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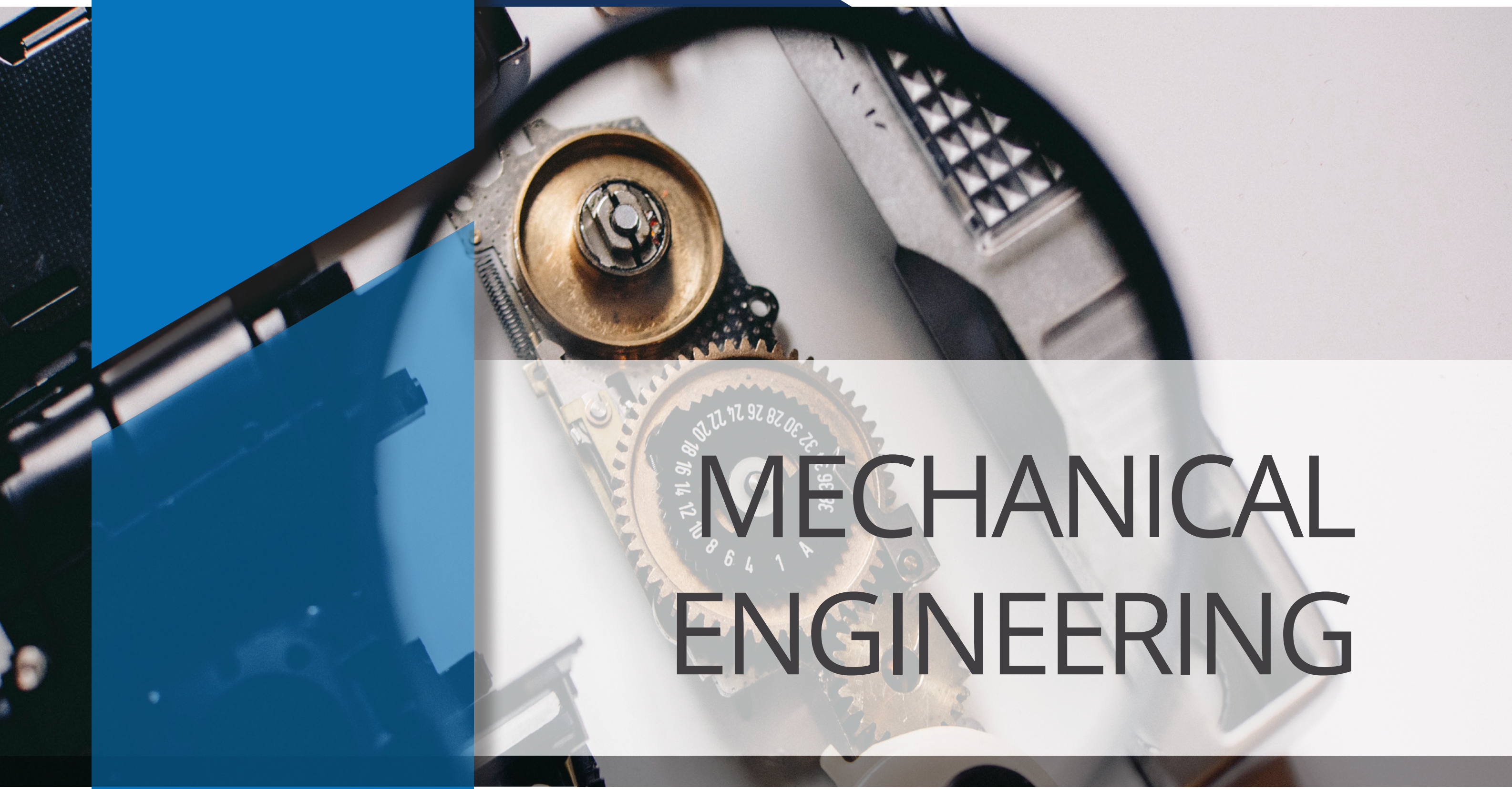

MECHANICAL ENGINEERING

Engineering technologies 3

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA
VŠTE
EUROPEAN UNION

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1. RAPID PROTOTYPING

1.1. Rapid prototyping

History

- 1980´s – first method developed (RP – **STEREOLITHOGRAPHY)**

Application

- Creation of a model – Rapid modeling
- Manufacturing of tools and devices – rapid tooling
- Marketing and piece production – rapid manufacturing

Advantages

- Reduction of production costs
- Quality improvement
- Product and technology development
- Manufacturing of products of a complex shape
- RP enables to verify the function, design and ergonomics of a product in even under development

Materials used

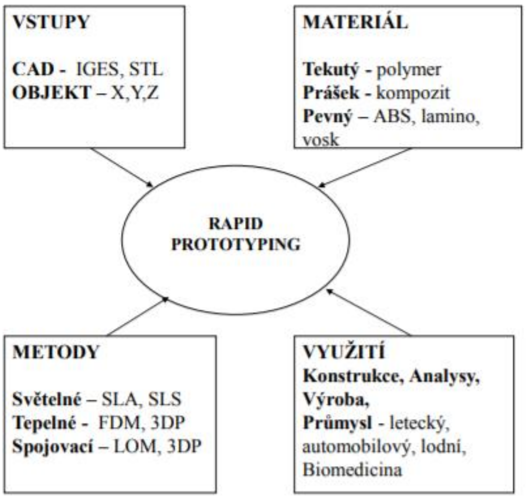
- liquid, powder, polymer, paper

Development of technology

- Materials with better technological properties
- Using compound materials for production (glass, carbon or Kevlar fibers filled plastics)
- Increasing products precision and quality
- Reducing production costs of products
- Reducing the equipment price
- Automation of production
- Material and energy saving

Definition of Rapid Prototyping

- Rapid prototyping includes all technologies that automate production process of 3D and compact objects from original materials
- A set of technologies that enable the production of models and prototypes of complex parts directly based on 3D CAD data. The product can be manufactured using various materials depending on the equipment.



