Ti | -- | 0 | +++ | + | + | = | 0 |
| Vanadium V | --- | 0 | ++ | ++ | ++ | = | 0 |
| Tungsten W | -- | ++ | ++ | ++ | + | +++ | -- |

Note: Discussed alloy addition has the definite property: ++ increases; +++ considerably increases; + poorly increases; -- decreases; --- considerably decreases; - poorly decreases; = it has poor influence; 0 no influence steel it is divided into a carbon cast steel and an alloy cast steel and can be heat treated, especially the latter one.

Cast iron - the iron-carbon alloy containing 2-4,3% carbon and used as the castings only. The carbon cast iron contains more quantities of admixtures /especially silicon/ and impurities than the carbon steel. The alloy cast iron - contains moreover special additions, mainly chromium, nickel and silicon. The microscope observation of the polished and etched specimen of steels and cast irons shows that their structure is constituted with grains of the components given in table 1.6.

## 1.4. Iron-carbon ecuilibrium system

The iron-carbon diagram shows a behavior of the iron-carbon alloys during a slow heating and quenching /fig. 1.6/. The system does'nt take into account the time, which is very important factor in heat treatment processes, but this system has however the basic meaning for the theory and practice of this treatment. The alloy structure at the equilibrium state is a fiducial base in relation to the structures after the heat treatment, which aims to recede from the equilibrium state /e.g. hardening/ or to approach to it /e.g. quenching/. Moreover the equilibrium system allows to describe the heat treatment process kinds which at all can be applied as well as in what temperature ranges these heat treatment processes should be carried out.

During the heating /or quenching/ of iron-carbon alloys occur in them the many transformations to the melting inclusively. A run of these transformations depends on the carbon contents /see fig. 1.6/ and, in a small degree, on the carbon formation - cementite $Fe_3C$ /full lines/ or graphite.

The diagram top part /lines ABCD and AHJECF/ shows the run of the melting at a heating /or solidifying at self-cooling/, the low part /lines HNJ, GSE, GPSK, PQ/ - the run of s o l i d s t a t e t r a n s f o r m a t i o n s. From the heat treatment point of view, the low part is the most important one, but to contents of 2% carbon only.

Table 1.6.

Structural constituent of the steel and iron

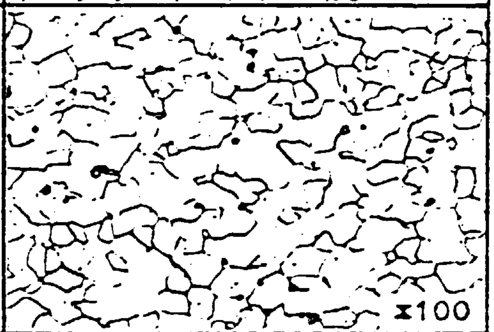
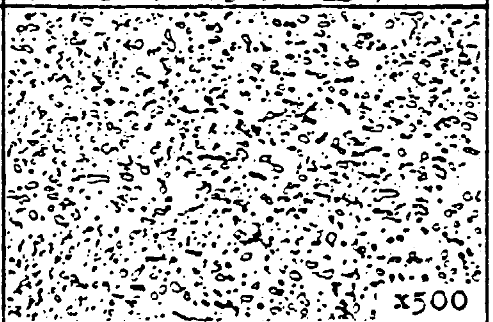
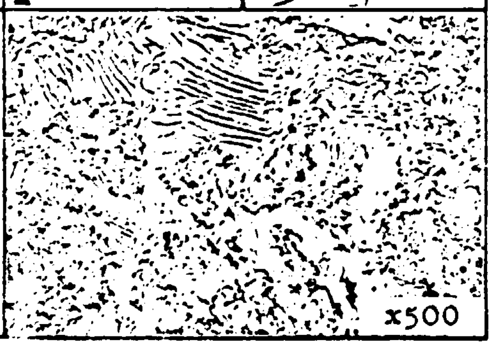
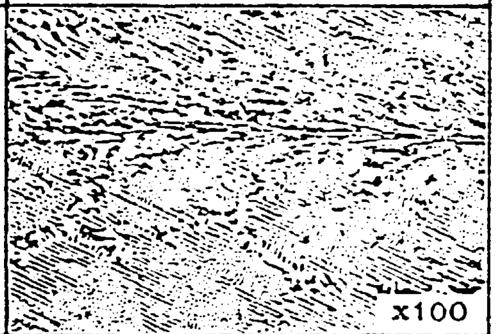
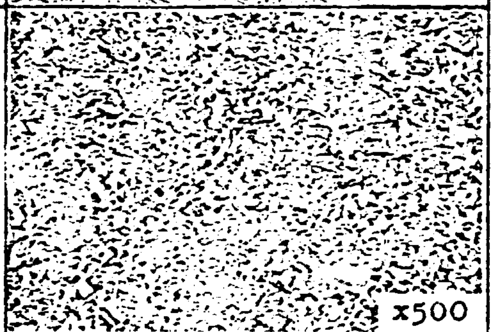
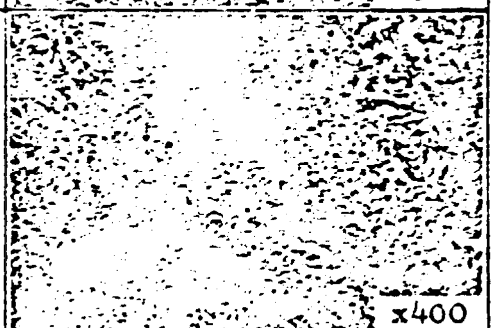
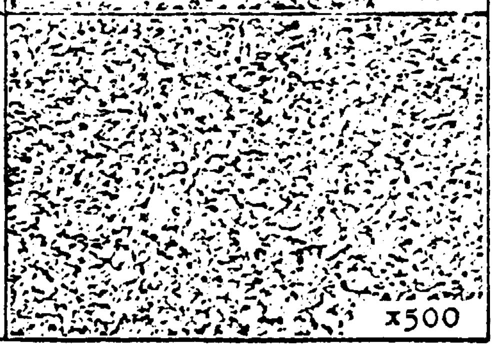
| Constituent name and description | Creating conditions | Physical proper-ties | Structure |
|---|---|---|---|
| Austenite:<br>solid solu-tion of car-bon /and other ele-ments/in iron $\gamma$ /gamma/; it contains to 2% C | at upheating above the critical temperatures $A_{c1}, A_{c3}, A_{cm}$ | plastic, non-ma-gnetic 170-220 HB |  |
| Ferrite:<br>solid solu-tion of car-bon /and other ele-ments/in iron $\alpha$ /alfa/; it contains to 0,03% C | at slow coo-ling below $A_{c3}$ of hypo-eutectoid - ferrite from austenite separates | plastic, magnetic 60-100 HB |  |
| Cementite:<br>chemical compound of iron and car-bon $Fe_3C$; it contains 6,67% C | at slow coo-ling it sepa-rates from liquid and solid solu-tions | brittle, magnetic to 210°C 820 HB |  |
| Graphite:<br>one of the carbon allo-tropic forms /another form - dia-mond/ | at slow coo-ling - from cementite unmixing. It occur mostly in cast iron /seldom in steels/ | brittle, non-ma-gnetic, very soft |   |
| Pearlite:<br>eutectoid composed of ferrite and cementite; it contains 0,8% C | at slow coo-ling - from austenite unmixing | less pla-stic than ferrite, magnetic 160-230 HB |  |

Table 1.6. /continued/

Structural constituent of the steel and iron

| Constituent name and description | Creating conditions | Physical properties | Structure |
|---|---|---|---|
| Ledeburite: eutectic composed of austenite and cementite; it contains 4,3% C. Below 723 oC composed of pearlite and cementite | at solidifying of the liquid solution containing above 2% C at temperature 430°C | very hard and brittle 450 HB |  x100 |
| Martensite: supersaturated solid solution of carbon and other elements in iron α/alfa/, having an acicular structure | at quick quenching from temperatures above $A_{c3}$ - $A_{cm}$ separates from austenite /conventional hardening/ | brittle, magnetic, hardness depends on carbon contents 600-700 HB |  x500 |
| Bainite: mixture of cementite and ferrite having an acicular structure and big grain refining | at isothermal transformation of austenite in temperature range 250 - 400°C /isothermal hardening/ | low plastic, magnetic 400 HB |  x500 |
| Temper troostite: mixture of cementite and ferrite having very big grain refining /bigger than in pearlite/ | at upheating of martensite at temperature 250-400°C /low and middle-temperature tempering/ | low plastic, magnetic 350-400 HB |  x400 |
| Temper sorbite: mixture of cementite and ferrite having big grain refining /less than in troostite/ | at upheating of martensite to temperature 500-650°C /high-temperature tempering/ | plastic, magnetic 270-320 HB |  x500 |

Self-cooling of the liquid alloy. If the liquid iron-carbon alloy begins to cool, the start of solidifying will be - depends on the carbon contents - on the liquidus line ABCD and a solidifying end - on the solidus line AHJECF. At temperatures above the liquidus line the alloy is in liquid state, on the field between liquidus and solidus lines - the alloy is in a partly liquid state /a liquid with precipitated crystals/, below the solidus line - the alloy is completely solidified. E.g. an alloy with contents 2,5% of carbon will begin to solidify at temperature about 1350°C precipitating the crystals with a composition shown by the line JE. A remained liquid enriches itself simultaneously in carbon and a start temperature of its solidifying decreases and moves in a direction of point C. The last drop of the alloy will have a composition acc. to point C and will be solidified at temperature 1148°C /eutectic temperature/. The same solidifying end temperature have all of the iron-carbon alloys containing no more than 2% carbon.

The pure iron melts and solidifies at a constant temperature 1148°C. Also at the constant temperature 1148°C /not in temperature range/ melts and solidifies an alloy contains 4,3% carbon, named ledeburite.

Pig irons and cast irons - contain a carbon mostly in the range 2-4,3%. They begin to melt - where there is no influence of alloy additions - at the temperature 1148°C/1154°C/ and they finish to do it at different temperatures, depends on a carbon contents, acc. to line BC /the more the carbon - the lower melting end temperature/.

Steel - the melting start temperature at heating /or melting end temperature at cooling/ depends on a carbon contents /line AHJE/ and when the temperature is higher - the steel contains less carbon.

Solidified alloy cooling. When a hot, solidified iron-carbon alloy will be cooled to a temperature below 1148°C /or when a cold alloy will be heated to this temperature/, so in the alloy will occure t e solid state transformations. They are caused by an appear nce in the iron the allotropic formations, different in the crystallographical structure as well as physical - chemical and mechanical properties.

There are following allotropic formations of the iron: $\alpha$, $\gamma$, $\delta$ /$\alpha$/. To 770°C /Curie temperature/ the $\alpha$ formation is a ferromagnetic substance /it has magnetic properties/, above this temperature it is paramagnetic substance /it has not magnetic properties/.

The particular formations show the different carbon solubility: $\alpha$ iron solutes the carbon in small degree only, $\gamma$ iron distinguishes itself with the large carbon solubility.

The allotropic transformation $\alpha \rightleftharpoons \gamma$ and connected with it a solution and a precipitation of the carbon does'nt occur in a constant temperature but in the temperature range - from 727°C to the temperature described by GSE line. At heating this transformation begins at 727°C and finished at various temperatures - acc. to GSE line - depends on the carbon contents.

The transformation start temperature $\alpha \rightleftharpoons \gamma$ is marked with letter $A_1$ - it is so called point $A_1$ of steel. At the cooling occurs certain over-cooling and the transformation takes a place below 727°C.. At the heating - a little above. It is why the point $A_1$ is marked at heating as $A_{c1}$ /c = chauffage = heating/ and at cooling as $A_{r1}$ /r = refroidessement = cooling/.

The transformation end temperature $\alpha \rightleftharpoons \gamma$ is marked with letter $A_3$ - $A_3$ point for steel /and analogically - $A_{c3}$ and $A_{r3}$/. The temperature of this transformation describes the GSK diagram line in dependence to the carbon contents. For the steel which contains C > 0,8% - points $A_1$ and $A_3$ are the same.

For steel with contents C > 0,8% the solution finish of cementite is marked as $A_{cm}$ /SE line/.

For steel with contents 0,8% of carbon /S point on the diagram/ the transformation begins and finishes at the same temperature 727°C. This steel is called e u t e c t o i d steel. This steel in a fully annealed condition is composed of equal grains. Each grain is composed of the small, very hard cementite lamellas and ferrite lamellas. This structure after the etching looks like a pearl surface and for it is called pearlite.

Grains of all low-alloy carbon steels in the annealed condition are composed of a ferrite and a cementite. A steel without the heat treatment is the harder, the more it contains of the hard constituent- cementite, i.e. when the higher is a carbon percentage. The dependence between hardened and annealed steel hardeness and the carbon contents is shown in fig. 1.8.

Hypoeutectoid steels /C < 0,8%/ are composed of ferrite and pearlite grains; a contents of the pearlite increases along with increasing of the carbon contents.

Hypereutectoid steels /C > 0,8%/ are composed of pearlite and cementite grains. A contents of the cementite increases along with increasing of the carbon contents.

Alloy components have an important influence on the steel structure, decreasing the carbon contents which is necessary to obtain the pearlitic structure and which causes a left movement of S point on the iron-carbon diagram.

Besides, the alloy components dislocate /some of them even considerably/ the particular diagram lines /$A_1$ and $A_3$/. Especially important in practice is an influence of the components on the $A_1$ point location /fig. 1.9/, because a selection of a proper heating temperature at the hardening depends on the location of this point.

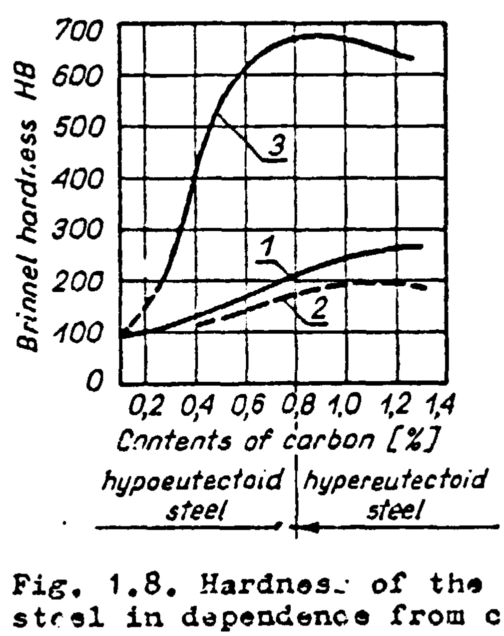



Fig. 1.8. Hardness of the carbon steel in dependence from carbon contents: 1 - annealed with lamellar cementite, 2 - annealed with spheroidal cementite, 3 - hardened in water.

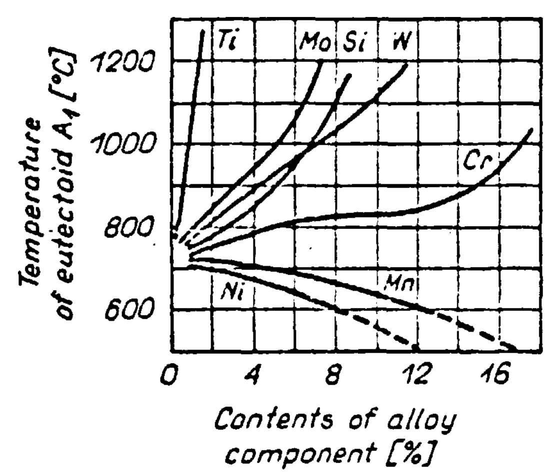



Fig. 1.9. Influence of alloy components on a location of a steel point A.

## 2. Conspectus of the selected heat treatment technologies

### 2.1. General characteristic of heat treatment processes

Every heat treatment process consists of heating of a charge to fixed temperature, holding it at this temperature for fixed time and quenching it at fixed rate /fig. 2.1/.

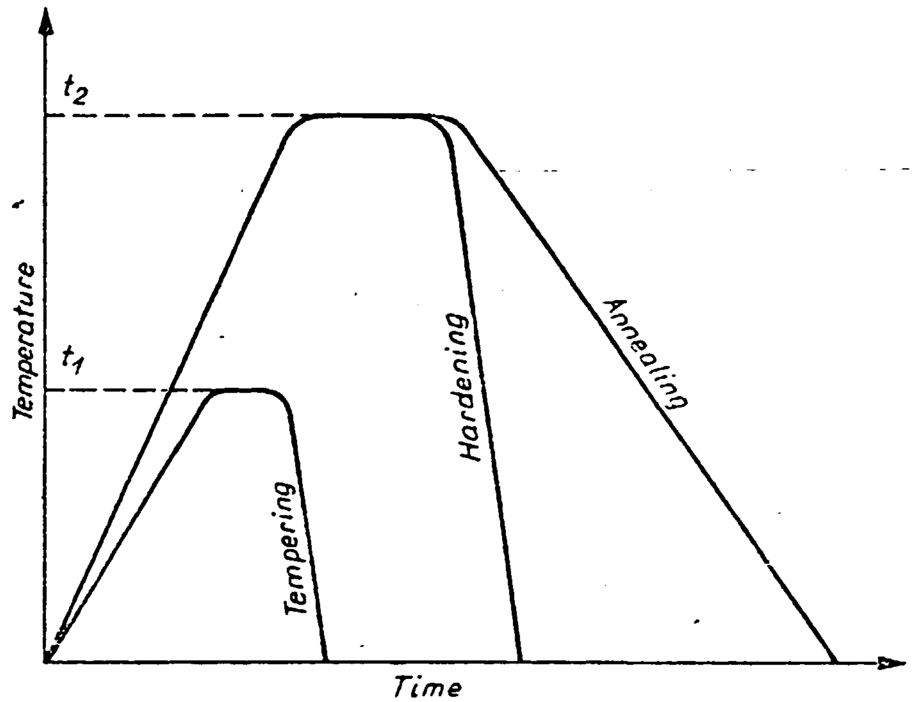



**Fig. 2.1. Run diagram of various heat treatment operations.**

Processes realized at temperature $t_2$, higher than phase transformation temperature, can after quenching to guide the alloy structure to the more or less distance from the physico-chemical and structural equilibrium. The slow quenching causes the approach to the equilibrium state and this process is named a n n e a l i n g . The quick quenching does not change the distance from the equilibrium state and that process is called h a r d e n i n g.

Processes realized at temperature $t_1$, lower than the phase transformation temperature, approach the alloy structure to the equilibrium state; in these processes the quenching rate has low influence on alloy properties. These processes are named t e m p e r i n g.

In non-deformed alloys with one-phase structure does not occur a property changes after heat treatment. The heat treatment results the property changes these alloys only, in which exists at least 2 phases submitting to transformations during the heating and quenching times. The transformations of the one into the second phase or a change their quantitative relation in heterogeneity alloys induce a change of the alloy properties. Only these alloys are heat treated which components forms the solid solutions and which change their solubility along with temperature, or the alloys in which the phase transformations occur during the quenching /allotropic transformations or the solution unmixing into more phases/.

A change of properties resulted of heat treatment depends not only on a quantitative relation of phases, given on the equilibrium diagram, but also from a magnitude of various phases defening an alloy microstructure and their mutual location. The microstructure depends on its forming conditions, i.e. depends on the heat treatment and a durability of the obtained alloy state.