Legend: vstupy – inputs, object – object, materiál – material, tekutý fluid, polymer – polymer, prášek – powder, compozit – compound, pevný – solid, lamino – lamino, vosk – wax, metody – methods, světelné – light, tepelné – heat, spojovací – connecting, využití – use, konstrukce – design, analýzy – analyses, výroba – production, průmysl – industry, letecký – air, automobilový – automotive, lodní – ship, biomedicína - biomedicine

1.2. Methods, Characteristics, Types of Rapid Prototyping

By production process, RP is divided into:

- Layers added using laser
  - Point curing
  - Layer curing
- Layers added without using laser
  - Point curing
  - Layer curing
- Examples:
  - **SLA** - StereoLithography Aparatus, liquid acrylate, point, laser
  - **SGC** - Solid Ground Curing, liquid acrylate, UV lamp

- **SLS** - Selective Laser Sintering, composite of 2 types of powder, sintered
- **FDM** - Fuse Deposition Modeling, ABS plastics added by extrusion
- **LOM** - Laminated Object Modeling, paper laminating, laser
- **3DP** - Three Dimensional Printing – layer printing, powder gluing

Function and importance of prototyping

- Concept – sharing all ideas
- Suitability – testing the design dimensions
- Shape – assessing the aesthetic and ergonomics of components
- Functionality – testing in working environment
- Offer – valuation of product in terms of offer
- Marketing – communication with customer on design

Types of prototypes

- Construction prototypes
  - Checking geometry and assembly
- Prototypes of design
  - Improving the communication between the partners – checking the design
- Functional prototypes
  - Testing and analysis of airflow types – models for wind tunnels
- Technical prototypes
  - Functionality, features

1.3. Stereolithography

- 1st RP technology
- The most precise production of complex products and models
- Addition-method of production (combining, adding materials)

Principle of the method

- 3D PC model is converted into a required format
- Entering data into the RP software
- Creating a virtual model and its cutting and setting the thickness of the layers
- Proposal of support

Application

- Products with inner cavities and complex details
- Models for foundry – manufacturing of molds and tools
- Replacement of wax models
- Models for medical industry and aerospace

- Checking the design of a designed object
- Disadvantages
- Slow polymer curing
- Low heat resistance
- Materials used
- Photopolymers – react to light by curing
- Acrylic or epoxide resins
- Parts of stereo lithographic equipment
- Work chamber
- Laser equipment
- Control system

Production process

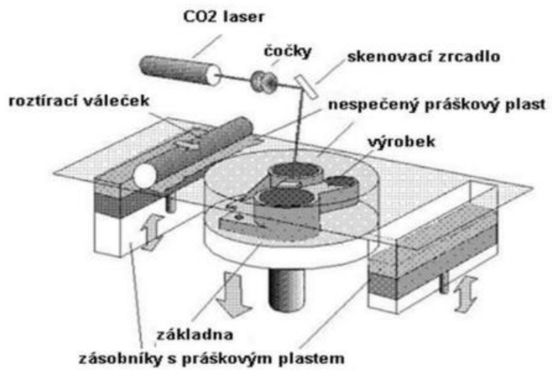
- Creation of a 3D PC model
    - Creating a model in a CAD/CAM system
    - Scanning from CAT tomography apparatus
    - 3D measuring apparatus – dimensions
    - Creating a working STL program
    - Moving the file into the software of the given program
    - The program prepares the model for the production process – creation of a working program with an STL ending
    - The model is cut into identical layers
    - Stereo lithographic process
    - Laser generates a ray
    - Drawing of layers surfaces – curing of material
    - The movement of laser is controlled by the program
    - Next layer is applied after curing of the previous one
- Product curing in UV furnace
    - Product is dried and cured
- Completion of product
    - Surface treatment
    - Possible to apply fillers, dye layer
    - Surface polishing
    - Surface roughness – 1-2 μm
    - Accuracy – hundredths of mm

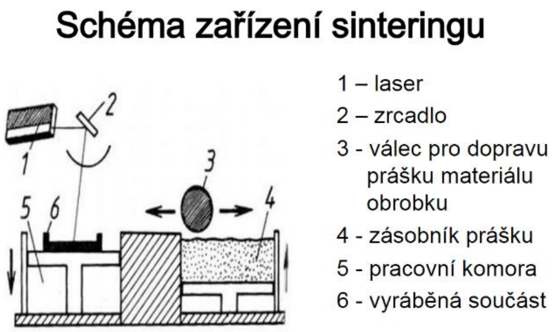
- Support
    - The most appropriate position of the model on the platform ensured by stands
    - The stands must be placed so that they could be easily removed after completion of the process
    - After curing process the model is taken out and cured in an UV chamber

- Facing cutter
    - After curing of each individual layer, the cutter aligns the resin level so that the same thickness of another layer is achieved

1.4. Selective Laser Sintering SLS

Scheme:





Legend: roztírací váleček – squeegee, čočky – lens, skenovací zrcadlo – scanning mirror, nespečený plastový prášek – non-sintered powder plastics, výrobek – product, základna – platform, zásobníky s práškovým plastem – feeders with powder plastics, schema zařízení sintering – sintering scheme, zrcadlo – mirror, válec pro dopravu prášku materiálu obrobku – cylinder for transporting the powder of workpiece material, zásobník prášku – powder feeder, pracovní komora – work chamber, vyráběná součást – component being manufactured

- Models are very strong
- Use of powder sintering by means of CO2 laser
- The powder is applied in layers on the carrier plate in the internal atmosphere (nitrogen or argon)

Principle

- Using laser, the material is sintered or it melts and solidify
- Surrounding material creates a natural support
- Manufactured by layers
- The carrier plate is moved down after creation of one layer

Materials used

- Powder that melts under heat
- Thermoplastics
- Special low-melting alloys
- Steel powder