Below will be discussed the heat treatment of the iron-carbon alloys.

## 2.2. Annealing

The annealing is applied on purpose:

- reducing of hardness and thereby making easier the machining and the plastic cold working,
- obtaining the proper structure from a point of view the further heat treatment operations or other technological operations,
- reducing of internal stresses.

In connection with purposes of the annealing, the following its kinds can be distinguished:

Diffusion annealing /homogenizing/ depends on slow upheating of the charge to the high temperature /1000-1250°C/, long soaking at this temperature /the bigger charge, the longer holding time/ and slow quenching in order to reduce local heterogeneities /microsegregation/ of a chemical compound. It is used for big steel castings and ingots /metallurgy/, mainly for alloy steel ones.

Full annealing depends on austenitizing of the charge at temperature 30-50°C above a GSE line and slow cooling, mostly a furnace cooling, for a purpose:

- to full recrystallize the steel for obtaining a fine-grained structure, distinguishing itself by low hardness and good ductility,
- to remove internal stresses,
- to improve the workability.

The slow upheating is applied only for brittle steels, the soaking exists average 2-3 hours in relation to size of the charge, the slow quenching to 400-500°C.

The quenching rates are:

- carbon steels about 200°C/h
- low-alloy steels about 100°C/h /fig. 2.3/
- high-alloy steels about 50°C/h.

The steel structure after annealing is ferrite and pearlite.

The full annealing is applied for forgings, bars and castings made of cast steel, mainly of hypoeutectoid steel.

Isothermal annealing depends on austenitizing of the charge like at full annealing, quick quenching to temperature inside a pearlite transformation range /110-120°C below $A_{c1}$/, soaking at this temperature /2-3 h/ till an austenite transformation into pearlite will be finished and next on free cooling, e.g. an air cooling /fig. 2.3b/. Purposes and the structure - like after the full annealing. The isothermal annealing is applied mainly to tool steels for the purpose to do shorter an annealing time.

Normalizing depends on austenitizing of steel at temperature like in fig. 2.2 and quiet air cooling on purpose to obtain the uniform and fine grains. For hypereutectoid steels is applied a partial normalizing, depending on the soaking at temperature above SK line. Upheating for normalizing - the quick; soaking time: objects of small and middle sizes - 0,25-1 h, castings - to 6-12 h /fig. 2.3c/. The normalized

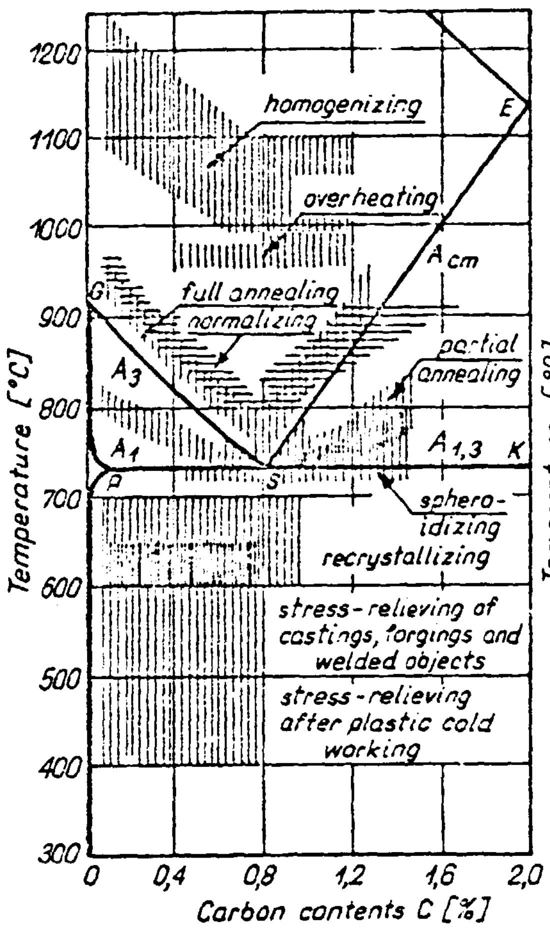



**Fig. 2.2. Approximate temperature ranges of various annealing kinds against a background of the iron-carbon diagram.**

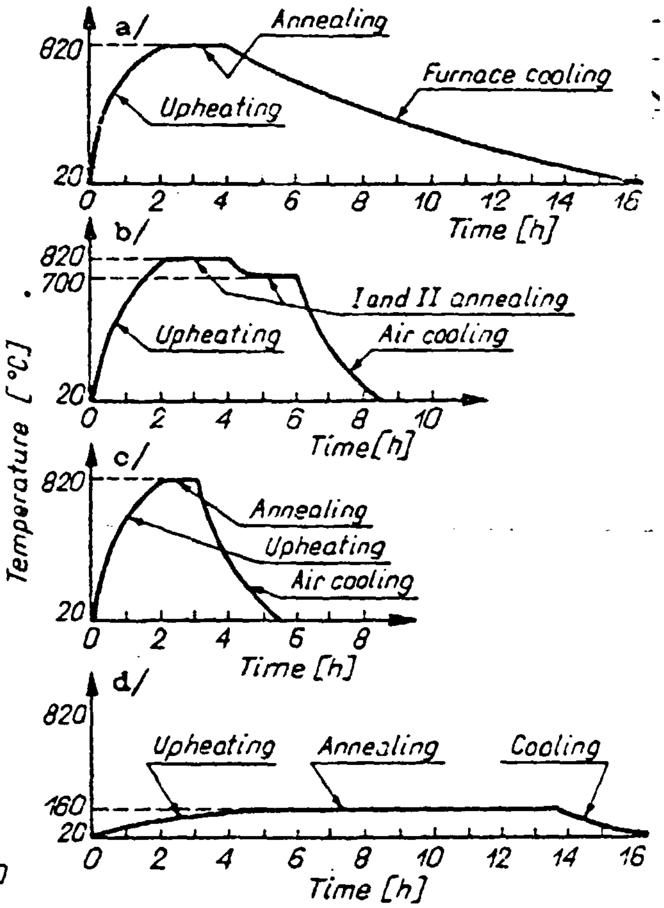



**Fig. 2.3. Run diagrams of various annealing kinds for a object made of lowalloy tool steel: a - full annealing; b - isothermic annealing; c - normalizing; d - stabilizing.**

steel structure: carbon steels - ferrite and pearlite, alloy steels - sorbite and martensite /at air hardening/. After normalizing of alloy steels there is applied a soft annealing. The purpose of normalizing is a grain refining, improving of strength, removing of internal stresses /e.g. after forging/, removing of hardening state and preparing the steel for further heat treatment /toughning, hardening, carburizing/. Normalizing is applied to forgings, bars and cast steel castings.

Partial annealing depends on soaking of the charge in critical temperature range /between $A_{c3}$ and $A_{c1}$ for hypoeutectoid steels and between $A_{c1,3}$ and $A_{cm}$ in hypereutectoid steels/ and next on cooling at least to overcrossing the temperature $A_{r1}$

for the purpose of partial recrystallizing and obtaining the properties like at full annealing. Heating and quenching - like at full annealing. A structure after the process - ferrite and pearlite in hypoeutectoid steels as well as pearlite and cementite in hypereutectoid steels. The partial annealing is mainly applied to tool steels and the bars made of hypoeutectoid steels before the machining - in order to remove the stresses and improve the workability.

Soft annealing /spheroidizing/ depends on upheating to temperature shown in fig. 2.2, cyclic /multiple/ or single annealing and next slow cooling on purpose to obtain a spheroidal cementite structure against a ferrite background. The spheroidizing is mainly applied to hypoeutectoid and hypereutectoid tool steels on purpose to reduce hardness, to improve a workability and to increse the plasticity and ductility.

Recrystallization annealing depends on upheating the previously submitted to cold working /forging, stamping, rolling, drawing/ steel to temperature a little above the recrystallization start temperature /600-700°C/, soaking /about 0,5 h/ and quenching at a free speed - on purpose to remove the cold work results and to replace the deformed and hard structure by the soft, usually fine-grained one. The recrystallization annealing is applied to pressed or cold forged products as an interoperation or final working in order to reduce the hardness, increase plasticity and to remove stresses.

Stress relief annealing /stress relieving/. It is not too fast upheating of the charge to temperature lower than $A_{c1}$, soaking during 1-6 h and slow cooling /a furnace cooling to 200-300°C/ for the purpose of prominent internal stress reducing without marked structural changes. The stress relieving is applied to cast iron /450-550°C/, cast steel /500-550°C/, welded objects /500-600°C/, forged and cold presses products /400-450°C/, after hot forging /600-650°C/, after heat treatment, e.g. on purpose to remove the stresses which arisen as a result of too quick quenching /450-500°C/.

Graphitizing. It is upheating the charge to temperature at which occur the cementite unmixing, soaking and quenching for the purpose of the full or partial unmixing of cementite into graphite /temper carbon/ and ferrite. Graphitizing is mostly applied for special grades of the white cast iron in order to obtain the black heart malleable cast iron.

Decarburizing annealing. A long /some scores of hours/ soaking of the charge in temperature, at which occurs the removal of carbon by diffusion on purpose to remove partially or campletly the carbon out of the alloy. Decarburizing annealing is applied to production of white heart malleable cast iron.

Stabilizing. It is a slow upheating and next soaking of the charge at temperature usually does not crossing 150°C /see fig. 2.6/ during the time limit from 2 till some scores of hours, slow quenching /fig. 2.3d/ in order to reduce the changes which occur at the ambient temperature as well as to reduce the internal stresses. The process is applied to steels and cast iron castings. There is also known a natural stabilizing depends on holding the cast iron castings at the ambient temperature during a few monthes or even years in order to remove the internal stresses and for obtaining the size atability.

## 2.3. Hardening

### 2.3.1. Bulk hardening

Bulk hardening depends on austenitizing and next on rapid quenching of the charge in order to obtain a martensite or bainite structures and hereby to increase the hardness of substance in the whole charge capacity.

When carbon or low-alloy steel, upheated to temperature in which they are in austenitized state /above GSK line - see fig. 1.7 and 2.6/, to submit to the rapid quenching - the soluted cementite will not be able to precipitate itself again and the steel obtains the fine-grain structure named martensite. With this structure the steel has the highest hardness and the small plasticity.

The martensite is not a component of the iron-carbon equilibrium system /see fig. 1.7/. At an ambient temperature it is however rather the permanent and its unmixing follows only after upheating; in this event one says that the steel dishardening itself /it loses its hardness/.

The upheating for hardening should be carried out with a moderate rate which does not cause the stresses in the charge material. Steels with high carbon contents and alloy steels are usually slow upheated alike the charges with a large section and a developed shape.

A heating temperature at hardening should cause a passing a structure of the steel into austenite state. In practice it is the temperature about 30-50°C higher than a temperature corresponding to GSK line /see. fig. 2.6/. A considerable excess of this temperature effects the symptoms of overheating, i.e. coarse grainedness, high stresses and even hardening cracks. Alloy components, reducing or increasing the location of a point $A_2$, affect desiderable upon the heating temperature at hardening.

A soaking time at hardening temperature /austenitizing/ depends on a material sort and on a size and a shape of the charge.

The transformation of austenite in martensite begins and finishes at fixed temperature depended on the chemical composition of the steel. For carbon steels a start temperature of the martensite transformation $M_s$ is in the range 100-300°C, a finish temperature $M_f$ - correspondingly from -200°C till +200°C.

A rapid quenching has at first in view an overcooling of the austenite to the temperature $M_s$ /start of the martensite transformation/ on purpose to enable this transformation. If the quenching is too slow so before the martensite transformation temperature will be obtained, the martensite begins to decompose into other structures /hardening troostite and sorbite/ and the steel achieves the lower hardness.

A decomposition grade of austenite for the steel depends on a staying time of the charge at stated temperature /fig. 2.4a/. If you know these data for a train of successive temperatures - you can draw a diagram of the austenite isothermal transformations /fig. 2.4b/ which is a base for working out of the hardening technologies.

In fig. 2.4 the following ranges can be distinguished:

- above $A_1$ $A_3$ line: austenite /A/ in the equilibrium state;
- to left from the transformation start line: overcooled austenite /A/, i.e. the austenite which in spite of temperature reducing did not yet the transformation and is in the metastable equilibrium state;
- between the transformation start line and the transformation finish line: austenite /A/ with partially precipitated ferrite /F/ and cementite /C/;
- to right from the transformation finish line: the completely finished transformation - the various components depended on quenching temperature, shown on the right side of the diagram and containing ferrite /F/ and cementite /C/ only;
- below the martensite transformation start time $M_s$: There can't be already the overcooled austenite alone, because at the crossing moment of the $M_s$ line the transformations begins at once and, till its finishing $M_f$, in this range can be only austenite /A/ and martensite /M/; below $M_f$ line will be only the martensite /M/ alone.

From the figure 2.4 results that the durability of the overcooled austenite is unequal and depends on the quenching temperature. Austenite is the least durable in temperature range of 500-600°C; in this range the transformation begins in less than 1 sec. At higher and lower temperatures from stated above so called maximum range of the transformation rate, the austenite durability is considerable higher, e.g. at temperature 700°C and 350°C the transformation begins in about 30 sec.

There should be then such quenching of the steel so lest the charge will achieve the start temperature of the austenite transformation in the non-desired moment.

The most desired structure after hardening is martensite /so called martensite hardening/. The austenite transformation can start before the charge achieves the mar-

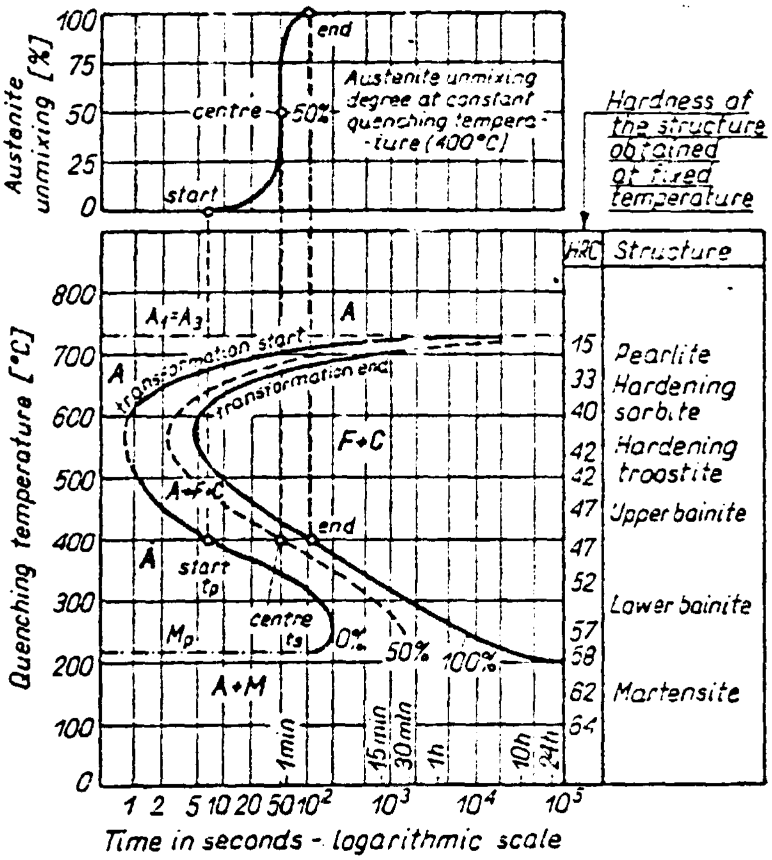
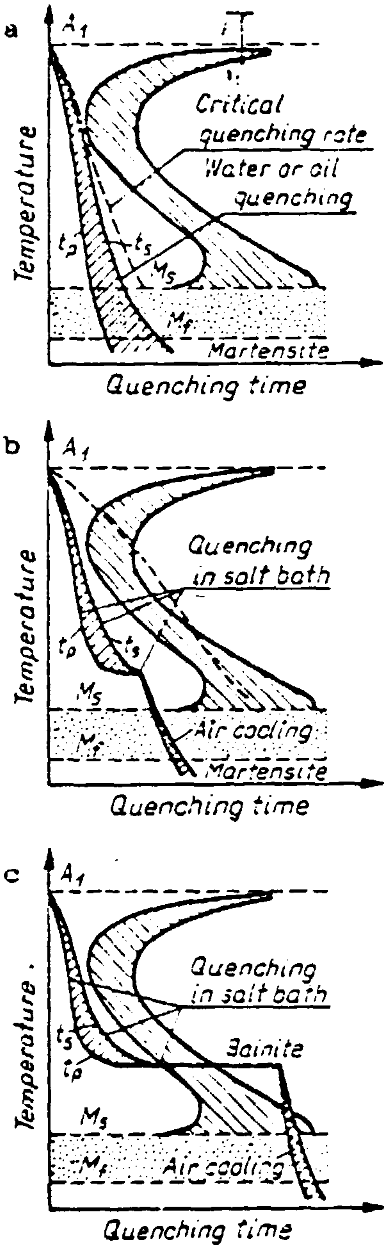



Fig. 2.4. Austenite isothermal transformations of the steel closed to eutectoid steel /about 0,9% C/.




Charge temperature: -
$t_p$ - on a surface,
$t_s$ - inside a section,
$t_g$ - inside a object with a large section which cant be bulk hardened

Fig. 2.5. Quenching run of the eutectoidal steel at the hardening: a - conventional; b - step; c - isothermal.

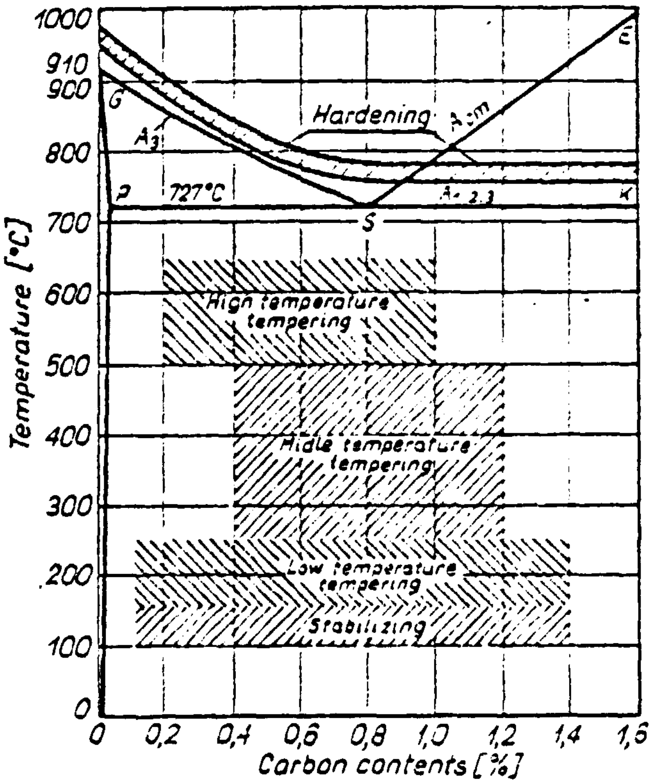



Fig. 2.6. Temperature ranges of hardening, tempering and stabilizing of the steel on the background of iron-carbon system.

tensite transformation temperature. The bainitic structure appears seldom after hardening /so called bainitic hardening/.