Production equipment

- Powder feeder
    - By means of a lifting piston and cylinder, the powder is transported to the place of curing
- Optical systems
    - Laser cures a chosen surface, than the platform is moved down by the thickness of the layer and the process is repeated
    - Platform – the product is placed there

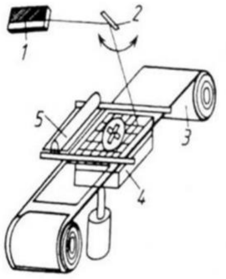
Model = product

- Model is placed in uncured powder
- After curing, the powder must cool down
- Due to ensure the protection of the surface quality, the chamber is filled with inert gas

1.5. Laminated object manufacturing LOM

- The principle consists in laminating the individual layers on each other
- Materials used include paper, plastics, wood, tin
- The method is based on layering a sticky material
- Components are created of special plastic foils or many paper layers impregnated with a strengthening material
- The individual layers are cut into a proper shape by a CO2 laser
- Product characteristics
    - Similar to wood
    - Hand-held laser processing for smooth surface
    - Suitable for larger components
    - Disadvantage

LOM scheme



1 – laser
2 – zrcadlo
3 – role fólie
4 – nosná deska
5 – vyhřívané přítlačné válce

Legend: zrcadlo – mirror, role fólie – foil roll, nosná deska – carrier plate, vyhřívané přítlačné válce – heated pressure rollers

- LOM layering of a sticky material
    - Layering of foil and bonding material
    - The material is unwound to the carrier plate
    - The desired shape is created by the laser
    - The layers are connected under pressure of heated roller
    - The remaining foil is wound back to the roller
    - The carrier plate moves down and the process is repeated

1.6. 3D printing

3D printing definition

- 3D It is connected with the technologies related to the processes of applying thermoplastic / thermoset polymers and wax to create 3D solid objects

Basically two technologies are used

- A single nozzle production
- A multiple nozzle production

Types of material used

- Wax
- Heat curable UV resin
- Thermoplastic polymers containing paraffin, hydrocarbon wax and dyes
- Thermoplastic polymers containing hydrocarbons, amides and esters for higher durability
- Cannot be recycled – filtered product

“3D printing includes the technologies used for layer approach of creating products or components by applying powder layers and subsequent binding into a shape of a solid object

It´s a process similar to laser sintering x binder blasting binds powder

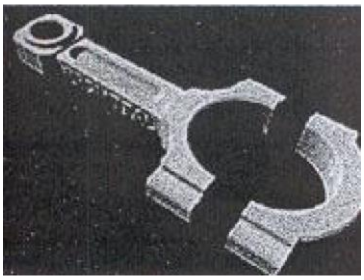
3D Printing uses inkjet heads for application

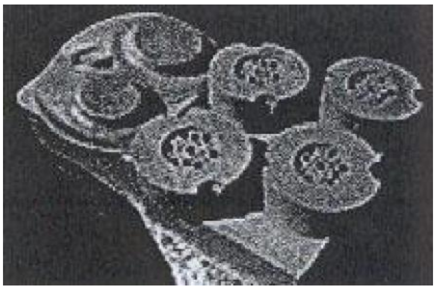
Process of components producing

- Importing an STL file to software interface
- Filling the vat with powder
- Spreading of the powder from the vat
- Pressing the binding material on the powder and shaping the first cut
- The remaining powder creates a support for the overhanging layers
- Lowering the carrier plate and applying a new layer on the surface
- The whole process is repeated

3D Printing – Metals

- Application and binding of metal powders
- The process itself is the same, what is different is post processing, during which the components are sintered in the furnace in order to remove the binding material and to connect the metal molecules





2. STEEL PRODUCTION

Steel production is a metallurgical process of producing steel from pig iron by removing excess carbon and other unwanted elements such as phosphorus and sulphur and adding necessary elements, such as manganese, aluminum, silicon and others.
Steel se produced in specialized metallurgical plant called steelworks.

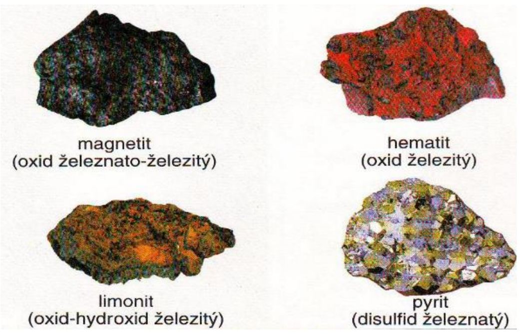
2.1. Raw materials

Iron ore (consists mainly of oxygen compounds of iron):

- Fe_2O_3 – red iron ore (hematite)
- Fe_3O_4 – magnetic iron ore (magnetite)
- $Fe_2O_3 . nH_2O$ – limonite
- FeS_2 – pyrite

Coke (black coal) – it is almost pure carbon, it is used to reduce iron oxides

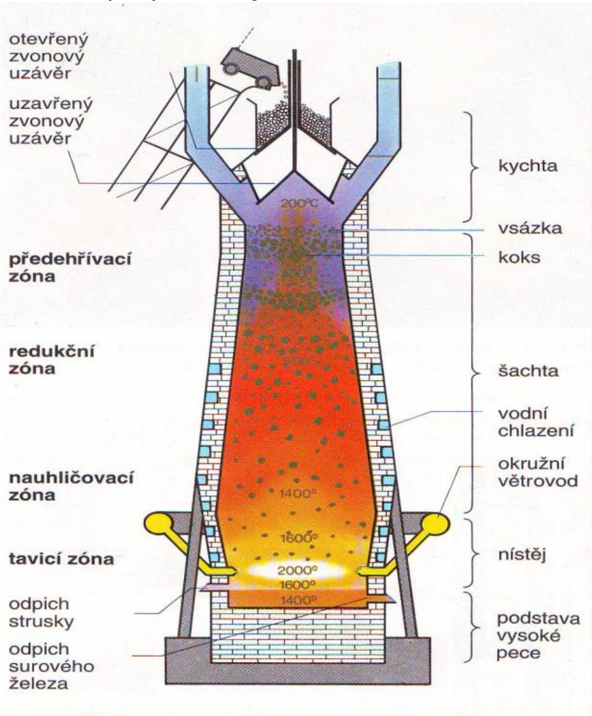
Limestone CaCO3 – helps form so-called slag from rock that occurs with iron ore. Additional iron ore rocks are called **gangue** which is mostly removed before the blast furnace.



Legend: magnetit (oxid železnato-železitý) – magnetite (iron oxide-ferric oxide) , hematit (oxid železitý) – hematite (ferric oxide), limonit (oxid-hydroxid železitý) – limonite (ferric oxide-hydroxide), pyrit (disulfide železnatý) – pyrite (ferrous disulfide)

2.2. Blast furnace

Up to 40m high, 15m wide shaft furnace of steel, with fire-resistant bricks inside. It works non-stop up to 10 years.



Legend: Otevřený zvonový uzávěr – open bell-shape closure, uzavřený zvonový uzávěr – closed bell-shape closure, předehřívací zóna –pre-heating zone , redukční zóna – reduction zone, nauhličovací zóna – carburization zone, tavicí zóna – melting zone, odpich strusky – slag tapping, odpich surového železa – pig iron tapping, kychta – blast furnace , vsázka - charge, koks - coke, šachta - shaft, vodní chlazení – water cooling, okružní větrovod – air duct, nístěj - hearth, podstava vysoké pece – blast furnace base

2.3. Reactions in blast furnace

Drawing raw material:

$Fe_2O_3 . nH_2O \rightarrow Fe_2O_3 + nH_2O$

Iron reduction:

$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$
$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Burning coke:

$C + O_2 \rightarrow CO_2$
$CO_2 + C \rightarrow 2CO$

2.4. Pig iron and slag

Slag protects the surface of melted iron against oxidation.

Pig iron and slag tapping from the bottom of the blast furnace is carried out each two hours.

Pig iron contains the following additives: about 4% of C, Mn, Si, P, S. It is very hard but brittle. It is cast into molds (cast iron) and it is used for manufacturing heaters, machine parts, pipelines etc., but mostly it is further processed into **steel.**

- Pig iron is a **primary product** of melting iron ore with coke, limestone and other additives in blast furnace.
- **High carbon content** – more than 2.14 %, typically even more than 3.5 %.
- Due to high carbon content, pig iron is hard and brittle. It melts when heated to **1150°C - 1250°C** without heating over a ductile state.
- Therefore, hot or cold forming is not possible.
- It is also called **non-malleable iron** and its direct use is very limited.
- However, it is the starting material for producing other types of technical iron.

Classification of pig iron

Grey pig iron – the more iron is removed in the form of graphite, the darker the color is, it is softer and better malleable. It is well cast, therefore it is used for foundry purposes.

- Steel
- Foundry: grey cast
    - Cured cast
    - Modified cast
    - Malleable cast
    - Alloyed cast
    - Non-alloyed cast

White pig iron – removed cementite caused its hardness; it is therefore further processed in steelworks into steel.

- steel
- foundry:
    - white cast
    - non-alloyed tempered cast

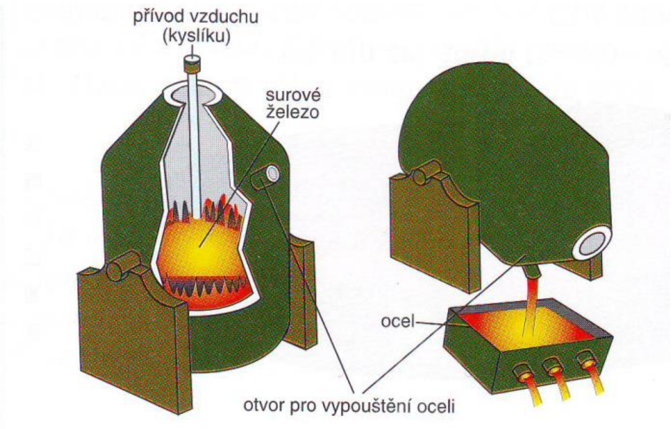
special pig iron – ferro-alloy – besides carbon, it contains other elements, such as manganese, silicon, chromium, vanadium, molybdenum. The elements are used as additives in production of alloy-alloyed steel and cast.

2.5. Steel production

For improving the quality of pig iron, the process of so-called refinement process is used in steelworks (it refers to removing most of carbon and other elements impurities).

Converter method: removing unwanted impurities consist in their oxidation by air oxygen in a converter (special tilting furnace).
In hearth furnaces: oxidation of unwanted impurities by oxygen from ferrous scrap or treated iron ore.

Converter for steel production



Legend: přívod vzduchu (kyslíku) – air (oxygen) intake, surové železo – pig iron, ocel – steel, otvor pro vypouštění oceli – steel outlet

Steel

- Slowly cooled (tempered) steel is less hard and bendable.
- Quenched (fast cooled) steel is hard but brittle.
- Max. 1.7% of carbon.
- The more carbon the steel contains, the harder it is.
- Steel properties are improved by adding small quantities of some other metals (chromium, nickel, vanadium, tungsten, etc.).

Kinds of steel

Proportion of carbon	Carbon steel		Special steel	
	Properties	Use	Additives	Use
About 0.25 %	Malleable and ductile	Sheets for cans and car bodies, wires, nails	Chromium 25 %, nickel 20 %, silicon 0.5 %	Very strong: armored plates
0.25 – 0.7 %	Hard and rigid	Rails, axes, structural steel	Chromium 18 %, nickel 8 %	Stainless steel
0.7 – 1.7 %	Very hard	Steel springs, blades, tools	Chromium 6 %, Tungsten, vanadium, cobalt	Heat resistant: steel machining tools

3.STEEL MARKING

Steel marking is given by standards. The individual bars, tubes or sheets are **color marked** in production.