In dependence from quenching methods can be distinguished the following hardenings: conventional, interrupted, step and isothermic ones.

Conventional hardening -.it is a hardening with a continuous cooling in the medium at a temperature lower than the temperature of the martensite transformation start $M_s$ /fig. 2.5a/, usually to the ambient temperature. Thanks to occuring the martensite transformation the charge achieves indeed the maximum hardness, but inside the charge arise high stresses resulting deformations and cracks. Their reason is a fact that a martensite capacity is 1-1,5% bigger than an austenite one.

A quenching rate below the temperature $M_s$ has no influence on the obtained hardness. Then in order to avoid the deformations and cracks, in this temperature range should be used a possible slow quenching. Carbon steels and low-alloy steels are quenched in water. Steels with higher contents of alloy additions are quenched in oils and a pressed air blast.

The conventional hardening has in practice the most applications. Usually it is a martensite hardening, for some alloy steels is applied a bainitic hardening.

In the high temperature range a water ought to apply for quenching of a steel with lower carbon contents; for quenching of alloy steels an oil can be used.

Step hardening - a hardening with a non-continous quenching which is divided in 3 steps /fig. 2.5b/:

- quenching in a hot oil or in a melted salt from the austenitizing temperature to a temperature about 20-40°C higher than the temperature $M_s$ /the lower than $M_s$ exceptionally only/,
- holding in a hot bath during a time which is necessary for leveling of the temperature in a whole section, but no longer than a durability time of the austenite /as usual it is from few seconds to few minutes/,
- slow cooling /usually in air, seldom in oil/ to the ambient temperature.

A quenching to an intermediate temperature is carried out mostly in melted bathes of saltpetre, chloride, sodium hydroxide water solution /5-15% of water/. The bath temperatures depend on the carbon contents in the steel:

| carbon contents /%/ | 0,4 | 0,6 | 0,8 | 1,0 | 1,2 | 1,4 |
|---|---|---|---|---|---|---|
| bath temperature /$^{o}$C/ | 350 | 300 | 250 | 220 | 190 | 160 |

and a holding time /in minutes/ depends on a section thickness or diameter:

| | | | | | | |
|---|---|---|---|---|---|---|
| 25 mm | 3 | 3,5 | 4 | 5 | 5,5 | 6 |
| 50 mm | 3,5 | 5,5 | 7 | 8 | 8,5 | 9 |
| 75 mm | 10 | 11 | 12 | 13 | 14 | 16 |

During a holding time of the charge in the bath occurs an overcoolig of austenite to a bath temperature. The martensite transformation arrives after getting the charge out of the bath

- during the further air cooling. In a result of the step hardening is obtained martensite and retained austenite structures, reaching into the depth of 3-5 mm from the object surface.

The advantages of the step hardening are low stresses and small deformations, warpings and cracks; the fault - difficulties at settling of a short holding time in the bath /the great experience is necessary/.

The step hardening is applied to carbon steels and low-alloy steels destined to quenching in water and oil - constructional and tool steels, carbon steels with carbon contents closes to eutectoid steels /at an active mixing of the bath at temperature 200$^{o}$C/ as well as castings of grey and spheroidal cast irons. Low alloy steels with a low hardenability can be hardened with sections no larger than 15-20 mm.

The step hardening can be applied also to previously carburized machine parts, especially hard for the grinding /e.g. gears, cams/.

On account of temperature - directly after taking objects out of the bath, the objects can be easy straightened and even formed by the forging and pressing.

After martensite hardening the steel has to be dutifully tempered.

Isothermal hardening /austempering/ - it is a hardening with quenching in the bath at higher temperature than a temperature of martensite transformation start $M_s$, holding in the bath to a finish of the bainitic transformation /fig. 2.6c/ and after cooling to the ambient temperature at a free rate /usually in air/. The austenite transformation runs at constant temperature - it is a reason of the name: isothermal hardening.

As the quenching media are used salt bathes at temperature 250-400°C /like for the step hardening/ or lead bathes which temperatures are selected in dependence from properties which ought to be obtained. The holding time for the bath is long and usually total to few hours /the mostly 3-4 h/.

The steel structure after isothermal hardening is the bainite /lower and upper one/ and retained austenite structure.

The isothermal hardening allows to achieve a hardness, structure and other properties - alike to hardened in regular style and tempered steel, but with ommiting of the martensite transformation. It is why this process does not almost result of the warping, assures the high hardness /40-50 HRC/ and the high tensile strength along to the good ductility.

This process can be however applied mainly to carbon steels with higher carbon contents and for small objects only /section to 12-15 mm/, to alloy steels /section over 20 mm/ as well as to grey and spheroidal cast irons.

After the bainitic hardening, the steels don't need of the tempering.

Steel hardenability - It is a property that determines the depth and distribution of hardness induced by quenching. It is connected with a reduction of the quenching rate of the hardened object, when the quenching is going from the object surface into its section center.

The steel hardening depends on the quenching rate. The process can be done, if so called "critical quenching rate" is achieved, i. . when in the steel, which is upheated to the austenite state temperature, occurs the martensite transformation, too. For carbon and alloy steels this quenching rate is very high /200-600°C/sec./. At hardening of the bigger size objects, the steel layers, located in more distance from the surface, get cooling with the less rate than the critical one and this steel does not itself hard.

As a hardened case /effective depth of hardening/ can be taken the layer with high contents of martensite. There is not necessitate the structure 100% of martensite. Mostly, as the hardened case limit, is taken the structure 50% of martensite.

The hardening depth of the carbon steels is rather small and amount to 3-10 mm. The more depth can be achieved only for alloy steels. The influence of alloy elements on the hardening depth is following /in decreasing train/: manganese, molybdenum, chromium, silicon, nickel. Some of components /nickel, manganese and silicon/, dissolve in ferrite, create the solid solution. The others /chromium, vanadium, molybdenum/ favor the creation of carbides. The steel hardness is higher, when in a composition of the steel are components of both these groups, even in the small quantities. For it, the most part of the used constructional alloy steels - they are the multicomponents steels.

The highest hardness after hardening depends:

- for carbon steels - on the carbon contents; the more carbon /up to about 0,7%/, the higher hardness;
- for alloy steels - on the kind and contents of the alloy components; their influence is seen especially at the low carbon contents in the steel/<0,4% C/. The components make possible to obtain the martensite at less intensive cooling than it is required for carbon steels /possibility of oil cooling instead of water one/.

### 2.7.2. Surface hardening

The surface hardening depends on quick upheating of the surface layer of the object over the temperature $A_{c3}$ and next on quenching, in order to achieve the martensite structure and high hardness only in this layer. The hardened layer depth is from several tenths to one's teen of milimeters, in dependence from conditions, heating and quenching methods as well as from a material of the charge.

The tempering at temperature 160-220°C should be applied at once after hardening, on purpose to remove the internal stresses.

The surface hardening is applied for carbon and alloy steels with the carbon contents above 0,3% C, previously toughened or normalized. In many events this process can replace the more expensive bath carburizing or carbonitriding /cyaniding/. It can be also used for the treatment of the grey and spheroidal cast irons.

The surface of hardened objects only slight warp itself. The plastic core makes easy eventual straightening. With regard to a short heating time, the object surface after this hardening is rather clean /small oxidized/.

The upheating of the charge for bulk hardening is realized in chamber or pit furnaces, with air or controlled atmospheres, as well as in salt bathes. For the surface hardening only exceptionally salt and metal heating bathes /1100-1200°C, heating time 10-30 sec/ are applied. The induction or flame heating is usually used.

Induction hardening - depends on upheating of the object surface layer with the aid of eddy currents, excited in this layer by the quick variable current, flowing in the inductor. The higher current frequency - the more shallow the object is upheated. The frequency in a range 0,5-1000 kHz is mostly upheated.

The induction hardening has many advantages, e.g. it is excellent for quantity and mass productions; there is a low energy consumption. This process has but the fault that it requires the expensive induction generators, cooperating mostly with the charge feeders /hardening machines/ and outfitted with the special quenching equipment. Induction heaters can not be done single-handed.

Flame hardening depends on upheating of the charge with the gas flame /usually oxy-acetylene/ by help of the one or several properly shaped blowpipes with the proper heating capacity, and next on quenching through the spray or immersion, usually into water or synthetic quenching media.

In the industry of high-industrialized countries, there are wellknown and wide applied the flame heaters and entire complicated hardening aggregates.

The flame hardening has but this advantage that can be realized at poor conditions in workshops and small production plants. There is only necessary to have the one or several blowpipes. The sprayers or quenching tubes can be done single-handed.

The surface hardening, especially induction one, has this fundamental advantage that allows to quick heat of selected parts of the big objects /e.g. gear teeth, shaft pins/.

## 2.4. Tempering

The tempering depends on upheating of the charge to lower temperature than $A_{c1}$ /180-650°C/, soaking its in this temperature and quenching /fig. 2.6/. The process is applied for previously hardened steels. Its purpose is to remove hardening stresses and to change the mechanical properties, i.e. to decrease the hardness and the tensile strength and to increase the elongation and the impact strength /fig. 2.7/.

During tempering occurs the following structure change: basic component of the hardened carbon steels - martensite - unmixes itself, precipitating the small grains of cementite. There arise so called the tempered steel structures: temper troostite and temper sorbite.

In dependence from tempering temperature the different strength properties of the hardened steel are achieved /fig. 2.7 and 2.8/. The following kinds of the tempering are distinguished:

Low-temperature tempering - is realized in the range 150-250°C /fig. 2.6/, aiming mainly at removing of hardening stresses at a small hardness change and a friction wear resistance. The structure - it is a tempered martensite. The pro-

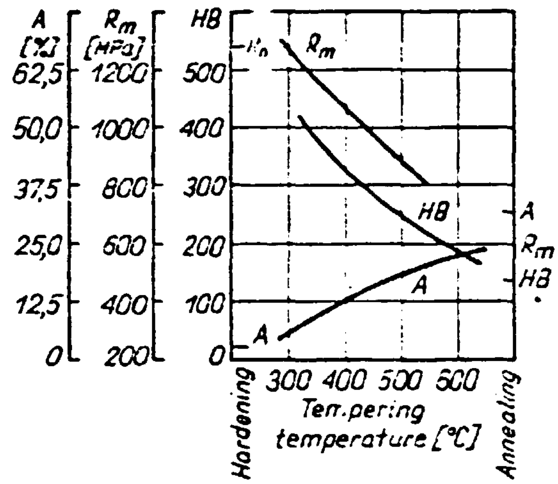



Fig. 2.7. Influence of the tempering temperature on mechanical properties of the hardened steel containing 0,4% C. In Y-axis are additional given the values of these properties for the hardened and annealed steel.

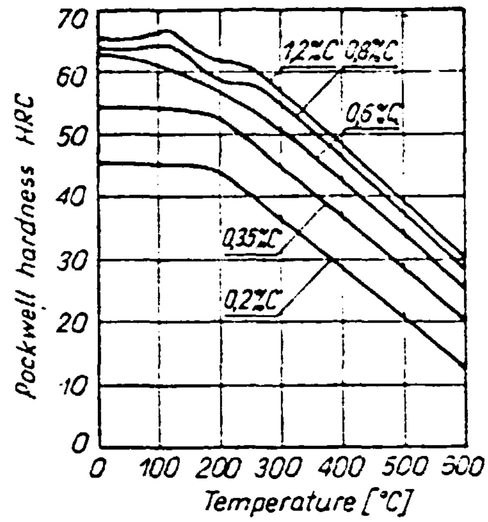



Fig. 2.8. Influence of the tempering temperature on hardeness of the hardened steels having the different carbon contents.

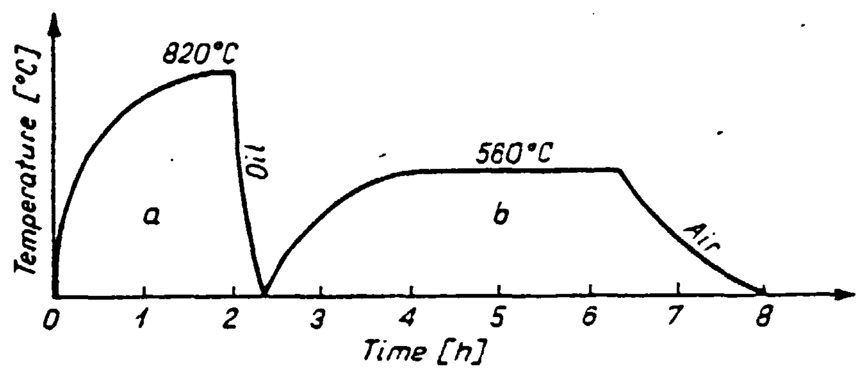



Fig. 2.9. Diagram of the heat toughening: a - hardening; b - tempering.

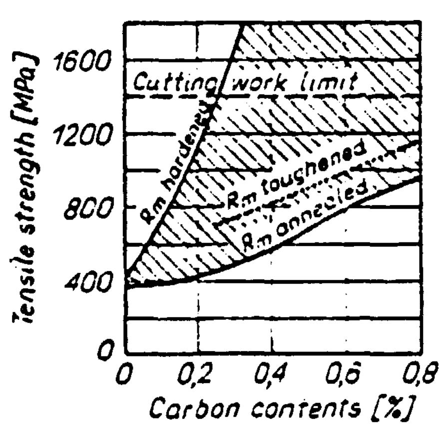



Fig. 2.10. Range of the carbon steel heat toughening.

cess is applied for cutting and measuring tools made of carbon and low alloy steels and for carburized objects, which later are hardened, step hardened or surface hardened.

Middle-temperature tempering - is realized in the range 250-500°C /fig. 2.6/ on purpose to achieve the great strength and elasticity at the sufficiently impact strength and hardness. At the beginning of the temperature range for this tempering /200-300°C/ succeeds the transformation of retained austenite into bainite; at the end - the temper troostite appears. This treatment is applied to springs, dies, tools and impact working machine parts /e.g. pneumatic hammers, bumpers and others/.

High-temperature tempering - is realized in the range 500-650°C /fig. 2.6/ on purpose to achieve the high strength properties at slightly reduced plastic properties. Hardness of the high-tempered steels is about 250-350 HB. These steels can be formed by cutting, because there is the sorbite structure /as a result of the carbide coagulation in ferrite/. The process is applied to machine parts destined for heavy duty and are exposed to impacts /crankshafts, connecting-rods, axes, tools made of high alloy steels/.

The upheating for the tempering should be rather slow in order to avoid the stresses in the brittle /after hardening/ steel. The soaking time is long, espacially at high-temperature tempering /2-3 h/. Quenching after tempering - usually in air. At high-temperature tempering the chromium-nickel, chromium or manganese steels are water or oil quenched /then appears so called "temper brittleness"/.

## 2.5. Toughening

The toughening is a combination of the hardening and tempering /usually high-temperature one - fig. 2.9/ processes on purpose to obtain the best mechanical properties, but also to retain the possibility of cutting works /fig. 2.10/. The process is usually realized by the iron-works, but can be also done in the small forging and casting plants. It is applied for forgings, bars of constructional carbon and alloy steels, castings of the constructional cast steel or grey and spheroidal cast irons. The treatment is used as a final process /before eventual cutting operations/ as well as the prior process to surface hardening, nitriding and stabilizing.

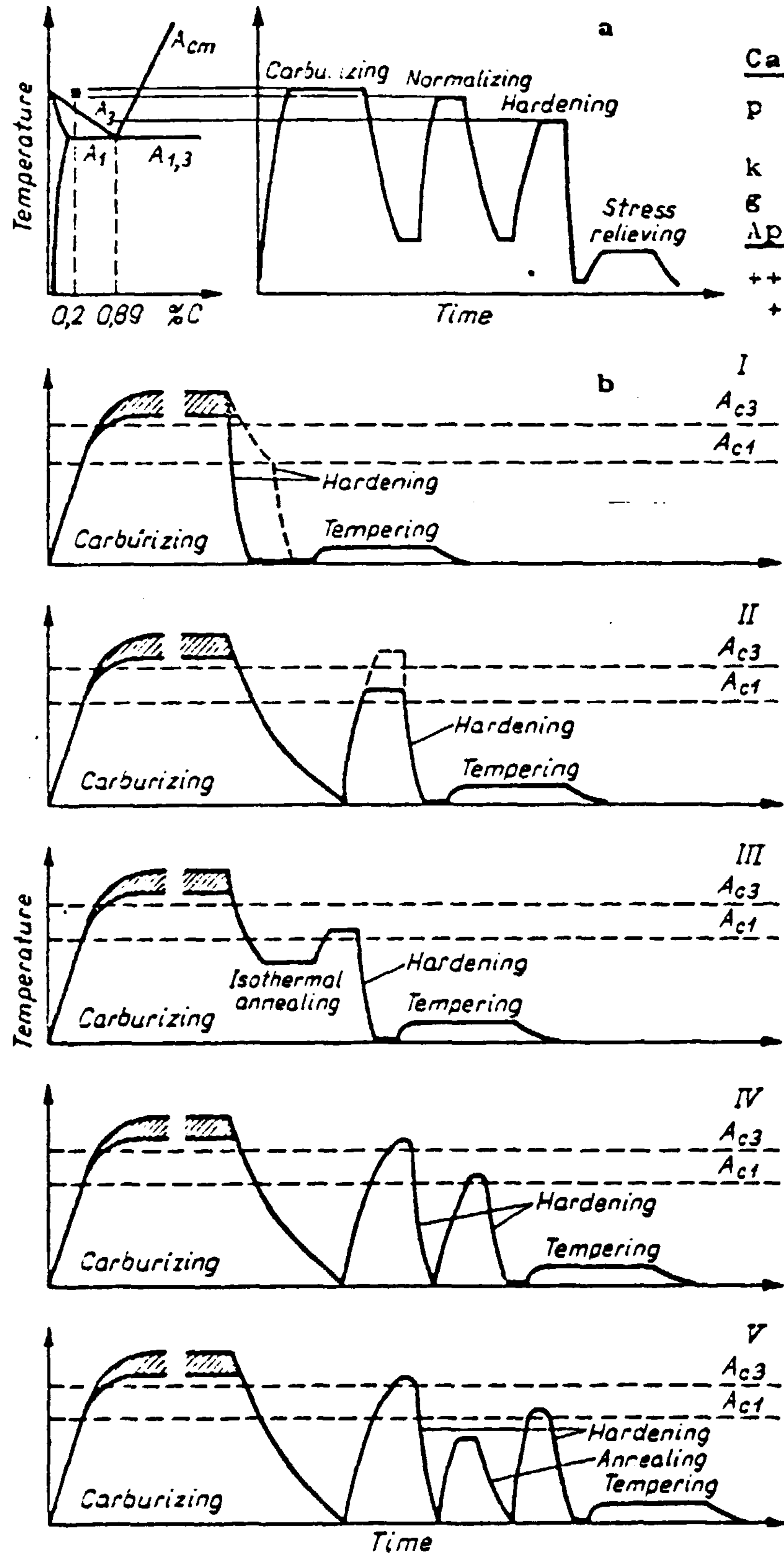
## 2.6. Carburizing

Bases of carburizing. The carburizing is the diffusion process depending on enriching of the carbon contents in the surface layer of the steel object /commonly the soft steel/, through upheating of this object in carbirizing media at usually higher temperature than $A_{c3}$ /880-950°C/ - on purpose to obtain the hard, wear resisted surface layer with retaining of the malleable core. It is impossible to obtain these properties as a result of the carburizing only. For it, there are necessary the additional heat treatment operations.