Besides color marking, also **numeric marking** is used. The numeric mark of steel consists of a **basic numeric mark** (5 or 6 digits). This mark can be complemented by **additional numeric mark** – a two-digit mark, separated by a dot from the basic mark.

Forming steel mark: 1x xxx or 1x xxx.xx
Foundry steel mark: 42 xxxx or 42 xxxx.xx

3.1. Forming steel

Steel class 10 – structural steel, carbon steel of common quality

Steel class 11 – structural steel, carbon steel of common quality

Steel class 12 – structural steel, special carbon steel

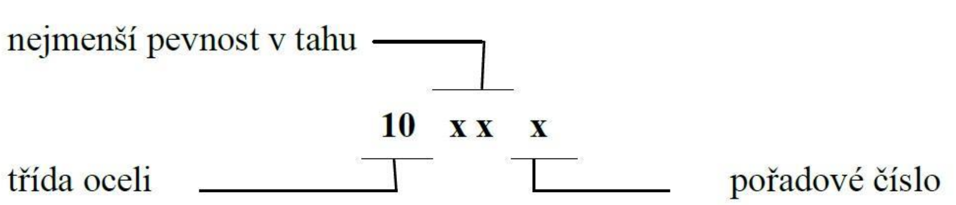
Steel class 13 – 16 – structural steel, special steel, alloy steel

Steel class 13 – 15 low alloy steel
Steel class 16 low and medium alloy steel

Steel class 17 – structural steel, special high alloy steel

Steel class 19 – tool steel

Oceli třídy 10 – oceli konstrukční, uhlíkové obvyklých jakostí



Legend: oceli třídy 10 – steel class 10, oceli konstrukční, uhlíkové obvyklých jakostí – structural steel, carbon steel of common quality, nejmenší pevnost v tahu – low tensile strength, třída oceli – steel class, pořadové číslo - order number

Legend: oceli třídy 11 – steel class 11, oceli konstrukční, uhlíkové obvyklých jakostí – structural steel, carbon steel of common quality, 1 značí ocel vhodnou k obrábění - 1 is steel suitable for machining, střední obsah C v desetinách % zaokrouhlený na nejbližší celé číslo – medium C content in tenth %, rounded to the nearest whole number, třída oceli – steel class, střední pevnost v tahu – medium tensile strenth

Význam jednotlivých číslic číselné značky u ocelí třídy 12 – 16 se posuzuje stejně: individual digits for steel class 12 – 16 are identified in the same way. Součet obsahu přísad. prvků kromě uhlíku v % - sum of content of additives besides carbon in %, střední obsah C v desetinách % - medium C content in tenths %. Pokud je obsah C větší než 0.9 %, čtvrtá číslice je 0 – if the C content is higher than 0.9 %, the fourth digit is 0.

Steel class 17

By the alloy degree, steel class 17 is divided into medium alloy and super alloy steel.

These steels are alloyed by several times higher number of alloy elements (as in the cases of steel classes 13 – 16).

There are many kinds of steel class 17. These are steels that can be **corrosion-resistant, refractory, heat resisting and special** steels. They are alloyed mostly by chromium, manganese, silicon, nickel, tungsten, titanium, vanadium and other noble elements.

Numeric mark	Significance of the third digit
17 0 xx	steels alloyed by chromium, chrome steel
17 1 xx	chrome steel + other elements Mo, Al
17 2 xx	chrome-nickel steel
17 3 xx	Chrome-nickel steel + other elements Ti, Nb, Mo, V, W
17 4 xx	manganese-chromium or manganese-chromium-nickel steel
17 5 xx	Nickel steel
17 6 xx	Manganese steel
17 7 xx	Manganese-nickel steel
17 8-9 xx	Special combination of elements
The fourth digit expresses the amount of additives. The fifth digit expresses increasing C content	

Steel class 19 – tool steel

<table>
<tr><td>Numeric mark</td><td colspan="2">Third digit in the mark</td></tr>
<tr><td>19 0 xx
19 1 xx
19 2 xx</td><td colspan="2">Tool carbon steel</td></tr>
<tr><td>19 3 xx</td><td>Manganese steel</td><td rowspan="6">Alloy tool steel</td></tr>
<tr><td>19 4 xx</td><td>Chromium steel</td></tr>
<tr><td>19 5 xx</td><td>Chromium-molybdenum steel</td></tr>
<tr><td>19 6 xx</td><td>Nickel steel</td></tr>
<tr><td>19 7 xx</td><td>Tungsten steel</td></tr>
<tr><td>19 8 xx</td><td>High-speed steel</td></tr>
<tr><td colspan="3">The fourth digit indicates the combination of additives. Fifth digit indicates the method of steel production</td></tr>
</table>

Casting steel

Numeric mark	Significance of third and fourth digit in the mark
42 26 xx	Casting steel - carbon
42 27 xx	Casting steel – low and medium alloyed, cast into sand molds
42 28 xx	Casting steel, low and medium alloyed, cast in other way than in sand molds, steel for permanent magnets
42 29 xx	High-alloy casting steel
The first two digits – 42 indicates the steel industry standard Second two digits indicates the group of steel Third two digits indicates the following: Carbon steel – 00-29 – steel is cast in other way than in sand molds 30 – 99: value of tensile strength in MPa Alloy steel: groups of alloying elements	

Numeric mark	First additional digit
1x xxx.0 x	Not heat-treated
1x xxx. 1 x	Normalized and annealed
1x xxx. 2 x	Normalized with a specified type of annealing
1x xxx. 3 x	Soft annealed
1x xxx. 4 x	Hardened or hardened and tempered
1x xxx. 5 x	Normalized and tempered
1x xxx. 6 x	Refined to lower strength typical of specific steel
1x xxx. 7 x	Refined to medium strength typical of specific steel
1x xxx. 8 x	Refined to higher strength typical of specific steel
1x xxx. 9 x	Heat-treatment than cannot be written using digits 0 - 8
Second additional digit indicates the degree of forming materials	

3.2. Grey cast

Grey cast is a mixture of a basic steel material in which graphite flakes are dispersed in various directions.

The shape depends on the chemical composition and the cooling rate on cast.

Cast properties are influenced by the size and distribution of the chips.

There can be several shapes of graphite: crisp, spider´s grip, regularly grainy or imperfectly grainy.

The distribution of graphite can be uniform, in rosette, controlled, uncontrolled, mixed.

3.3. Malleable cast

Malleable cast is produced of grey cast by so-called **inoculation**. This refers to adding magnesium directly into casting ladle with melted cast.
Due to magnesium added, graphite flakes turn into **balls** – so-called graphite crystallization occurs.

Such a structure is called **perlitic.** With this structure, the properties of the new cast change significantly.

Malleable cast structure: ferritic, perlitic, ferritic–perlitic, perlitic–ferritic

3.4. Tempered cast

It is produced by means of **tempering** – **long-term annealing** of white cast iron, during which **cementite** is decomposed into iron and graphite.

Tempered graphite is eliminated in the shape of irregular grains. Its presence influences the properties of tempered cast iron similar to ball graphite in malleable cast iron.

In some cases, cast iron has greater shrinkage rate and worse excursiveness; therefore it is not suitable for manufacturing of large castings (up to 100 kg).

4. NON-FERROUS METALS AND THEIR ALLOYS

4.1. Classification and marking of non-ferrous metals

Besides ferrous metals, **non-ferrous metals** are irreplaceable or poorly replaceable in technical practice.

Most of these pure metals do not have the properties required in the construction of machine parts.

They are heat and electric conductors, oxidation (corrosion)-resistant, but they are mostly soft and have low tensile strength.

Classification of non-ferrous metals:

- **Heavy non-ferrous metals** and their alloys (density over 5 kg/dm3),
- **Light non-ferrous metals** and their alloys (density to 5kg/dm3).

Numeric marking of non-ferrous metals and alloys

- **<u>42</u>** x x x x **– 42** indicates the **metallurgy** class
- 42 **<u>3</u>** x x x **– 3** indicates **heavy metals and their alloys**
- 42 **<u>4</u>** x x x **– 4** indicates **light metals and their alloys**
- 42 x **<u>x</u>** x x **–** fourth digit **0, 2, 4, 6, 8** –**wrought products**
- 42 x **<u>x</u>** x x **–** fourth digit **1, 3, 5, 7, 9** –**foundry products**
- 42 x **<u>x x</u>** x **– heavy or light metals**
- 42 x x x **<u>x</u> –** sixth digit is order
- 42 x x x x. **<u>x</u>** x **–** first additional – heat treatment
- 42 x x x x. x **<u>x</u> –**cast method in the case of casting

4.2. Heavy non-ferrous metals and their alloys

Heavy metals include:

- lead,
- nickel,
- antimony,
- tin,
- zinc,

- cadmium,

The main representative of the heavy non-ferrous metals and also the most widely used one is **copper and its alloys.**

4.3. Copper and copper alloys

- Melt temperature 1083 °C.
- Density 8.96kg/dm3.

+ It has six times higher heat and electricity conductivity than steel.
+ Tough.
+ Easy to weld and solder (both brazing and soldering is possible).
+ Corrosion-resistant.

- Soft.
- More difficult machining due to copper softness.

Classification of copper:

- **Copper for forming purposes –** directly processed
- **Copper for foundry purposes –** used mainly for alloys.

Copper alloys:

- Copper alloys for forming purposes,
- Copper alloys for foundry purposes.

4.4. Bronze

Bronze is alloy of copper and various non-ferrous metals **except for zinc.**

Bronze is classified as **bronze for forming purposes and bronze for foundry purposes.**

There are several types of bronze based on the major alloying element:

- Tin bronze – up to 20% Sn
- Red bronze – up to 10% Sn + Pb
- Leaded bronze – up to 33% Pb + Sn
- Nickel bronze
- Aluminium bronze

4.5. Brass

Brass is copper alloy with zinc and other metals. If brass contains more than 80 % of Cu, it is called **tombac.**

Best alloyed: 60 % Cu.

The highest tensile strength: 70 % Cu.

Marking: Ms 70 – the number expresses the Cu content in %. (e.g. Ms 85, Ms 90 – **tombac).**

Architectural brass, e.g. Ms 63 Pb is brass with added lead.

Foundry brass is marked **Ms L 60 –** where the number indicates % of Cu content.

4.6. Lead and its alloys

- Density 11.34 kg/dm3,
- Melt temperature is 327 °C.

+ easy to alloy
+ easy to machine (except for filing)
+ corrosion-resistant, resistant to chemicals
- Soft

4.7. Nickel and its alloys

- Density 8.9 kg/dm3
- Melt temperature 1453 °C,
- Its electricity conductivity is 4 times lower than copper x better than steel.
- Easy to alloy, solder and weld
- Good corrosion-resistance.
- Ferromagnetic up to the temperature of 356 °C.
- Heat resisting to 800 °C (+ Cr up to 1300 °C)
- Used mostly as an alloying element in manufacturing various kinds of steel, especially steel class 17.
- For manufacturing of alkaline battery, as a positive plate,
- Used in food industry, chemicals industry, production of surgical instruments
- Used for metal protection against corrosion (nickel plating)

4.8. Zinc and its alloys

- Density 7.13 kg/dm3,
- Melt temperature 419 °C,
- Electricity conductivity is slightly higher than that of nickel
- Easy to alloy and solder.
- Mechanical properties change with temperature changes
    - brittle at normal temperature,
    - malleable at the temperature of 100 - 150 °C
    - at 200 °C it loses its malleability and it´s brittle.
- Various corrosion-resistance.

Zinc used to be produced using the same technology as in the case of copper production. Currently, zinc is produced electrolytically (99.9%).