The layer, which is obtained directly after carburizing, is relatively soft. Its hardness, at air quenching of the object inside the box, amount to carbon steel 240-280 HB and to low alloy steels 250-350 HB. The higher is the contents of the alloys components, the higher is the hardness after carburizing. Moreover, mechanical properties of the carburized layer and the core are low, with regard to increase of the grain size after upheating in carburizing temperature. The heat treatment, applied after carburizing, aim at:
- hardening of the carburized layer /usually up to over 60 HRC/;
- obtaining of the malleable core with the suitable tensile strength and the sufficient impact resistance;
- grain refining of the core and the surface layer.

The guide doagram of the carburizing process run, with heat treatment succeeding after it, is shown in fig. 2.11a. In fig. 2.11b are ahown the typical hardening methods after carburizing - in rotation of reducing their practical applications.

During carburizing the steel /e.g. carbon steel with contents of 0,2% C - fig. 2.11a/ is in general put to a long standing action of the high temperature, so its grain coarses. For purpose to reduce of the grain sizes, the steel sho-




Designations:

<u>Carburizing:</u>

p - in powders and pastes
k - in bathes
g - in gases

<u>Application:</u>

+++ wide
++ rather wide
+ seldom
\- none

I - Finegrained steels only
g +++
k ++
p +

II - Regular steels for carburizing
p,k +++
g ++

III - Regular steels for carburizing
g ++ /in aggregaces/
p,k -

IV - Regular steels for carburizing, thick layers
g +++
p +
k -

V - High-alloy steels
g +++
p +
k -

Fig. 2.11. Carburizing and hardening after carburizing: a - guide diagram; b - typical hardening methods: I - direct hardening /——/ and with subcooling /---/, II - single hardening, III - single hardening with previous isothermal annealing, IV - double hardening, V - double hardening with interoperational annealing.

uld after carburizing be normalized, acc. to the chemical composition of the object core /chemical composition of the core remains always the same/. Then the object is hardened at hardening temperature, suited to a chemical composition of the carburized layer. After carburizing the carburized layer has usually an eutectoid or hypereutectoid />0,8% C/ structure, so the hardening temperature should be about 750°C. After heating - the object is quenched in water or oil. The low-temperature tempering is always applied after hardening, for the purpose of stress relieving of the steel.

After hardening the structure of the carburized layer should be composed of the fine acicular martensite. More precipitations of cementite network at a grain boundary are intolerable. In the carburized layer can appear the small quantities of retained austenite. There is profitable the presence of carbides, improving the wear resistance.

Carburizing temperature and time depend on the sort of steel and a carburizing medium. Usually steels are carburized up to the layer thickness 0,5-2,5 mm.

Carburizing is applied to carbon and alloy steels with the carbon contents of 0,08-0,25%. Exceptionally can be used the steels up to 0,35% of carbon.

Carburizing is the oldest and up today the widest applied method of thermo-chemical treatment. About 60-70% /acc. to weight/ of the thermo-chemical treated objects - they are carburized machine parts and tools.

This process is worthy of noticing also for this reason that some its methods can be realized in regular chamber or pit furnaces as well as in ba... furnaces.

In dependence on a kind of the used carburizing medium, the following carburizing methods are distinquished:

Powder carburizing is the oldest, simplest and the most easy to realization carburizing method. The basic component of carburizing powders /carburizers/ is a charcoal, crushed into grains 3-6 mm, with additional accelerating media of carburizing /mostly 10-20% of carbonates/ and bonding agents /table 2.1/. In result of the reaction, the active carbon appears and quick diffuses into austenite.

Table 2.1.

Composition of fresh powders for carburizing

| Kind of component | Contents, % | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Charcoal | 72-75 | 60-70 | 87 | 85-90 | 90 |
| Barium carbonate $BaCO_3$ | 10-15 | 8 | - | - | 10 |
| Calcium carbonate $CaCO_3$ | 4-6 | 2 | - | - | - |
| Sodium carbonate $Na_2CO_3$ | 1-2 | 2 | 10 | 10-15 | - |
| Potassium carbonate $K_2CO_3$ | - | - | 3 | - | - |
| Coke | - | 20-25 | - | - | - |
| Melasses or mazout | 5-7 | - | - | - | - |
| Tar | - | 3 | - | - | - |

The objects, destined for carburizing, after removing the rust, oxides and impurities, are stacked with layers inside boxes, covered with powders and, after sealing, put into the furnace. The furnace should be previously upheated to carburizing temperature: for carbon steels - 920-940°C, for alloy steels - 890-910°C, for steels containing over 4%Ni - 870-890°C, for very small and thin objects - 850-870°C. The temperature uniformity inside the heating chamber of the furnace should be ± 10°C.

The carburizing begins in 2-4 hours from loading moment of the boxes into the furnace, when the charge achieves the temperature, closed to $A_{c3}$.

Carburizing time depends on a material of the charge, a carburizing medium and a carburizing temperature /table 2.2/. A dependence of the carburized layer thickness from the carburizing time and temperature is exampled in. fig. 2.13. A carbon contents in the carburized layer, closely to the surface, should be about 1% and decreases into a center direction, so that in the half of the layer thickness should be about 0,8%; the contents achieves deeper the same value like the core.

On purpose to settle the proper time in order to carburize the required thickness of the object - the testing specimens are put outside and inside the box. The specimens are made of the same material like carburized objects. The first specimen is taken out at end of the process in order to measure the carburized layer thickness and, in dependence on results, to prolong adequately the process. The second specimen allows to state the real thickness of the carburized layer without destroying of the carburized object.

Paste carburizing. The entire object or its part can be carburized by help of special pastes for carburizing /table 2.3/. They are made of dry components - fine crushed into a powder - mixed with a proper diluent. The object is several times dipped into the thin paste or is covered with 3-5 mm ply of the paste. Then the object is dryied, put into the shut closed carburizing box - with the object bottom up - and loaded into a furnace; the furnace should be previously upheated to temperature 910-950°C.

Table 2.3.

Chemical composition of the carburizing pastes

| Component name | Contents, % | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Soot /carbon black/ | 30 | 55 | 28 | -- | 60 | 70 |
| Charconal dust | -- | -- | -- | 75 | -- | -- |
| Calcium carbonate $Na_2CO_3$ | 10 | 30 | 3,5 | 5 | 30 | 10 |
| Potassium ferrocyanide $K_4Fe/CN/_6$ | -- | -- | 1,5 | 10 | 5 | 10 |
| Sodium oxalate $Na_2C_2O_4$ | -- | 15 | -- | -- | -- | -- |
| Dextrin | 20 | -- | -- | 10 | 5 | 10 |
| Motor oil /used/ | 40 | -- | 67 | -- | -- | -- |

Pastes No 2, 4, 5 and 6 are mixed with water, and pastes No 1 and 3 with kerosene for required density. Pastes No 3 - 6 gave results like at carbonitrioling.

Table 2.:.

Approximate ·pheating ånd soaking times at steel carburizing in powder at temperaturé 925°C in dependence from layer thickness and box size

| The least size of the box section, mm | Layer thickness, mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0,5 | 0,7 | 0,9 | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 |
| 100 | 4,0 | 5,0 | 6,0 | 7,0 | 7,5 | 8,0 | 8,5 | 9,5 |
| 150 | 4,5 | 5,5 | 6,5 | 7,5 | 8,5 | 9,5 | 10,5 | 11,5 |
| 200 | 5,5 | 6,5 | 7,5 | 8,5 | 9,5 | 10,5 | 11,5 | 12,5 |
| 250 | 6,5 | 7,5 | 8,5 | 9,5 | 10,5 | 11,5 | 12,5 | 14,0 |

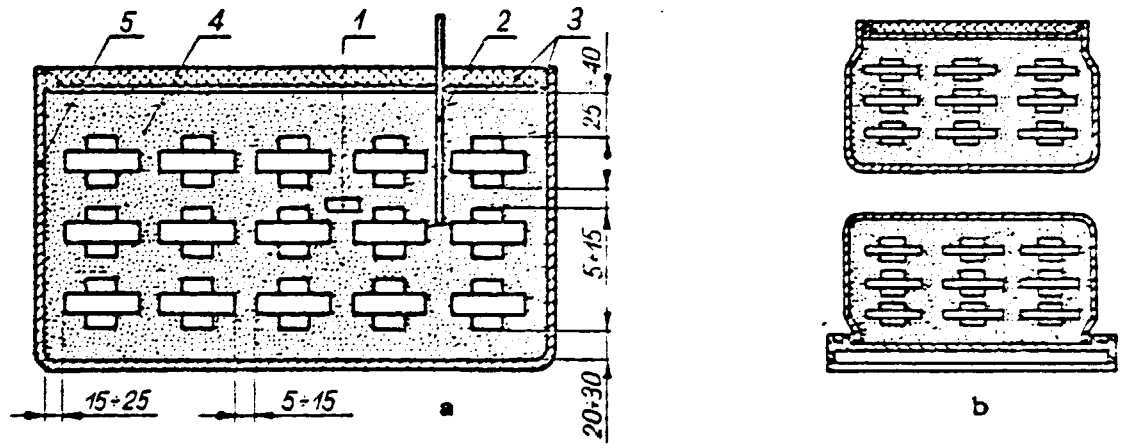



Fig. 2.12. The box for carburizing in powders: a - loading style into the box; b - box loading style into the furnace; 1 - inside testing specimen; 2 - outside testing specimen; 3 - seal with a clay; 4 - carburizing powder; 5 - box /casted of the heat resisting cast steel or welded with low-carbon steel sheets and nex aluminized/.

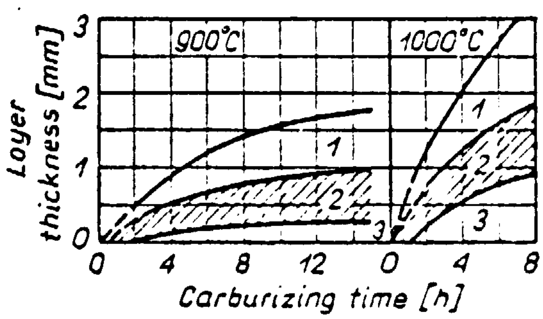



Fig. 2.13. Influence of carburizing time and temperature on the thickness of the carburized layer: 1 - transition layer; 2 - eutectoid layer; 3 - hypereutectoid layer.

The box is holding in the properly long time at the carburizing temperature /table 2.4/, getting out and slow quenching without opening /like at the powder carburizing/ - or the object can be taken out of the box and quenched in water or oil /hardening/.

Table 2.4.

Approximate time of carburizing by help of pastes, given in hours, in dependence from temperature and the layer thickness

| Carburizing temperature °C | Layer thickness, mm [1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0,6 | 0,8 | 0,9 | 1,0 | 1,2 | 1,4 | 1,6 | 1,8 | 2,0 |
| 950 | 1,5 | 2,0 | 2,5 | 3,0 | - | -- | - | - | - |
| 1050 | - | 1,5 | - | - | 2,0 | 2,5 | 3,0 | 3,5 | 4,0 |

[1] Paste No 2 from table 2.3.

Liquid carburizing occurs in the melted salt bathes /table 2.5/ at temperature 870-890°C for low-carbon steels, at 850-870°C - for alloy steels and at 820-840°C for middle-carbon steels. The carburizing time is shorter than for previously processes.

Table 2.5.

Chemical composition of carburizing salt bathes

| Component name | Contents, % [1] | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Calcium carborate $Na_2CO_3$ | 83-84 | 78-82 | 60 | 78-81 |
| Sodium chloride NaCl | 8-10 | 12-14 | 20 | 5-6 |
| Silicon carbide SiC | 7-8 | 5-6 | 15 | 8-6 |
| Amonium chloride $NH_4Cl$ | - | - | - | 8-7 |
| Barium carbonate $BaCO_3$ | - | - | 5 | - |

[1] The bathes require a periodical supplying with SiC in order to fill up the used component. The bath No 4 is carbonitrioling one.

Quenching after carburizing usually joins with hardening in water /carbon steels/ or oil /alloy steels/.

The process results the small warping of parts and is usually applied for small parts with thin carburized layers /0,1-0,5 mm/.

Gas carburizing is the newest process, which easy allows to controll the carburizing rate and carburizing layer thickness. The process enable to obtain the considerable thickness layers /even to 50 mm/ without too high carbon contents and the repeatability of results. The process is easy for an automatization and suits for a quantity production and requires the special air-tight furnaces /chamber, muffle, pit and continuous ones/ with forced atmosphere convection. It allows on hardening of the finegrained steels directly after carburizing.

Carburizing media are active, containing carbon gas atmospheres, which are the mixture of hydrocarbons. There can be non-diluted gases, mainly natural one, or diluted gases - so called endothermic atmospheres /e.g. endogas + 10-20% of natural gas + 1-3% of propane, sometimes with addition of nitrogen/, supplied in different methods into the furnace chamber. The liquid organic compounds /kerosene, petroleum spirit, benzol, benze, xylene, methyl alcohol, isopropylene alcohol and the others/ are dropped directly into the furnace chamber.

The carburizing gas media have to be dry /stripped of water steam/ and clarified /they can contain only small quantities of oxigen/. In general, the preparation and clearance of the atmospheres is the basic and hard part of the process.

It is why the gas carburizing exceptionally only can be applied at workshops and small production plants.

## 2.7. Others technologies

Above are discussed at first these heat treatment technologies, which can be applied in small casting and forging plants, using the simple, typical heating equipment and methods. Very briefly was described the thermo-chemical treatment, which is now most dynamic developed, as well as the induction hardening. There was not discussed a construction of the heating and quenching equipment as well as control means and methods of processes and metal structures.

It is worth to emphasize that in the industrialized countries very popular are the all kinds of nitriding /regular gas nitriding, in controlled atmospheres, short- and long-period, bath and ion nitriding/ as well as secondary processes: nitrocarburizing in gas and bathes, oxynitriding, sulfonitriding and others; carbonitriding, powder and gas chromizing; titanizing, siliconizing, vanadizing, boroding; immersion aluminizing, different kinds of heat treatment in vacuum and protective atmospheres. They have this main advantage that they give the great technical and economical profit, impossible for obtaining at other methods, and this main fault that they require the expensive and complicated equipment and measuring apparatus, and for it they are applied only at the big industrial plants.

## 3. Manufacturing methods of the semi-finished machine parts by casting and forging

### 3.1. Comparative characteristic of the methods

There are usually no troubles at a selection of manufacturing methods of blanks /semi-finished products/, because in practice the method results, more or less, from a kind of the selected material. However, every basic method contains a considerable number of manufacturing methods of blanks /see table 3.1/.

A decision about the method and range of its application depends on a production scale, a manufacturing precision, construction shapes and dimensions of the blanks. At many events the different methods can equally satisfy the specifications of blanks. For that reason, beside the strength calculations, one should compare the suitable manufacturing methoda of blanks and to decide, which among them are the best, acc. to the constructional, technological and economical requirements.

At this kind of selection, one should take into consideration not only economical parameters, but also an influence of the selected method on work-capacity of the next working processes. For example, when one compares a suitableness of the application of the various manufacturing methods of blanks by castings, and does not take into consideration the work-capacity of the later machining, it is easy to choose the sand castings. In practice the metal mould castings can be proper way for the reason of reduced work-capacity of machining operations.

The comparison skould contain a work-capacity analysis of the blank forming methods and the further working. The selection should assure the least cost of finished machine parts at keeping all other technical requirements.

At designing and dimensioning of the object, must be taken into consideration the geometrical likeness between the blank and finished part, made from this blank. It follows for best utilization of the material through the elimination of technological wastes.

Characteristic of basic manufacturing methods of making [illegible]
by casting and forging

| Manufacturing method of blanks | Dimensions or mass | | Complexity of form | Accuracy of manufacturing in mm | Surface quality | Material | Kind of production |
|---|---|---|---|---|---|---|---|
| | the most | the least | | | | | |
| Sand casting with hand forming | no limits | the least wall thickness 3-5 mm | the most complex | 1-10 depends on dimensions | very rough | iron-carbon alloys, non-ferrous metals and their alloys | piece and small-lot productions |
| Sand casting with machine forming | to 250 kg | as above | as above | 1-2 | rough | as above | quantity and mass productions |
| Sand casting with strickle moulding | no limits | as above | mainly rotary shapes | 4-15 depends on dimensions | very rough | as above | piece and small-lot productions |
| Cored casting | as above | as above | the most complex | 1-10 depends on dimensions | rough | as above | piece, middle-lot and mass productions |
| Centrifugal casting | usually to 200 kg | as above | mainly rotary shapes | 1-8 depends on dimensions | smooth | as above | quantity and mass productions |

Tablo 3.1 /continued/

Characteristic of basic manufacturing methods of machine part blanks by casting forging

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Permanent-mould casting | usually to 100 kg | 20-30 g | simple and average, depends on taking the casting out the form | 0,1-0,5 | smooth | as above | as above |
| Precision casting | no limits | wall thickness 0,8 mm | very complex | 0,05-0,2 | very smooth | mainly the hard for cut working | piece and small-lot productions |
| Pressure die casting | 10-20 kg | wall thickness 1,0 mm /for zinc - 0,9 mm/ | limited only by possibility of the die manufacturing | 0,05-0,2 in direction of die partition - a little less | as above | alloys of zinc, aluminium, magnesium, copper, tin and lead | quantity and mass productions |
| Blacksmith forging | no limits | - | simple | 1,5-2,5 | very rough | carbon and alloy steels, nanferrous metal alloys | piece and small-lot productions |
| Die hammer forging | usually to 100 kg | wall thickness 2,5 mm | limited only by possibility of the die manufacturing | 0,4-2,5 in direction of die partition - less | rough | as above | middle-lot and mass productions |

Table 3.1 /continued/

Characteristic of basic manufacturing methods of machine part blanks by casting forging

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Machine forging | usually to 100 kg | wall thickness 2,5 mm | as above | as above | as above | as above | quantity and mass productions |
| Extrusion | diameter to about 200 mm | wall thickness for Al alloys from 1,5mm | simple | 0,2-0,5 | smooth | as above | as above |
| Roll forging | usually to 50 kg | as above | as above | 0,4-2,5 | rough | as above | as above |
| Die press forging by sizing press machine | usually to 100 kg | wall thickness 1,5 mm | limited only by possibility of the die manufacturing | 0,4-1,8 | smooth | as above | as above |
| Striking and burnishing of die forgings | as above | as above | as above | 0,05-0,1 | very smooth | as above | as above |
| Cold upsetting | avarage do 30 mm | avarage 3 mm | simple | 0,1-0,25 | smooth | steels and plastic materials | as above |
| Sheet stamping | thickness to 15 mm | thickness 0,1 mm | complex | 0,05-0,5 | smooth | different kinds of the sheets for stamping | quantity and mass productions |

## 3.4. Selection of the manufacturing method of semi-finished machine parts /blanks/

At the selection should be taken into consideration the following factors:

1/ constructional - the material should be in accordance with specifications;

2/ technological - work-capacity, necessary for proper shaping of the material, should be the least;

3/ economical - the unit cost of the finished part should be the least.