4.9. Tin and its alloys

- Density 7.3 kg/dm3,
- Melt temperature is 232 °C,
- Relatively low electrical conductivity
- Corrosion-resistant.
- There are 2 modifications:
- β **modification –** the prevailing one. This modification is called **white tin**
- **α modification –** also called grey tin (grey powder). Modification starts at its cooling to the temperature of 13 °C
- β-α transformation **tin pest**.

4.10. Cobalt

- Density 8.9 kg/dm3**,**
- Melt temperature is 1495 °C.
- Used as metal admixture in steel,
- Increases the refractoriness and heat resistance of steel up to the temperatures of 800 - 850 °C.
- Production of air jet and rocket engines, alloying element for high speed steel, production of **cemented carbide**

4.11. Tungsten

- Density 19.3 kg/dm3 ,
- Melt temperature is very high: 3380 °C.
- Relatively good electricity conductivity (about twice as high as steel).
- Tensile strength 1100MPa.
- High hardness - 200HB.
- Production of components working at high temperatures, alloying element for refractory and heat-resistant steel, component of tool steel, production of cemented carbide, products of powder metallurgy.

4.12. Molybdenum

- Density 10.2 kg/dm3,
- Melt temperature 2630 °C.
- Its electricity conductivity is lower than that of tungsten.
- Strength 700MPa
- Hardness 150HB
- Creates refractory and heat-resistant alloys.
- Alloying element for production of steel components working at high temperatures, tool steel – for production of high-quality cutting tools
- In powder metallurgy, for production of thermally and mechanically stressed products.

4.13. Chromium

- Density 7.14 kg/dm3,
- Melt temperature is 1910 °C,
- Corrosion-resistant, resistant to chemicals.
- It is both heat-resisting and refractory
- Brittle

Alloying element in manufacturing structural, corrosion-resistant, and tool steel.
Steel protection against corrosion.
Decorative surfaces in automotive.

4.14. Light non-ferrous metals and their alloys

- aluminium – **Al** and its alloys
- titanium – **Ti** and its alloys
- manganese – **Mg** and its alloys.

They are used in production of steel as well as of non-ferrous alloys, significantly affecting their mechanical and other properties.

4.15. Aluminium and its alloys

- Density 2.7kg/dm3,
- Good heat and electricity conductivity (60% conductivity of copper)
- Easy to form and weld (+Si).
- Corrosion-resistant, resistant to chemicals.
- Forming at the temperatures of 450 - 500 °C.

Changes of mechanical properties =Al+Cu;Mg;Si;Mn;Zn...

Production of Al

- Aluminium content in ores - over 8 %.
- Produced almost exclusively from so-called **bauxite.**
- Chemically - alumina Al_2O_3.
- Electrolysis – Al of 99.3% - 99.8% purity,
- **Zone refining** - Al of 99.999% purity.
- Cast in so-called pigs, ingots, blocks, or slabs

Classification of Al

- **By number of melting processes:**
  - First melting aluminium – is obtained directly from raw material.
  - Second melting aluminium – re-melting of aluminium waste.
- **By its use:**
  - Aluminium and its alloys used for forming purposes
  - Aluminium and its alloys used for foundry or metallurgy purposes

Aluminium alloys used for forming purposes

The best known alloy: Al – Cu4 – Mg -– **Dural.**

- Strength at cured state - 400 MPa.
- Low corrosion-resistance; therefore it is coated by aluminum

Al – Cu4 – Mg1- **superdural**

- Strength over 500MPa.

Both alloys are used for manufacturing bar profiles and sheets; used in air industry.

Al + Cu + Ni

- Stable mechanical properties even at high temperatures.
- Strength 400MPa
- Used for manufacturing combustion engines components, such as pistons or pis-ton-rods.

Al + Mg with Mg content from 2 to 8 % - **Hydronalium**

- Corrosion-resistant,
- Strength over 400MPa
- Used in air industry

Al + Mn

- Corrosion-resistant
- Used for manufacturing of containers in food or chemical industries.

Alloys Al + Sn

- Production of sliding bearings. Al – Sn20,
- Cladded into steel sliding bearings in the form of thin bands, as **lining**.

Foundry aluminium alloys

- Temperature of the melted metal 700 – 750 °C.
- They are cast into sand and metal molds (**ingot molds**); also die-casting.
- Alloying element for these alloys is Si – silicon

Silumin Al Si13 – with a small quantity of magnesium,

- Melt temperature 577 °C,
- Inoculated by Na before casting.
- For production of aircraft or combustion engines.

4.16. Magnesium and its alloys

- Its density 1.74kg/ dm^3.
- Low weather resistance.
- Extremely low resistance to sea water.
- Mg has a high affinity to oxygen; therefore it is used as deoxidizer, for welding in controlled atmosphere CO2.
- Protection against corrosion by chromating = pickling in the solution of potassium or sodium dichromate – coating of chromium compounds.
- Mg alloys welding is difficult.
- Soldering not possible.
- Connecting is done mostly by riveting.
- Magnesium can be obtained from sea water 0.14%.
- Other raw materials: **magnesite and dolomite**.
- It is produced by **electrolysis** at temperatures 700 - 750 °C, or by **refining** or **silicothermic reduction** of dolomite by silicon at the temperature of 1200 °C.

Magnesium alloys

Magnesium alloys are always with manganese, which improves their corrosion resistance and its combustibility.

Electron Mg+3-10%Al+Zn+Mn.

- Density 1.8kg / dm^3.

Good fire protection is necessary when machining magnesium, as there is a high risk of combustion, especially when there is dust from its sanding.
Mg alloys are easy to machine, the highest machining speed is chosen

4.17. Titanium – Ti

- Density 4,5kg/dm3
- Mechanical properties similar to steel.
- Non-magnetic
- High corrosion-resistance.
- Resistant to acids and lye.

- Easy to weld using arc welding and resistance welding.
- Machining is not very easy.
- Treated by forging, rolling into forgings, rolled steel and sheets.
- Good mechanical properties of titanium and its alloys.
- Widely used in air industry, health care (mostly bone substitute)
- One of the disadvantages is its high price. Titanium is a very important alloying element in steel production. The strength of titanium alloys is higher than the strength of pure titanium.