A designer ought to decide about the kind of the blank and material, but he should does it in agreement with a technologist and a metallurgist.

To-day's manufacturing methods of the blank give a possibility to obtain a dimension accuracy of 8-10th Class acc. to ISO, and a surface roughness of 3-4th Class.

If constructional and exploitation requirements of these machine parts permit the selection of manufacturing method of the blank, an economical analysis ought to indicate, which method will be, for mentioned factory, the cheapest.

For this analysis can be use a formula, which describes factory costs $K_w$ for manufacturing of the parts:

$$K_w = M + \left(1 + \frac{K_p + K_o}{100}\right)\left(Z_p + \frac{Z_{p/p}}{n_p}\right) + \left(1 + \frac{K_m + K_o}{100}\right)\left(Z_m + \frac{Z_{p/m}}{n_p}\right) + \frac{O_p}{N_p} + \frac{O_m}{N_m}$$

where:

$M$ - material costs of the one part

$K_p$ - workshop costs of the division, where the blank is produced

$K_o$ - on-costs /the general costs/

$Z_p$ - labour costs of the one blank

$Z_{p/p}$ - preparation labour costs of the one blank batch

$n_p$ - quantity of pieces in the batch at the blank production

$K_m$ - workshop costs of the division, where the blank is machined

$Z_m$ - labour costs of the one blank machining

$Z_{p/m}$ - preparation labour costs for machining of the one batch of blanks

$n_m$ - quantity of pieces in the batch at machining

$O_p$ - costs of a designing, manufacturing and testing of workshop devices, used at the blank manufacturing

$N_p$ - durability of the equipment, used at the blank manufacturing /in quantities of blanks made with its help/

$C_m$ - costs of workshop devices used for machining of the blank

$N_m$ - durability of the equipment, used for machining of the blank /in quantities of parts made with its help/.

The calculation ought to be made for each, possible at this event, manufacturing methods of blank as a function of the quantity of pieces.

E.g. if we have analysed the possibilities, how to make the blank of the determined part by methods: black-smith forging, die forging and steel casting /in dependence from a quantity of pieces/, then we will receive the diagrams, like these ones in fig. 3.1.

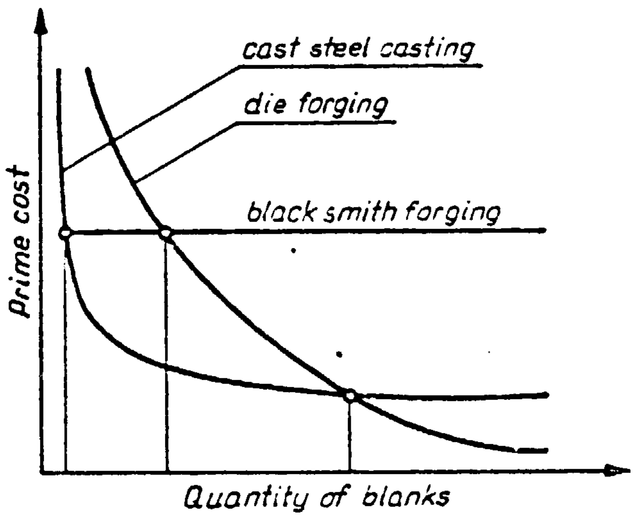



Fig. 3.1. Diagram of the prime cost in relation to a quality of manufactured parts and a kind of the blank /semi-finished product/.

The intersection points of lines indicate the least quantity of pieces, when the selected production method of the analysed blank is economic profitable.

## Location of heat treatment in technological process

... into consideration the changes, which occur in the ... heat treatment processes /warping, sweling/, this ... should be located at the beginning of the mechanical process.

... heat treatment of casted blanks is mostly applied di... after their manufacturing, and its main purpose is the ... stability of the casting dimensions during next me... working. In this event, the heat treatment have to ... the casting stress equalization in order to avoid the ... deformations in entire mechanical working process.

The heat treatment of casted blanks is applied, according ... general obliging rules, for increasing of their strength ... wear resistance.

The blanks, made by forging, obtain the required proper... e.g. increase of strength, but also undesirable ones, e.g. rising of certain internal stresses, which cause the war... ing or even cracking of the worked parts, especially during the mechanical working.

These unprofitable results can be removed applying the proper heat treatment of blanks. The settlement of temperature ranges for heat treatment desires the knowledge about changes, which occur in deformed material during its heating. These changes are shown schematically in fig. 4.1.

The important factors, which decise about location of heat treatment in technological process, are the structures, coming into existence after heat treatment. The structures have real influence on further mechanical working of blanks, especially on the cutting work.

The structures have the following main properties:

For steel:

- ferrite - decreases the resistance of cutting
- cementite - increases the resistance of cutting
- laminated pearlite - good properties for cutting work
- sorbite and austenite - bad properties for cutting work.

For cast irons: in dependence on their structures, properties can be put in order, according to worse and worse ability for

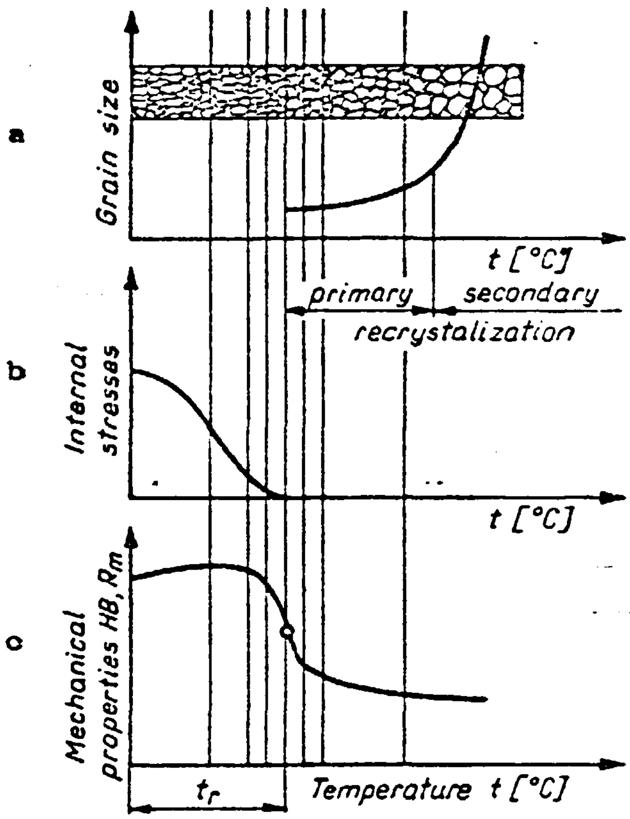



Fig. 4.1.
Influence of the annealing temperature on the structure and propeıties of materials.

cutting work, as follows:

- ferritic cast irons - contain lot of graphite
- pearlitic-ferritic cast irons - contain high percentage of graphite, pearlite and ferrite
- pearlite cast irons - graphite and pearlite
- mottled cast irons - contain pearlite, graphite and concentrations of cementite
- white cast irons - contain pearlite and cementite.

Taking into consideration an economy of the cutting working, the heat treatment operations, giving good structures for cutting work, should be located before this working. The heat treatment operations, increasing a tensile strength over 900 MPa or hardness over 40 HRC, should be located after cutting working. After this kind of heat treatment, can be done in practice only abrasive /grinding, superfinishing/ or chem-milling working.

The same conclusions connect to parts or their fragments, which have to be put to diffusion hardening processes /e.g. cyaniding, nitriding and so on/.

# 5. Heat treatment of cast steel and cast iron castings

## 5.1. Heat treatment of cast steel castings

### 5.1.1. Sorts of cast steels and their applications

The cast steel is the steel with contents usually 0,1-0,6% C, poured into sand or metals forms. The highest quality cast steel is made in electric or open-hearth furnaces with a basic lining, the lower quality - in the open-hearth furnaces with an acid lining, the lowest one - in the convertor /high contents of phosphorus and sulphur/.

Alike the steels - the cast steels can be distinquished into carbon cast steels and alloy cast steels.

Carbon cast steel represents average 80-90% /acc.to weight/ of produced cast steels. It is applied for different machine parts: beds and bodies of machine tools, bodies of valves and bolts, water pumps, brackets, holders, rolls, chain wheels, anvils, jaws of big vices and others.

Alloy cast steel; it is the cast steel, in which the contents, at least the one of the alloy components, is equal or higher than: Mn - 0,9%, Si - 0,5%, Ni - 0,3%, Cr - 0,3%, W - 0,2%, Co - 0,2%, Cu - 0,2%, Al - 0,1%, Mo - 0,05%, V - 0,05%, Ti - 0,05%.

They influence on temperature of the transformations, occuring during the heating, and on hardening critical rates /it can be decreased even to several grades per 1 second/. Chromium, silicon, titanium, molybdenum and tungsten increase the eutectoid transformation temperature, manganese and nickel - decrease it. In dependence from the kind, quantity and contents of the alloy components, there are distinquished the cast steels: constructional, anti-corrosion, stainless and acid-proff, for working at higher temperature and heat-resisted /stove plates and doors, braziers, grills and furnace muffles, boxes, stove equipment/, tool /tools for cold and hot working, submitted to different mechanical duties/, wear-resistance /hammers, jaws and tapers for crushing mills, road wheels for girder cranes, parts of bailers, caterpillars, cement mills, coulters/.

5.1.2. General notes and heat treatment examples of cast steel castings

Cast steel castings, alike the cast iron ones, characterize themselves by the heterogene and coarsegrained structure, depended on ceystallization of the material, poured into a casting form. For the purpose of improving and homogenizing of properties, the cast steel is submitted to heat treatment, as a rule to the same treatment like for steel, then depended on the carbon contents and presence of the alloy components. Moreover, it depends on the kind, size and shape of the casting. There is estimated that about 60% of castings, made of carbon cast steels, and about 85% castings of alloy cast steels, are heat treated. Some castings, e.g. the ones, destined for working at high temperatures or those ones, from which the definite properties are not required, are applied without heat treatment.

The heat treatment of the cast steel is mostly conducted at higher temperatures and in longer soaking times, than these parameters suited for the steel, which has the similar chemical composition. For the purpose of the structure homogenizing and grain refining, there is recommended the heat pretreatment before the regular treatment, i.e. before toughening, surface hardening, solutioning.

The big and thick-wall castings, as well as castings with changeable sections, require the long soaking time and possible the slow heating and quenching. The heating rate of cast steel castings usually amount to 30-50°C/h, and for castings with simple shape - even over 200°C/h.

The heat treatment of the carbon cast steels includes:
- normalizing or full annealing with succeeding high-temperature tempering or without it; it is the most often applied kind of the cast steel heat treatment. The small castings are not tempered after normalizing;
- stress relief annealing is applied for the rough machined castings /usually at temperature 200-700°C in 2-4 h/ on purpose to remove the internal stresses;
- spheroidizing /annealing/ is seldom applied on purpose to

reduce a hardness, improve a workability and to remove the internal stresses;

- bulk hardenind /is seldom applied with regard to the low hardenability and because there are necessary to apply the high quenching rates/ and surface hardening. After bulk hardening, used as the hardening, there is applied the low-temperature tempering; after hardening, used as an element of a toughening - the high-temperature tempering;
- toughening is applied only for cast steels, containing over 0,3% C;
- carburizing, nitriding and carbonitriding of low-carbon cast steels is seldom applied.

In table 5.1 are given parameters of the mostly met heat treatments of the carbon cast steels, and in fig. 5.1 and 5.2 is shown an influence of the carbon contents on mechanical properties of the annealed carbon cast steel.

Heat treatment of the alloy cast sttels includes in addition:

- homogenizing /diffusion annealing/, which is applied especially for cast steels with higher contents of the alloy components;
- softening /soft annealing/, which is applied before toughening or as a final treatment for some cast steels with high contents of the alloy components;
- solutioning /solution heat treatment/, which is applied only for austenitic cast steels.

With regard to the great variety of chemical compositions of the alloys cast steels, the general principle, connected of the typical heat treatments for different compositions, can not be given. For all events, the proper heat treatment should be fixed by help of the special guide-books, which will give you the necessary informations, based on the chemical composition and required utilitarian properties. In table 5.2, there are given the kinds of basic heat treatments for different groups of the alloy cast steels as well as average temperature ranges and hardnesses, possible for achieving.
In the table 5.3 exampled the heat treatment kind and parameters of construction elements of the cement mills, made of

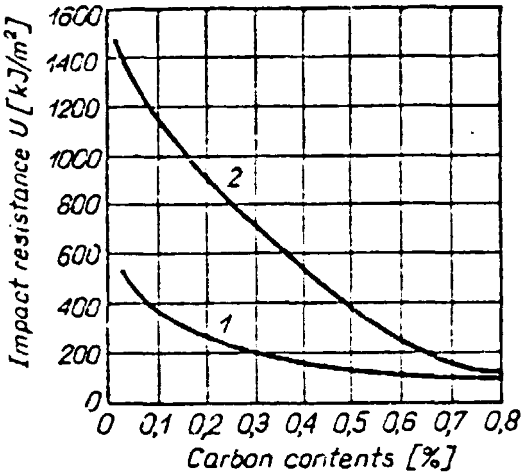



Fig. 5.1. Influence of carbon contents on impact resistance of carbon cast steel:
1 - in casting state;
2 - after annealing.

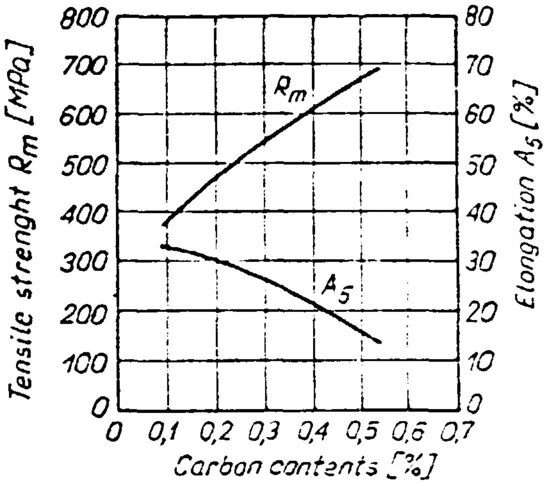



Fig. 5.2. Influence of carbon contents on mechanical properties of annealed cast steel.

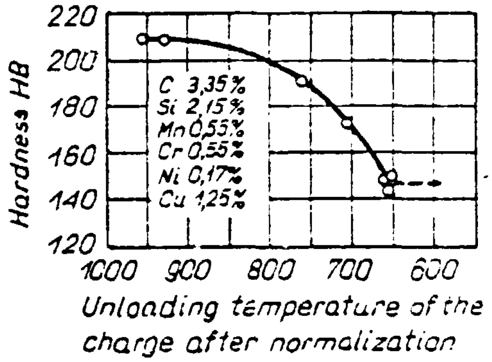



Fig. 5.3. Influence of quenching on cast iron hardness after normalizing.

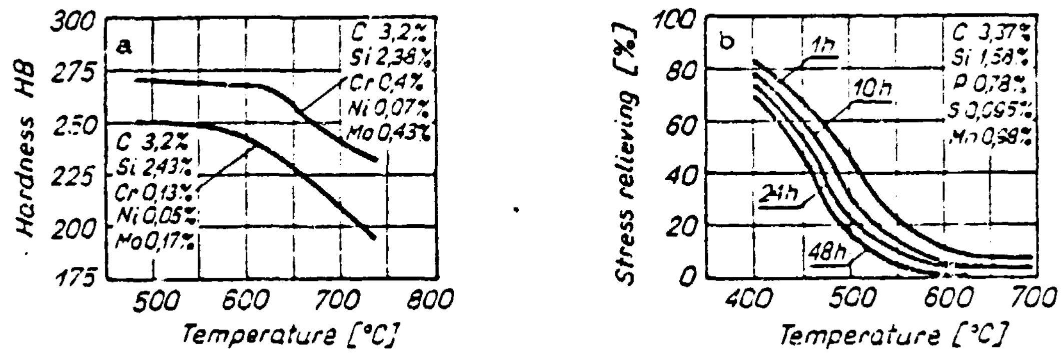



Fig. 5.4. Influence of tempering temperature for grey cast iron on: a - hardness; b - internal stresses value at different times of stress relieving.

Table [illegible]

## Heat treatment of carbon cast steels

| Carbon contents /%/ | Annealing 1-normalising; 2-full: temperature /°C/ | Annealing: soaking time | Annealing: quenching | Hardness after annealing | Toughening – Hardening: temperature /°C/ | Toughening – Hardening: soaking time | Toughening – Hardening: quenching | Toughening – Tempering: temperature /°C/ | Toughening – Tempering: soaking time | Toughening – Tempering: quenching | Hardness after toughening |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,15 | 900-920 | 2,5 minutes per 1 mm of thickness | 1 - in air<br>2 - with furnace to 500°C | 114-156 | - | - | - | - | - | - | - |
| 0,20 | 890-910 | | | 118-156 | - | - | - | - | - | - | - |
| 0,25 | 870-890 | | | 128-170 | 860-880 | 0,6 minutes per 1 mm of thickness | water 25°C | 560 - 640 | at least 2 h | in air | 156-192 |
| 0,30 | 850-870 | | | 137-183 | 840-860 | | water 55°C | | | | 170-212 |
| 0,35 | 850-870 | | | 140-192 | | | | | | | |
| 0,40 | 830-850 | | | 149-195 | 820-840 | | water 55°C or oil | | | | 192-235 |
| 0,45 | 830-850 | | | 156-207 | | | | | | | |
| 0,50 | 810-830 | | | 163-212 | 800-820 | | | | | | 207-235 |
| 0,55 | | | | 170-217 | | | | | | | |

Table 5.2

## Heat treatment kinds of cast steels

| Sort of the cast steel | Heat treatment /designation/ and average temperature | Hardness after treatment |
|---|---|---|
| Constructional | Qb/T 850-900/530-660<br>N/T 860-890/570-650 | 170-300 |
| Constructional for working at higher temperatures | N/T 880-960/600-730<br>Qb/T 1030-1050/670-710<br>A/N/T 940-960/920-930/690-710<br>H/A/T 1030-1050/980-1000/710-730 | 130-280 |
| Corrosion - resisted | A/Qb/T 800-850/970-1020/650-750<br>Aso 700-800<br>S 1020-1070 | 130-280 |
| Heat-resisted | Aso 700-850<br>S 1050-1100 | 150-350 |
| Tool | A/N/A/N/A 880/900/880/900/720-750<br>A/Qb/T 810-830/1070-1100/440-550<br>A/N/T 700-720/970-890/450-500<br>A/N/W 780-930/870-970/500-700<br>H/N/A 1100/880-900/540-560<br>A/N/A/A 840-860/880-900/740-760/500-600<br>Aso/Qb 760-780/950-970 | 170-500 |
| Wear-resisted | N 890-930<br>N/Qb/T 840-910/830-890/450-600<br>Qb/T 800-900/530-500<br>S 1050-1100 | 130-400 |
| Designations | Qb - bulk hardening<br>T - tempering<br>N - normalizing<br>A - annealing<br>H - homogenizing<br>Aso - annealing for softening<br>S - solution heat treatment | |

Table 5.3

Heat treatment of the wear-resisted alloy cast steels, applied to cement mills

| Lp. | Name of mill part | | Kind of the used cast steel | Average chemical composition of the cast steels | Heat treatment | Properties after treatment $R_m$ /MPa/ | U /kJ/m$^2$/ | $A_5$ /%/ | /HB/ |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Barrel linings | sieve plates | manganese-silicon, toughened | 0,25-0,35% C; 1,1-1,4 Mn; 0,6-0,8 Si | normalizing 870-890°C | 620 | 400 | 16 | 170 |
| | | | | | hardening 870-880°C water quenching tempering 570-600°C | 700 | 600 | 16 | 192 |
| 2. | | wall linings | chromium-titanium, toughened | 0,35-0,45% C; 0,4-0,7 Mn; 0,4-0,6% Si; 2,8-3,2 Cr; 0,1-0,3 Ti | normalizing 890-910°C | 800 | 250 | 10 | 229 |
| | | | | | hardening 870-890°C oil quenching tempering 450-470°C | 1200 | 200 | 4 | 352 |
| 3. | | very dynamic loaded wall linings | manganese-silicon, solutioned | 1,0-1,4% C; 12-14% Mn; 0,3-1,0% Si; do 1% Cr; 0,1-0,2% Ti | solutioning 1050-1100 water quenching | they are not tested | | | 170-217 |
| 4. | Balls | | as 1, 2 or 3 | as above | as above | as above | | | |

...t steels, resisted against to wearing. For compari- ... normalizing parameters are given, too.

## .. Heat treatment of cast iron castings

### .2.1. Kinds of the cast iron and their applications

Cast iron is a casting alloy of the iron and carbon /usu-...y from about 2,0 to 3,8% C/, silicon, manganese, sulphur, ...sphorus and others, with the chemical composition alike to ... pig iron /with total contents of alloy components no less ...an 6-7%/. The cast iron is obtained by melting of the pig ...ron inside the cupola, flame or electric furnaces - usually ...ith the addition of the scrap iron or steel and ferroalloys.

The low production cost, good casting properties and good exploitation properties - especially after heat treatment - it is a reason of the broad application of cast iron at industry, agriculture, transportation and at the consumer goods production.

The cast iron structure and properties depend mainly on the chemical composition and the quenching rate. The base component - carbon - can exist as a graphite /grey cast iron/, a cementite formation /white cast iron/ or into the both these formations /mottled cast iron/.

Silicon, nickel and aluminium, as well as slow quenching, favor the precipitation of graphite, instead manganese and sulphur with quick quenching - constituting of cementite. The presence of graphite in cast iron structure results that the cast iron is brittle, but has good casting properties. Phosphorus causes liquidity /cast iron well fills up the forms/, in higher percentage increases but the brittleness of the casting. Sulphur makes worse the casting properties and increases the brittleness.

White cast iron is hard, brittle, heavy workable and has not very good casting properties /viscosity and casting shrinkage to 2%/. It is sporadic applied /like the mottled one/, when the high hardness of the casting is required /e.g. the hardened sieve plates of cement mills/.

Grey cast iron distiguished itself with good casting properties /liquidity and the casting shrinkage about 0,7-1,2%/, a good workability, a high wear resistance, a vibration damping ability and a dimension stability /no sweling at repeated heating/. It is broad applied in the machine industry /e.g. foundation plates, machine bodies, gear casing, pumps/, the transport industry /cylinder sleeves crankshafts, brake drums/, the agriculture /about 60% of the agricultural machine weight are the cast iron castings, e.g. frames, and teeth of mowers, rolls/, the consumer goods production /grills, braziers, stove plates, drainboard sinks, thickwall pots, heaters for central heating, tubes etc/ and the extractive industry /elements of excavators, crushers, cement mills - made of hardened, low alloy, die casted cast iron, contains Cr, Ni, Mo, V, T and others/.

Inoculated grey cast iron - it is the grey cast iron with refined graphite and, thanks to it, with the high-tensile strength. It is applied to gears and machine parts, working at changeable loadings.

Spheroidal grey cast iron - it is the grey cast iron /over 2% C/, which is so inoculated that graphite occurs in spheroidal formation on the pearlite substrate /it is applied to machine parts with the high tensile strength, hardness and wear resistance/, or the ferrite substrate /it is applied to machine parts with some plasticity and impact resistance/. The strength properties are alike to cast steel properties. The participation of spheroidal cast iron in entire production of cast iron is low, but continuously rising, and exampled in high-industrialized countries overcrosses 10%. It is usually applied to heavy duty machine parts, including agriculture ones. It can replace not only cast steel, but also steel forgings for the car or tractor parts production.

Malleable cast iron is obtained by longlasting annealing of the white cast iron castings at temperature 800-1000°C, therefore is achieved the malleable material, which properties are close to steel properties.

White heart malleable cast iron /with pearlite-ferritic structure/ occurs during annealing in oxidizing atmosphere. Its fracture is light and the material has low plastic properties. This kind of heat treatment is called decarburization.

Black heart malleable cast iron /with ferritic structure, occurs during annealing in an inert atmosphere /e.g. inside the boxes filled up with sand/. Its fracture is dark and the material has good plastic properties. During annealing follows the unmixing of cementite into iron and graphite, and for it this kind of heat treatment is called graphitizing.

Pearlite malleable cast iron occurs as a result of annealing of the white cast iron in inert medium, but without finishing of the graphitizing process.

The malleable cast iron is applied to castings, from which are required the strength, plasticity, workability, impact resistance and resistance against to the action of smoke and acid mine water. It find the application in automotive and machine tool industry, rail road system and building industry. With good results it replaces the more expensive non-ferrous alloys. It has intermediate properties between grey cast iron /good casting properties/ and cast steel /good mechanical properties/.

With regard to the chemical composition, there is distinguished:

Carbon cast iron /simple grey one/ - containing 2,2-3,6% C /mostly 3-3,5% C/, to 3% Si, to 0,7% Mn, to 1% P and to 0,12%S. The application is very broad.

Alloy cast iron - containing also the additions, which increase the heat resistance /nickel and molybdene/, corrosion resistance /silicon, chromium, aluminium/ and other properties. The application is not very broad, only for special heavy duty castings.

In table 5.4 are given the mechanical properties of the carbon cast irons.

### 5.2.5. Heat treatment of cast iron

The most castings, made of the given cast iron kinds, mainly grey, high-quality /spheroidal and alloy ones/ and malleable cast irons, can be with good results used in the raw state. At many events, the heat treatment allows to exploit bet-

Table 5.4

Mechanical properties of carbon cast irons

| Sort of cast iron | | | Immediate strength $R_m$ /MPa/ | Elongation | Hardness /HB/ |
|---|---|---|---|---|---|
| Grey | non-inoculated | | 100 - 400 | - | 160 - 280 |
| Grey | inoculated | | 260 - 380 | - | 170 - 260 |
| Grey | sphe-roidal | ferritic | 400 - 500 | $A_5$ = 5 - 10 | 155 - 210 |
| Grey | sphe-roidal | pearlitic | 450 - 620 | $A_5$ = 2 | 200 - 300 |
| Malleable | white | | 350 - 450 | $A_5$ = 4 - 5 | 220 |
| Malleable | black | | 300 - 350 | $A_3$ = 6 - 12 | 170 - 190 |
| Malleable | pearlitic | | 450 - 700 | $A_3$ = 2 - 7 | 220 - 280 |

ter the cast iron possibilities. The heat treatment improves the casting properties, for it is more frequent applied in the practice. At the real events, there can be the requirements contrasting with each other, e.g. to decrease or increase the tensile strength, at last to increase the plasticity, which usually decreases this strength.

The heat treatment of cast irons differs, in some details, from the heat treatment of steel with regard to differences in the structure and, partially, in the chemical composition /mainly - high silicon contents/. In the structure of cast iron castings, besides the structure components, typical for the steel /ferrite, pearlite and cementite/, additionally occurs graphite, which precipitates already during the casting solidifying, or in a result of the later heat treatment /cementite unmixing into graphite and ferrite, otherwise so called graphitizing/. The influence of silicon on graphitizing of cast irons is so high that the low alloy grey irons can get entire graphitizing below the temperature $A_{c1}$ - during upheating to austenitizing temperature.

Precipitations of graphite have the very low strength and result the material discontinuity, especially when they occur in more quantities. They are the main reason that some heat treatment operations, e.g. hardening and tempering, applied for some kind of cast irons, containing graphite as the larger flakes /e.g. simple grey cast iron/ - don't give expected results.

Purposes of the cast iron heat treatment is given in table 5.5.

The heat treatment is broadest applied for grey, spheroidal and amlleable cast iron. Mostly there are applied the different kinds of annealing /at first the ferritizing, full and graphitizing ones/, seldom hardening and toughening.

In table 5.6 given the basic parameters of the most frequent met heat treatments of cast iron and their applications.

In fig. 5.3 - 5.5 shown some properties of the grey cast iron, as a function of temperature, for various heat treatment operations. In fig. 5.6 shown the run diagrams for different kinds of annealing.

Table 5.5

Purposes of cast iron heat treatment

| Purpose | Kind of heat treatment operation |
|---|---|
| Removing of internal stresses /casting, welding, hardening/ and stabilizing of casting dimensions | stress relief annealing tempering |
| Hardness reducing - softening /by cementite unmixing/, improving of workability and plasticity | annealing: softening, graphitizing, normalizing, ferritizing |
| Hardness increasing, improving of strength properties and wear resistance | hardening, temper-ing, toughening |
| Transformation of white cast iron into malleable cast iron | graphitizing annealing |
| Increasing of resistance against to wearing and corrosion /atmospheric, temperature ones/ | hardening, toughening thermo-chemical treatments: nitriding and secondary operations, immersion aluminizing, siliconizing |

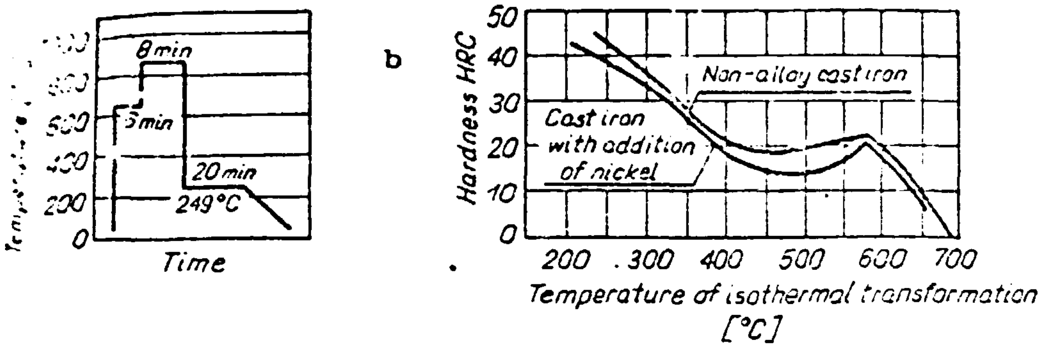



Fig. 5.5. Run diagram of isothermal hardening /a/ and influence of transformation temperature on grey cast iron hardness /b/.

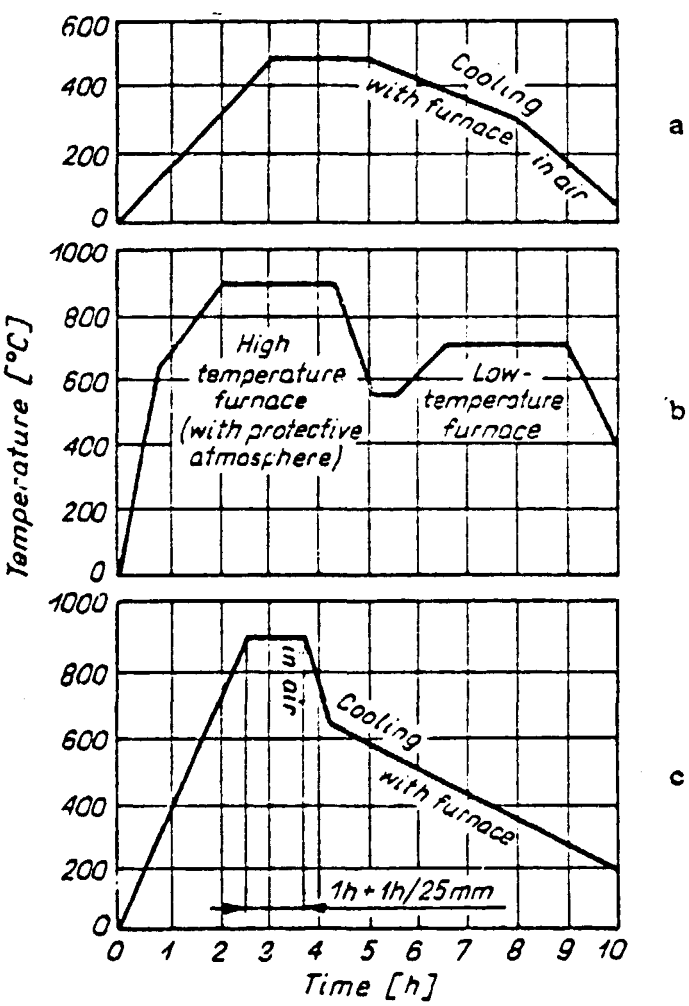



Fig. 5.6. Run diagrams of annealing: a - stress relief annealing of grey cast iron; b - two-stage graphitizing annealing of spheroidal cast iron; c - normalizing, connected with stress relieving, of spheroidal cast iron.

Table 5.6

Applications and parameters of the most applied heat treatment of cast irons

| Treatment kind | Cast iron sort | Upheating rate | Temperature /°C/ | Soaking time /h/ | Quenching. | Hardness after treatment | Purpose of the treatment |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| ferritizing annealing | grey | | 700-760 | to finishing of graphitizing | slow, simple castings - to 100°C/h /to 300°C/ | | workability improving of non-alloy and low-alloy cast irons |
| full annealing | grey | | 790-900 | | slow in range | | instead of softening annealing - for high - alloy cast irons |
| graphitizing annealing | grey | | 900-950 | usually 1-14 | 1/to 540°C in air 2/to 540°C with furnace 1/ and 2/ in range 540-300°C with the rate to about 100°C/h | | full unmixing of large precipitation of carbides into graphite and pearlite 1/high strength and wear resistance 2/workability improving |

Table 5.6 /continued/

Applications and parameters of the most applied heat treatment of cast irons

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| graphitizing annealing | white, hard spotted /free cementite in structure/ | slow for complicated castings and faster for simple ones | stage I: 900-1050 stage II: 800-700 | up to achieving of full unmixing of cementite into austenite and temper carbon | stage I: slower /250-300°C/h/ to 800°C, very slow /2-3°C/h/ to 700°C stage II: slow to 650°C, further air cooling | max. 163 | obtaining of black heart malleable cast iron /with ferritic-graphite structure/ 2-stage annealing accollerates the process |
| graphitizing annealing | white | slow-about 7 h in oxidizing atmosphere /decarburizing/ or in iron ore | 1050 | 30-60 depending on thickness of a section | slow /5-16 h/ to 500°C | max. 201 | obtaining of white heart malleable cast iron with ferritic-pearlitic-graphite structure |
| stress relief annealing /stabilizing/ | all kinds | slow /70-100°C/h/ | 450-570 non-alloy 600-650 low-alloy | 2,5-4,5 min. per 1 mm of section thickness | slow /usually to 300°C and exceptionally to 100°C - with furnace/ about 25-50°C /h, further - air cooling | without considerable changes | removing of stresses /1 h of annealing = removing of 75-80% stresses/ stabilization of casting dimensions |
| | spheroidal | | 540-680 | 1 h/25 mm section thickness | | | |
| | inoculated | | 600 | | | | |

Table 5.6 /continued/

Applications and parameters of the most applied heat treatment of cast irons

| 1 | 2 | 3 | 4 | 5 | 6. | 7 | 8 |
|---|---|---|---|---|---|---|---|
| stabilizing /pearlitizing annealing | grey | slow for complicated castings and faster for simple ones | 830-930 | 0,5-3 or 1 h/25 mm of section thickness | in air; for complicated castings - to 650 $^{\circ}$C - in air; further slow furnace cooling | - | strength increasing, wearing reducing; it is applied after graphitizing annealing, soaking, before and after welding, for restoration properties of the raw casting; after normalizing succeeds tempering 650-680 $^{\circ}$C/1-1,5h |
| | malleable spheroidal | | 850-950 | 1-2 | | 241 | |
| softening annealing | grey, spheroidal malleable | as above | 650-750 | 3-6 with regard to demanded hardness | slow 60-180 $^{\circ}$C/h with furnace to 400 $^{\circ}$C | 131-163 | partial unmixing of carbides, hardness reducing, improving of workability and plasticity, removing of stresses |
| | hard spotted in half | | 825-900 | 0,5-5 for achieving of homogeneous austenite | | | |

Tablo 5.6 /continuod/

Applications and paramoters of the most applied heat treatmont of cast irons

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| convon-tional hardoning | malleable grey | as above, in range 600-650°C slow up-heating | 830-900 / 100°C over $A_{c3}$/ | 3 min/1 mm of thickness /for middle thiokness castings/ | in oil or water /high-alloy grey cast iron - in air/ at about 150°C to transfore into the furnace for tempering | | increasing of hardness, strength and wear resistance |
| | spheroidal | | 845-925 | | in oil or water and water solutions /simple castings/ | | |
| isother-mal hardening | grey, malleable | | 830-900 | as above | in salt bath or oil 230-425°C during 0,5-1,5 h later in air | 429-311 | as above with keeping of higher plasticity |
| | spheroidal /pearlitic/ | | 900-950 | | | 363-311 | |
| stop hardening | grey | as above | in regard to chemical composition | as above | in salt bath, oil or lead 205-260°C during about 1 h later in air | | obtaining of the martensite state without occuring of stresses |

Tablo 5.6 /continued/

Applications and paramoters of the most applied hoat treatment of cast irons

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| surface hardening | grey malleable spheroidal /pearlitic/ | with an oxy-acetylene flame or by induction | 900-1000 | very short | water, oil, oil emulsion | HRC = 50-60 | achieving of the hard and wear resisted surface layer, increasing of fatigue strength; after hardening-tempering at 160-200°C in furnaces, oil bathes or at flame upheating /reduces deformations and cracks/ |
| tempering | grey malleable | putting into the furnace at tempering temperature | 350-550 | 0,5-3 /1h/25 mm of thickness | in air | 430-290 | removing of hardening stresses, increasing of plasticity |
| | spheroidal | | | 1h + 1h/25mm of section thickness /alloy cast irons - longer time | | | |

## 6. Heat treatment of forgings

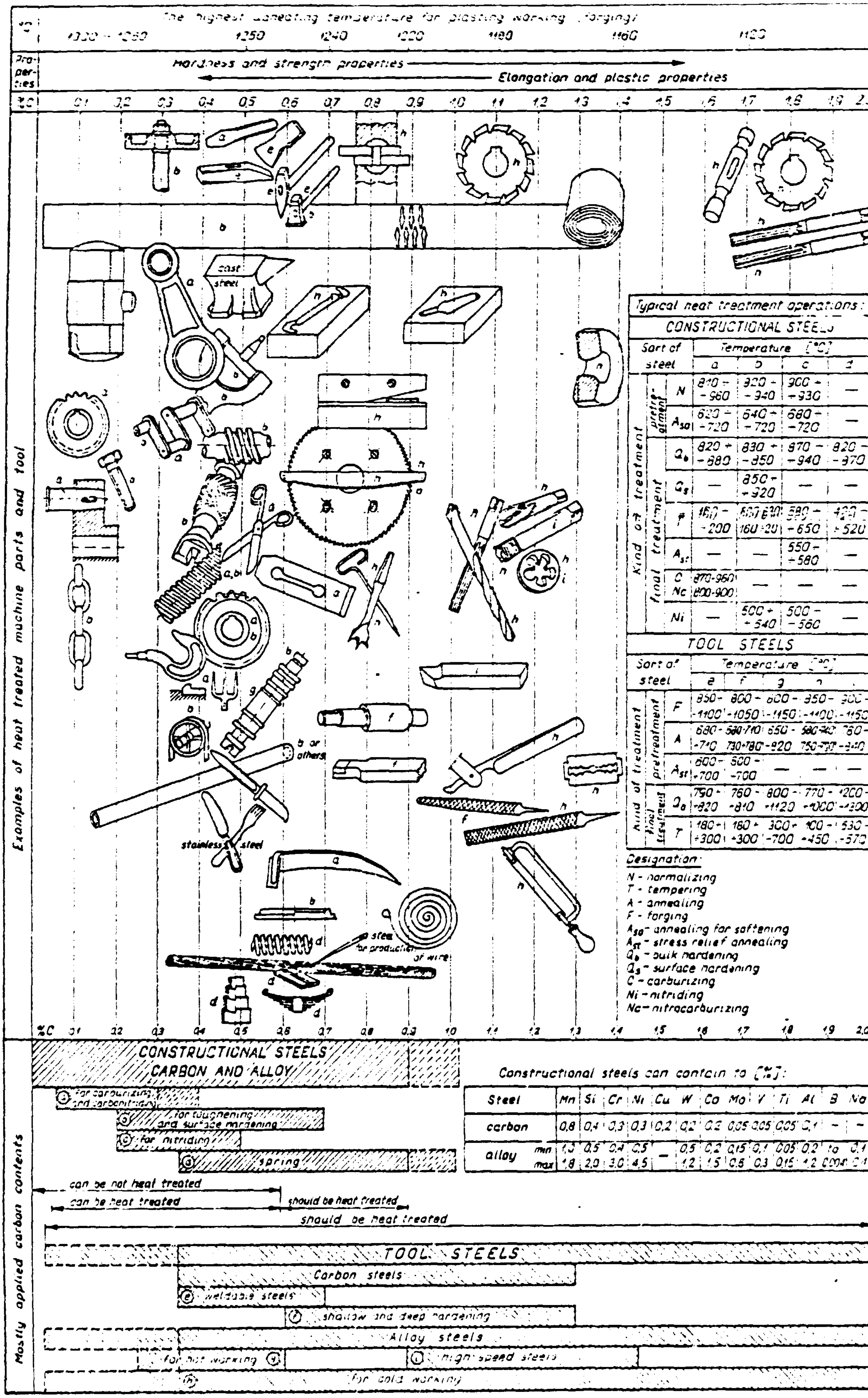
### 6.1. Classification of steels applied to forgings

The forgings can be made of all sorts of the steel. The steels can be divided as follows:

1/ with regard to the chemical composition:

- carbon steels - where the main component, which influences on steel properties, is carbon /to about 2% C/. Increase of the carbon contents improves the strength properties of the steel /tensile strength, hardness/ and makes worse its plastic properties /elongation, narrowing/. The carbón contents influences not only on the raw steel properties, but also on heat treatment course and steel properties after the treatment. Independence from the carbon contents, there are distinguisned the steels: low-carbon /to 0,25% C/, medium-carbon /0,25-0,65% C/ and high-carbon /over 0,65% C/ steels. The contents of the remained components should not overstep the fixed limits /fig. 6.1/. The worse quality carbon steels /for building industry, steel constructions/ are not heat treated. The remaining steels can be or ought to be heat treated. Carbon steels are 90% of the world steel production and are several times cheaper than alloy steels;
- alloy steels - where the contents at least of the one element, except of iron and carbon, oversteps the limits, fixed for carbon steels /fig. 6.1/. In dependence from the contents of alloy components, they are divided into: low-alloy /if the sum of alloy components is not higher than 2,5%/, medium-alloy steels /2,5-5,0%/ and high-alloy steels /over 5%/. The alloy components allow: to increase a hardness, to achieve higher strength properties in the heat treated state, to grant the special physical and chemical properties. In raw state there is small difference of properties between alloy steels and carbon steels with the same carbon contents. The advantage reveal themselves only after heat treatment. For it the alloy steels are always used in the heat treatment state;

2/ with regard to the destination:




Typical heat treatment operations:

| CONSTRUCTIONAL STEELS | | | | | | |
|---|---|---|---|---|---|---|
| Kind of treatment | Sort of steel | Temperature [°C] a | b | c | d |
| pretreatment | N | 840 ÷ 960 | 820 ÷ 940 | 900 ÷ 930 | — |
| pretreatment | $A_{so}$ | 620 ÷ 720 | 640 ÷ 720 | 680 ÷ 720 | — |
| final treatment | $Q_b$ | 820 ÷ 880 | 830 ÷ 850 | 870 ÷ 940 | 820 ÷ 870 |
| final treatment | $Q_s$ | — | 850 ÷ 920 | — | — |
| final treatment | T | 160 ÷ 200 | 600 ÷ 630; 160 ÷ 20 | 580 ÷ 650 | 420 ÷ 520 |
| final treatment | $A_{st}$ | — | — | 550 ÷ 580 | — |
| final treatment | C / Nc | 870-960 / 800-900 | — | — | — |
| final treatment | Ni | — | 500 ÷ 540 | 500 ÷ 560 | — |

| TOOL STEELS | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kind of treatment | Sort of steel | Temperature [°C] e | f | g | h | i |
| pretreatment | F | 850 ÷ 1100 | 800 ÷ 1050 | 600 ÷ 1150 | 850 ÷ 1100 | 900 ÷ 1150 |
| pretreatment | A | 680 ÷ 740 | 680-710; 730 ÷ 780 | 650 ÷ 920 | 680-740; 750-770 | 760 ÷ 840 |
| pretreatment | $A_{st}$ | 600 ÷ 700 | 600 ÷ 700 | — | — | — |
| final treatment | $Q_b$ | 790 ÷ 820 | 760 ÷ 810 | 800 ÷ 1120 | 770 ÷ 1000 | 1200 ÷ 1300 |
| final treatment | T | 180 ÷ 300 | 160 ÷ 300 | 300 ÷ 700 | 100 ÷ 450 | 530 ÷ 570 |

Designation:

N - normalizing
T - tempering
A - annealing
F - forging
$A_{so}$ - annealing for softening
$A_{st}$ - stress relief annealing
$Q_b$ - bulk hardening
$Q_s$ - surface hardening
C - carburizing
Ni - nitriding
Nc - nitrocarburizing

Constructional steels can contain to [%]:

| Steel | | Mn | Si | Cr | Ni | Cu | W | Co | Mo | V | Ti | Al | B | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| carbon | | 0,8 | 0,4 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,05 | 0,05 | 0,05 | 0,1 | – | – |
| alloy | min | 1,3 | 0,5 | 0,4 | 0,5 | — | 0,5 | 0,2 | 0,15 | 0,1 | 0,05 | 0,2 | to | 0,1 |
| alloy | max | 1,8 | 2,0 | 3,0 | 4,5 | — | 1,2 | 1,5 | 0,5 | 0,3 | 0,15 | 1,2 | 0,004 | 0,4 |

Fig. 6.1. Application examples, division and typical heat treatment operation of constructional and tool steels with different carbon contents.

- construc ional steels /carbon and alloy ones/
- tool steels /carbon and alloy ones/
- special steels - with special properties /alloy ones/.

The special steels demand the complicated and precision heat treatment. For it, further will be discussed only these groups of the constructional and tool steels, which can be heat treated with a relatively simple method.

A dividing of the constructional and tool steels, in dependence on their destination, examples of applications and typical heat treatment operations, were shown in fig. 6.1. The extention of the every object in the figure indicates the carbon contents in steel, of which this object can be manufactured, e.g. hammers and axes can be made of tool weldable steels with carbon contents from about 0,38% to about 0,71% C.

## 6.2. Constructional steels and their heat treatment

These steels are the material for manufacturing of machine parts and devices, working in common conditions and media, which have not the special pernicious influence on the material. The properties of these steels can be changed in very broad limits by the application of the proper heat treatment.

Carbon steels are cheap and commonly accessible, but distinguish themselves with the low hardenability. They usually demand of water hardening, what is connected with rather high tendency towards deformations and crackings. It is a reason, why only not too large part of them is heat treated. High quality carbon steels with contents below 0,2% C are carburized, next hardened and low-temperature tempered. The steel with contents 0,2% can be carburized as well as toughened. Steels with contents over 0,2% C are only toughened /hardened and high-temperature tempered/. Big objects are made of normalized carbon steels. Higher quality carbon steels are the material for manufacturing of the blacksmith /free forged/ or die forgings.

Alloy steels are expensive, and not always accessible in each country, distinguish themselves with high hardenability

/increasing along with heightening of alloy component contents/, they usually demand of oil for quenching, less warping and cracking.

### 6.2.1. Steels for carburizing and carbonitriding

Carbon and alloy steels for carburizing and carbonitriding /0,1-0,3%, seldom 0,05-0,45% C/ mostly are heat treated by following ways:

1. Pretreatment before carburizing, depending on normalizing and aims to refine the structure and remove internal stresses of the forging material. There is desirable that forgings, with complex or developed shapes, were roughly mechanical worked before normalizing. The normalizing is applied to most part of the forgings, submitted to carburizing. Some alloy steels are - after normalizing - softening annealed for improving of the workability.
2. Carburizing aims to produce the surface layer, enriched with carbon.
3. Final treatment after carburizing - annealing, hardening, tempering - aim to refine the stell structure /overheated during hardening/, profitable to dispose the carbides /cementite/ into carburized layer, to achieve the best strength properties for the core, to grant the high hardness and wear resistance for the carburized layer, to remove the hardening stresses.

   Example: for production of clutch centre plates, washers, wrenches, there are applied the higher quality constructional carbon steel with contents about 0,2% C. The steel is carburized at temperature 900-940°C, water hardened directly at carburizing temperature, tempered at temperature 150-170°C, in order to obtain the hardness 150-180 HB.

### 6.2.2. Steels for toughening and surface hardening

Carbon and alloy steels for toughening and surface hardening /0,2-0,7% C/ are mostly applied to forgings. For surface hardening are mostly applied the carbon steels with contents

After cutting working these steels are already not heat treated.

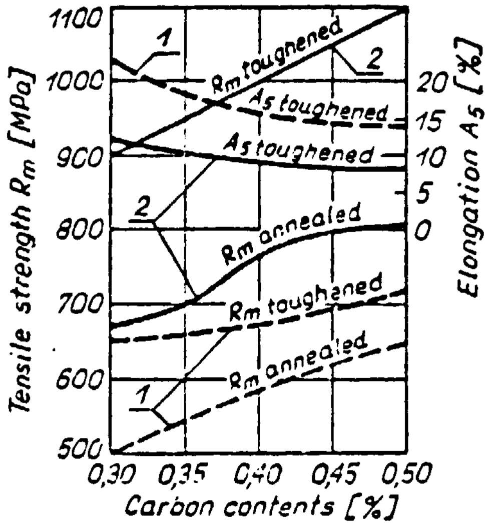



Fig. 6.2. Influence of toughening on carbon steels /1/ and alloy steels /2/ with different carbon contents - on their mechanical properties.

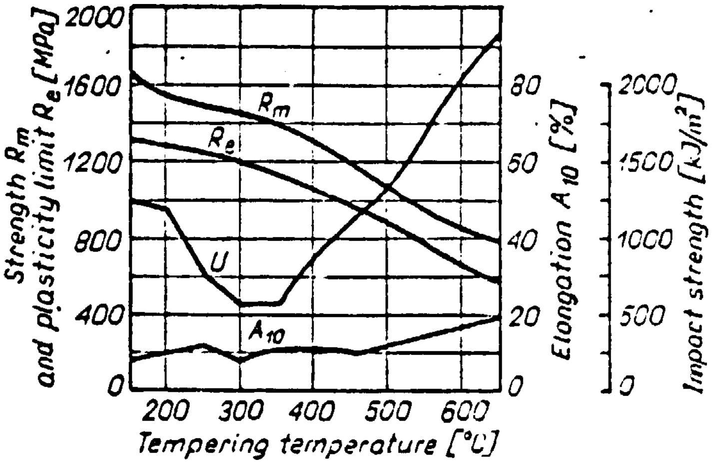



Fig. 6.3. Influence of the tempering temperature on mechanical properties of the alloy steel /0,26-0,34% C; 0,4-0,7% Mn; 0,17-0,37% Si; 0,8-1,1% Cr; 0,15-0,30% Mo/ - hardened in oil at 880°C.

[illegible] C Objects with thin sections /to 2,5 mm/ and simple shapes are made of carbon steels, the more complexed ones - of alloy steels.

Heat treatment of these steels depends on hardening at proper temperature - in water, water solutions or oil, and on tempering at temperature 500-650°C. The purpose of the treatment is to improve the strength properties and to keep the proper impact resistance as well as not too high hardness, because, after toughening, the steels are submitted to working by cutting /the hardness should not be higher than 360 HB/. Before toughening, the forgings can be normalized and annealed. In fig. 6.2 is shown the influence of toughening on strength and elongation of the carbon and alloy steels, in dependence from carbon contents. In fig. 6.3 is shown the influence of tempering temperature on mechanical properties of alloy steels with contents 0,26-0,34% C, 0,4 - 0,7% Mn, 0,17 - 0,37% Si, 0,8-1,1% Cr, 0,15-0,30% Mo, hardened in oil at temperature 880°C.

### 6.2.3. Heat treatment of more important machine parts

The most of machine parts are treated in 2 stages:

1. Pretreatment, including the treatment of forgings /and castings, too/ before cutting. Its purposes are different: to remove stresses, to refine the structure, to obtain the required mechanical properties, to improve workability. It can ibclude the operations of softening and full annealing, normalizing annealing, normalizing with pre-softening /tempering/, toughening.

   For following operations can be used the heat, obtained from the forging upheating: direct normalizing or hardening of the hot forging, isothermal annealing and direct isothermal hardening.

   Sometimes the pretreatment is as well the final treatment.
2. Final treatment is mostly conducted after working by cutting. Its purpose is to remove the stresses and to grant the desired mechanical properties for material. The most it includes: conventional, isothermal and surface hardening, tempering, stabilizing, stress relieving, carburizing, nitriding and secondary processes.

In table 6.1 are given the diagrams of the typical runs /courses/ of heat treatment for machine parts of constructional steels. The general parameters of the particular operations are given in fig. 6.1. The accurate parameters of the treatment should be at any time assorted to the sort of the fixed steel and to properties, demanded after heat treatment.

### 6.3. Tool steels and their heat treatment

Tool steels can contain from 0,01 to 2,1% C. They characterize themselves: high hardness after hardening, friction wear resistance, ductility of the core, insensibility to overgeating /some steels only/, low deformability. Some tool steels can be used as a constructional steels - and by contraries. The heat treatment of tool steels requires the particular care and accuracy.

Table 6.1.

Diagrams of the heat treatment runs for some forgings made of constructional steels

| Working object | Pre-treatment | M | Final treatment | M |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Forgings, bars and castings made of carbon steel - for light duty parts | Af | + | - | - |
| as above for heavy duty parts | N | + | - | - |
| as above, made of carbon and alloy steels - for heavy duty parts | Qb- Th | + | - | - |
| Parts with complex shape, made of alloy steels - for heavy duty | N -Qb- Th | + | - | - |
| as above, big sections - heavy duty | N | + | Qb- Th | + |
| Parts made of alloy steels, which are hardened during normalizing | N -Aso | + | Qb -Th | + |
| as above, parts made of carbon steel - heavy duty | N | + | Qs -Tl | + |
| Parts made of carbon and alloy steels - heavy duty | Qb -Th | + | Qs -Tl | + |
| as above - very heavy duty parts /gears, crankshafts/ | N-Qb -Th | + | Qs- Tl | + |
| Forgings with complex shapes or with big sections, made of carbon and alloy steels - heavy duty | N | + | Qb-Th-Ast or S | + |

/continued/ Table 6.1.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Forgings made of finegrained carbon steel | event. /N/ | + | C-Qb-Tl | + |
| Forgings of parts, made of alloy steel, - heavy duty | N | + | C-$Qb_1$-$Qb_2$ -Tl | + |
| Parts made of alloy steels, disposed to constitute of retained austenite | N | + | C-Aso-M- -Qb-Tl | + |
| Forgings made of carbon steel and alloy steels - for heavy duty parts | N | + | Nc-Qb-Tl | - |
| Simple forgings | /N/-Qb-Th | + | Ni | - |
| Forgingd with complex shapes | N-Qb-Th | + | Ast-M-Ni | - |

M - mechanical working
Af - full annealing
Aso - annealing for softening
Ast - stress relief annealing
N - normalizing
Qb - bulk hardening
Qs - surface hardening
Qa - austempering
Th - high-temperature tempering
Tl - low-temperature tempering
C - carburizing
Nc - nitrocarburizing
Ni - nitriding
S - stabilizing treatment

### 6.3.1. Carbon tool steels

Carbon tool steels /0,35-1,3% C/ vary from the constructional ones mainly on the higher fineness, less manganese contents, finegrainedness and low hardenability. Their main characteristic feature is small hardening depth, which is as follows:

3-5 mm for shallow hardening steels /the most expensive/
5-12 mm for deep hardening steels
5-10 mm for weldable steels /the most cheapest/.

This feature results that at bulk hardening only surface layer of the tool is hardened, and the core remains soft and plastic. Thanks to it, the tool is hard and wear resisted and simultaneously is impact resisted. These steels should not work at temperature over 200°C, because it causes tempering and reducing of hardness.

In table 6.2 are given the working parameters and applications of carbon tool steels. There is step upheating for hardening, with preheating. Upheating time amount to 0,35-0,5 min/1 mm of thickness at heating in salt bathes and 1,7-2,0 min/1 mm at heating in chamber furnaces. The tempering temperature is to 150-225°C for machine cutting tools, 225-275°C - for hand cutting tools, 275-300°C - for impact working and for saws, shears and single-point tools /turning tools/.

### 6.3.2. Alloy tool steels

Steels for cold working are destined for working at temperature not higher than 150-200°C.

Steels with the high carbon contents, with addition of tungsten, can be water hardened; they are used for manufacturing of the cutting tools.

Steels with the high carbon contents, with addition of chromium or manganese, are hardened in oil; they are applied to manufacturing of blanking dies and cutting tools.

Steels with the low carbon contents, with addition of tungsten, are used for manufacturing of pneumatic tools. Saws and rolls are made of low alloy steels. Dies are made of chromium-

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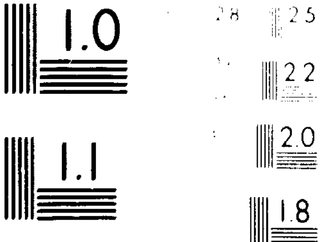
1.0
1.1
2.8
2.5
2.2
2.0
1.8


1.25
1.4
1.6

Table 6.2.

Heat treatment parameters of carbon tool steels

| steel | Carbon contents [%] | Forging temperature range [°C] [1] | Softening $<A_{cs}$ [°C] | Softening $>A_{c1}$ [2] [°C] | stress relieving | Hardening /in water/ [3] [°C] | tempering [4] [°C] | Hardness HB after softening | Hardness HRC after hardening | Main application |
|---|---|---|---|---|---|---|---|---|---|---|
| shallow and deep hardening itself | 1,25-1,35 | 1000-800 | 680-710°C, free quenching | 760-800 | 600-700°C, slow quenching | 760-780 | 1[illegible]0-300°C, in air | 217 | 63 | files, tools fo metal working at small speed of cutting, tools for working of honestone and for sharpening of knives, knives for paper, engraving tools, markers, scrapers |
| | 1,15-1,24 | 1000-800 | | 750-780 | | 760-780 | | 207 | 63 | |
| | 1,05-1,14 | 1000-800 | | 740-760 | | 760-780 | | 207 | 63 | drills, milling cutters, reamers, taps, thread dies, file cutters, blanking dies, circular tools, metal saws, moulds, jaws and knives for nail-making machines, steelpens, shoemaker's knives lathe centres |
| | 0,95-1,04 | 1000-800 | | 730-760 | | 760-680 | | 197 | 62 | |
| | 0,85-0,94 | 1000-800 | | 730-760 | | 760-680 | | 197 | 62 | punches, big reamers, and taps, cold working dies, hard wood cutting tools |
| | 0,75-0,84 | 1050-850 | | - | | 770-790 | | 187 | 62 | cold working dies, punches, chisels, band-saws for wood, knives for cold working shears, riveting snaps, stamps, pneumatic hammer chisels |
| | 0,65-0,74 | 1050-850 | | - | | 760-800 | | 182 | 61 | smith hammers, blanking dies, hand riveting snaps, wood cutting tools, soft stone working tools |
| weldable | 0,60-0,70 | 1050-850 | | - | | 780-810 | | 1[illegible]7 | 61 | axes, smith tools, wood cutting tools, leather working tools |
| | 0,50-0,60 | 1100-850 | | - | | 790-810 | | 187 | 58 | smith hammers, snaps, wood cutting tool |
| | 0,35-0,45 | 1100-850 | | - | | 800-820 | | 187 | 54 | hammers, axes, picks and others |

1/ Cooling in ash or sand

2/ Cooling with furnace to 600°C with rate 20°C/h, later free cooling

3/ Hardening temperature can be higher, but should not overstep the start temperature of the grain growth

4/ Tempering temperature is selected in dependence on requirements of tool hardness

Table 6.2.

nickel steel, which can be air hardened.

In table 6.3 are given working parameters and applications of some sorts of these steels. Upheating for hardening is usually one-step one.

Steels for hot working are used for manufacturing of tools for press machines and forms /dies/ for pressure casting. The steels are impact resisted, at high temperatures they are resisted against to cracking, too. In table 6.3 are given working parameters and applications of some sorts of these steels. The steels, in general, are tempered at this temperature, which is foreseen as a high temperature limit at working.

6.3.3. Heat treatment of some tools

The general rules of heat treatment of the tool steels are following:

- upheating in chamber furnaces - slow, in salt bathes - two-step
- upheating time - longer than for constructional steels
- quenching - slow

1. Pretreatment usually includes:
 - forging: change of the shape, refining of the crystallic structure, breaking of the carbide lattice and its uniform distribution; after forging the material, cooled to 650-700°C, should be replaced into the furnace at the same temperature for a purpose of annealing;
 - annealing above $A_{c1}$: to refine the grain and to constitute the spheroidal cementite structure /carbon and low alloy steels/ as well as the fine pearlite with uniform distributed carbides /high-carbon and high alloy steels/. Annealing should be conducted in non-decarburizing and non-oxidable atmosphere, and when this atmosphere is not accessible, inside the boxes, covered with th used carburizing powder or cast iron chips. The time is 2-4 h. Cooling with a furnace to 500-600°C, later in air. This annealing can be applied, too, before the repeated hardening;
 - annealing below $A_{c3}$ is applied as the softening and stress

Table 6.3

Parameters of typical heat treatment of alloy steels

| Steel | Chemical composition, average [%] | | | | | | Hardness | | Temperature °C | | | | | Main application /see below/ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | Cr | W | V | HB after softening | HRC after hardening | forging | softening $< A_{c1}$ | softening $> A_{c1}$ | hardening o=oil p=air w=water | tempering 1/ | |
| for hot working | 0,55 | 0,3 | 0,9 | 1,1 | 2,0 | - | 255 | 57 | 1050-800 | 710-740 | 760-780 | 850- 900, o | 220-320 | item A |
| | 0,25 | 0,3 | 0,9 | 1,1 | 2,0 | - | 223 | 56<br>54 | 1050-850 | 710-740 | 760-780 | 840- 880, w<br>860- 900, p | 220-320 | item B |
| | 2,0 | 0,5 | 0,3 | 12,0 | 1,2 | 0,25 | 255 | 58 | 1050-850 | - | 820-860 | 950-1000, p | 220-450 | item C |
| | 0,75 | 0,4 | 0,3 | 0,5 | - | 0,2 | 207 | 61<br>59 | 1000-800 | 690-710 | 750-770 | 770-800, w<br>790-820, o | 240-320 | item D |
| | 0,4 | 0,3 | 1,4 | 1,5 | - | - | 207 | 50 | 1050-830 | 710-740 | - | 840-870, o | 200-240 | item E |
| | 0,5 | 0,5 | 0,3 | 1,3 | 0,5 | 0,5 | 269 | 50<br>48 | 1050-850 | 580-600 | - | 810-840, o<br>840-870, p | 200-350 | item F |
| | 1,0 | 0,3 | 0,25 | - | - | 0,2 | 217 | 63 | 1000-800 | 690-710 | 750-770 | 770-800, w | 220-320 | item G |
| for cold working | 0,3 | 0,3 | 0,3 | 2,7 | 9,0 | 0,3 | 241 | 45 | 1150-900 | - | 740-780 | 1050-1120, o | 600-700 | item H |
| | 0,55 | 0,7 | 0,2 | 0,7 | - | 0,15 | 241 | 45 | 1100-850 | 650-680 | - | 820-860, o | 520-600 | item J |
| | 0,4 | 0,4 | 1,0 | 5,0 | - | 0,3 | 229 | 45 | 1100-850 | - | 780-820 | 1000-1050, o | 500-640 | item K |
| | 0,4 | 0,7 | 0,4 | 3,2 | - | 0,2 | 229 | 50 | 1100-850 | - | 730-760 | 950-980, o | 500-550 | item L |
| | 0,55 | 1,0 | 0,5 | - | - | - | 197 | 45<br>55 | 1100-850 | 690-810 | | 820-850, o 2/<br>770-800, w | about 300 | item M |

1/ Tempering conditions should be adapted to the shape, size and working kind of the tool.

2/ Given heat treatment don't subject the anvils and dies, which are applied in the raw or normalized state.

item A: dies, shear knives, rolls for straightening , wood cutting tools, coining punches, snaps, pneumatic punches and chisels.

item B: pneumatic tools, chisels, snaps, setts, markers for metals, shear knives.

item C: blanking dies, drifts, cutters, reamers, milling cutters, nail-making knives.

item D: circular saw blades, band saws, frame and hand wood cutting saws.

item E: pneumatic tools, hand chisels, stamping dies, shear knives, piercing punches.

item F: plunger dies, drifts, long knives for shears, moulds.

item G: jaws and knives for nail-making machines, small dies for screws and rivets, file cutters, coining and medal punches.

item H: Ni=1,5%; inserts for dies and punches, dies for screws, nuts and rivets, punches, pressure casting forms, forms for bronze and brasses forgings.

item J: Mo=0,25%, Ni=1 6%; smith dies, dies for hydraulic and mechanical press machines, die inserts.

item K: Mo=1,3%; pressure casting forms.

item L: Mo=0,3%; smith dies, punches for alloys Al, Mg, Zn.

item M: big dies for heavy forgings. Anvils for presses and heavy hammer machines.

relieving after mechanical working, before hardening of the tools with complex shapes;

- high-temperature tempering: improving of the workability and surface smoothness of the tools, hardened at proper for this steel temperature.

2. Final treatment usually includes: hardening, tempering, stabilizing and thermo-chemical treatment. It aims to increase the hardness and machinability /cutability/ as well as to ensure the dimension stability and high resistance against to wearing.

The general parameters of heat pretreatment and final heat treatment of different kinds of the tool steels - are given in fig. 6.1.

## 7. Heat treatment of non-ferrous metals

### 7.1. Briefly about heat treatment of aluminium alloys

Among the great many of non-ferrous metals and their alloys, the widest application have alloys of aluminium and copper.

Nevertheless we must take into consideration the fact, that aluminium alloys:

- are heat treated in the most already in a metallurgical process /e.g. building structure elements, furniture sections, standard castings and forgings/,
- require very accurate heat treatment, with close observing of the technology requirements, and the equipment applied for this purpose must have the very uniform layout and stability of temperature. There ought to be still possible the precision measurement of this temperature at the place, where the charge is located.

For above reasons, we omit the discussion about heat treatment of these alloys, because this treatment can be precisely carry out in practice only at modern, well equipped factories.

Instead of it, we advise users of this study that when they will order the ready construction profiles, sheets, standard castings or forgings, made of aluminium alloys, they should give in the order the basic parameters, which they require form ordered products /kind of aluminium alloy or its composition, strength in $R_m$, hardness in HB/. The users should demand, too, that standard castings and forgings, made of aluminium alloys, will be supplied in an aged state.

### 7.2. Heat treatment of copper and its alloys

We would like to devote more attention for heat treatment of copper and its alloys, because they are the material for production of great many very practical parts, e.g. ship propellors for cutters, the most of slide bearings /both are very useful at self-reliant repairs/, furniture, decorative small pieces /casing of watches, optical or musical instruments etc./, electrotechnical elements and so on.

It should be underlined that almost all these parts /casted and forged/ can be made of simple methods: castings - the mostly in sand forms, forgings - in the most they can be free forged with accessible hammers and presses, or using the simple, easy for executing, dies. The simple, single parts of copper alloys can be forged with hand hammers - it is known for hundreds, and even thousands years.

And, what is here more important, the heat treatment of copper alloys can be realized in the same chamber furnaces, which are used for heat treatment of castings and forgings made of iron alloys.

### 7.2.1. Heat treatment of brasses

Brasses are the alloys of copper and zinc /so called straight brasses or two-component alloys/ and mostly with other additions /so called complex brasses or multi-component alloys/ with melting temperature 860-1050°C, resisted against to corrosion and see water activity, good machineable, castable and malleable; some alloys are weldable, resisted against to high temperature and wearing.

Cast brass - multicomponent alloys of copper and zinc /about 40%/ and additionally: lead /to 4%/, manganese /to 4%/, aluminium /to 3%/, iron /to 1,5%/, silicon /to 4,5%/. These alloys are applied for sand and die castings; they are suitable for light section castings and pressure castings. A casting shrinkage 1,4-2,2%. They are heat treated very seldom and are applied to manufacturing of fixtures, resisted against to see water activity, smaller ship propellers, sleeves, some gears, furniture parts /door handles, shanks, knobs and others/.

Brasses for plastic working - there are two-component alloys /60, 63, 68, 70, 80, 85, 90 and 96% Cu, remains Zn/ or, mostly, multicomponent alloys: with lead /to 3%/, manganese /to 2%/, iron /to 1,5%/, aluminium /to 2,5%/, tin /to 1,5%/, silicon /to 4%/, nickel /to 6,5%/ and phosphorus /to 0,06%/. They are applied to production of forgings, sections, bars, wires, pipes, tapes and sheets. They can be plastic worked with cold and /or/ hot processes:

alloys containing up to 33% Zn - cold working
alloys containing up to 35-40% Zn - cold and hot working
alloys containing up to 40-48% Zn - hot working only /780°C/.

They are heat treated usually after plastic working or during the operation /interoperation annealing/. They are applied to electrotechnical parts, bulbs, watches, optical and musical instruments, furniture parts, small metal parts and others.

The heat treatment of brasses depends on a kind of the alloys and relys mostly upon different kinds of annealing: diffusion, recrystallization and stress relief ones. The hardening and tempering as well as precipitation hardening is seldom used.

Annealing does not improve the strength properties, but:

Diffusion annealing /homogenizing/ allows to get homogeneous structure and chemical composition; it is usually connected with simultaneous heating for hot plastic working. Annealing temperature should be about 50°C lower than solidus temperature of alloy, heating time - 6 h, air cooling.

Recrystallization annealing - the most popular kind of the brass heat treatment - it allows to improve the plastic properties /softening/ after plastic cold working; it is used as an interoperation or final process. The temperature about 520-700°C, soaking time - about 2 h, air cooling: one-phase brass - fast /quenching/, two-phase - slow /cooling/.

Stress relief annealing allows to remove the internal stresses of the objects, after heat treatment, or castings /seldom/, and prevents to season crackings. The temperature - 260-300°C, soaking time - up to 2 h, slow cooling /the best - furnace cooling/. This treatment is especially recommended for parts galvanic plating.

Precipitation hardening of straight brasses is possible only from contents about 32% Zn /with small effect/, complex brasses - only brasses with structure $\alpha + \beta$ and lead addition, and brasses Cu-Zn-Al /e.g. 18-30% Zn and 3-5% Al/. E.g. the brasses with structure $\alpha + \beta$ and Pb addition are heated to temperature of phase $\beta$ existing, soaked during about 0,5 h, cooled to an environment temperature and next soaked again at temperature 200-400°C during about 3 h.

The brasses are treared in chamber furnaces in air protective atmospheres /e.g. dries atmosphere obtained from dissotiated, partly burnt ammonia/. An oxide layer can be removed after annealing by etching, e.g. in water solution of $H_2SO_4$ /cold or preheated one to 40-60°C/ at initial density 1,036-1,043 g/cm$^3$.

## 7.2.2. Heat treatment of bronzes

Bronzes are the copper alloys with tin as a main alloy component /the oldest alloys known in history/, aluminium, silicon, beryllium, lead and others /except zinc and nickel/, no less than 2%; there are often other components, too. The melting temperature 940-1084°C.

All bronzes with smaller contents of the main alloy component are mostly one-phase and plastic ones, at higher contents or at the addition of other components, they are mostly two-phase and non-plastic, but, in general, they have the good casting properties.

Cast bronzes - the main alloy components are: tin /to 11%/, lead /to 33%/, aluminium /to 11%/ and silicon /to 4,5%/; additional components are: zinc /to 7%/, manganese /to 2%/, iron /to 5,5%/, nickel /to 5,5%/ and phosphorus /to 1,2%/. These bronzes are casted in sand or metal forms. Die castings /metal forms/ have the higher tensile strength, hardness and elongation than sand ones. A casting shrinkage - 1,5-2,5%.

Bronzes for plastic working. The main alloy components are: tin /to 7%/, silicon /to 3,5%/, nickel /to 6,5%/, manganese /to 5,5%/, aluminium /to 11%/ and beryllium /to 2,6%/; additional components are: phosphorus /to 0,3%/, zinc /to 5%/, lead /to 3,5%/ and iron /to 5,5%/. They are hardened by cold work /in connection with an annealing/ or by heat treatment /precipitation hardening/. The plastic working is executed almost only as cold working /except aluminium bronzes/. The bronzes are applied as pressed, annealed, half-hard, hard, elastic and they are heat treated in precipitation hardening and toughening processes.

Mechanical properties and heat treatment depend on chemical composition.

Tin bronzes have good casting properties /sand casting, die casting, centrifugel castin/ good machinability, high resistance against to acid activity and they are easy for soldering. Every remainded bronze has other advantages: corrosion resistance /aluminium bronze/, high strength /Al/, high-temperature resistance /Ni-Si-Mn/, anti-friction properties /Sn-Pb/.

Tin, tin-zinc, lead and some tinless bronzes are heat treated by the same way like brasses. Silicon-nickel, nickel-manganese-silicon and beryllium bronzes, besides various kinds of annealing /like brasses/, can be consolidated through precipitation hardening /solutioning and ageing/. Aluminium bronzes are hardened and tempered. In table 7.1 are given connections between various heat treatments and different bronze kinds as well as their location in technological process and obtained properties.

For heat treatment of bronzes are used equipment alike to brass treatment. With regard to better heat conductivity of bronzes, their upheating time to fixed temperature is about 10-20% shorter than upheating time of brasses.

Table 7.1

Average applications of heat treatment for some, frequent met bronzes

Marking: w=water, wz=cold water, p=air

| Bronze group kind / Application | Heat treatment /°C/, soaking time /h/ quenching medium: Annealing: homogenizing /is applied after casting/ | Annealing: recrystallization /is applied after plastic working/ | Annealing: stress relieving /is applied before plastic working and after casting/ | Precipitation hardening (obtaining of the best strength and physical properties and hardn.): solution heat treatment | Precipitation hardening: ageing | Toughening (improving or obtaining of the best mechanical properties): hardening: increases hardness and strength properties | Toughening: tempering: improves plastic properties and removes hardening stresses | Notices: |
|---|---|---|---|---|---|---|---|---|
| **Tin /4-25% Sn/** Very good mechanical properties; high corrosion resistance and wear resistance. They are casted and plastic worked. Coins, medals, springs, bells, machine parts, bearing bushes | 700-800 | 550-600/3-5 | 200/to 10 | - | - | - | - | After solidifying - dendrite structure. It can be removed by repeated homogenizing processes and cold plastic working |
| **Tin - Zinc** Resistance against to corrosion, wearing and thrusts. Bearings, machine and ship parts, chemical fittings | 750-800 | 600-650/3-5 | 200 | - | - | - | - | |
| **Lead /20-40% Pb/** Excellent properties against to friction. They are applied to bearing bushes, slide bearings | 600-650/ 2-2,5 | - | - | - | - | - | - | Annealing improves a corrosion resistance and homogenizes mechanical properties |
| **Aluminium /2-12% Al/** Parts resisted against to high temperature, corrosion, wearing /e.g. gears/. They can be casted and plastic worked | 850-900/ a few/wz | 600-700/a few/p,w | 100-200/a few | - | - | 800-900/3/ w | 300-500/ 2 | To contents of 9% Al and mostly for multic-components alloys - can be annealed only for homogenizing of a chemical composition in grain boundary. Over 9,4% Al - can be toughening |
| **Silicon /mostly 3%Si/** Annealed and hard: springs, nets, chemical apparatus, anti-friction elements, welded construction elements. It can be used as castings, too | 700-800 | 550-600/3-5 | 200/to 10 | 750-800/ a few | 400/14 | - | - | Precipitation hardening is profitable only at over 3,5% Si. Addition of Ni improves hardening effect |
| **Beryllium /2-3% [illegible]/** They can be plastic worked. Non-sparking tools and parts, spring elements. Cor- | - | 600/a few | - | 700-800/ /2-3/w | 250-350/ /2-3/p | - | - | Precipitation hardening is applied only at |