Titanium alloys

α alloys always contain aluminium (up to 8 %). Another alloying element is Sn. They are very easy to weld. By forging, e.g. steam turbines blades are made of them.

Β alloys contain aluminium and other elements, such as **Cr, V, W, Mo**, etc. After curing, the strength of these alloys is up to 1150MPa. They are used for producing engine components, in air and pharmaceutical industry.

4.18. Special alloys of non-ferrous metals

These alloys are used for production of plain (or sliding) bearings (their sliding part) – for production of linings, pouring of sliding bearings ladles and for production of solders.

There are two types of alloys used for production of sliding bearings – **refractory and easy to melt alloys.**

Refractory alloys include tin bronze, read bronze, lead bronze and many others. They are used for production of sliding bearings and other purposes.
Alloys used only for production of sliding bearings are called compositions. Compositions are alloys of non-ferrous metals, where the basic component is either tin or lead. Those are alloys with a very good sliding friction coefficient.

Tin compositions – the basic component is tin (85%) and other metals, such as antimony Sb, up to 10%, and Cu.

Lead compositions – lead as the basic component (75%) and antimony up to15 % and tin to 10 %

Solder is a non-ferrous metal alloy used as additive material used for material soldering.
According to the melt temperature, soldering and solders are classified into:

- Solder with melting temperature **to 500 °**C - **soft solder.**
- Solder with melting temperature **over 500 °C (approx. to 950 °C) - hard solder.**

Soft solder is tin - lead alloy, tin – zinc or also copper alloy, lead – copper – silver alloy, etc.

- Sn40Pb with melting temperature 185-225 °C
- Sn70Zn with melting temperature 200-320 °C.

Hard solder

- **brass solder** – used for soldering steel, copper, **silver solder –** used for soldering copper, bronze and connections in electrical engineering.
- Ag45CuZn with melting temperature 680-740 °C
- Ag28CuZnMnNi with melting temperature 680-860 °C.

5.POWDER METALLURGY

5.1. History

- Making tools and guns e.g. of some African tribes.
- Processing consisted in grinding ore and removing gangue.
- It turned into sponge iron after mixing it with wood charcoal in a special furnace.
- After its re-grinding and refining, the powder sintered in a closed clay pot.
- 19^{th} century in Russia – coining money from platinum (sponge platinum used)

5.2. Reasons for powder metallurgy

- Powder metallurgy enables to make products with special properties (e.g. heat resistant, abrasion resistant, etc.).

- Products with high porosity and products representing transition to composites which cannot be produced using other technologies.

- Powder metallurgy includes both powders producing and their densification (usually by means of pressing and sintering) into construction materials or parts.

5.3. Powders

- **Powders** are characterized by physical (distribution and size of particles, shape and morphology of surface, hardness, etc.) and technological properties (compressibility, liquidity, volume, etc.).

- There can be different powder shapes depending on the production method: ball, flake, irregular, rounded grains, etc.).

- Powders can be produced using physical, physical-chemical, chemical, or electrochemical methods.

- From economic point of view, the most important factor is powder price.

- Suitably modified powders are generally compressed into a required shape; the obtained shape is then processed by sintering so that the necessary physical and mechanical properties are achieved.

- The biggest advantage of powder technology is the use of metal with lower energy consumption, labor and costs, clean environment. Another advantage is the isotropy of mechanical properties.

Production process of powder metallurgy

Production process consists of several stages:

- Powder production
- Powder modification
- pressing
- sintering of powder pressings
- finishing products

5.4. Using powder metallurgy technology

This technology is used when

- it is not possible to process the given materials using a different technology, e.g. in joining components that do not merge

- this technology is more economic than the others, e.g. in processing materials with a high melting point or in series production of small components

- this technology shows better results than the other technologies, e.g. when there are high demands for materials purity, exact chemical composition or the requirement for special structure (porosity).

Powder metallurgy disadvantages

- lower density and the related strength and toughness of the materials produced
- high price of machines.

Densification of Metal Powders

- The size of the contact surface of powder metal particles depends on the degree and the quality of bond between the individual particles – on the degree of consolidation.

- For a fully consolidated body, all powder particles are in full contact all over its surface (as in the case of solid bodies); however, in loose state, the particles touch each other only in a small part of the overall surface of all particles.

- The values of physical and mechanical properties increase depending on increasing the contact surface of the particles.

- The degree of powder body consolidation is usually increased by compressive forces acting or sintering, in most cases by both methods

Pressing

- The powder metals body has a volume of both solid particles and gaps (pores).

- The volume of pores depends on the method of pressing and the magnitude of pressing pressure. In compressing the powder in the tool cavity, both external (between the powder material and the wall of the pressing mold cavity) and internal friction (friction between particles) are acting.

- Friction, which can be reduced by using lubricants, results in uneven distribution of the density in the pressing.

- By the direction of the pressure, pressing is divided into unilateral, bilateral and isostatic.

- In the case of unilateral pressing, the highest density is in the area below the punch, in the case of bilateral pressing, the lowest density is in the centre of the pressing.

- In the case of isostatic pressing, the external friction is eliminated and the product shows even density.

- Sintering.

- Pressing and sintering can be repeated several times in order to reduce the porosity.

- Pressing pressure ranges between 50 - 1800 MPa, its porosity is 50 - 8 %.

- Mechanical or hydraulic presses are used for pressing

Rolling

- Rolling is used to produce semi-finished products in the form of belts, bars, sheets, etc. The powder is smoothly supplied from the feeder into the gap between the cylinders, where it is carried by friction forces and compressed by the pressure of cylinders. The principle is shown in the figure. Relatively strong and flexible belt is lead to sintering furnace. Rolling and sintering can be repeated several times according to the required density. By a suitable hopper construction, multi-layer semi-finished products can be manufactured.

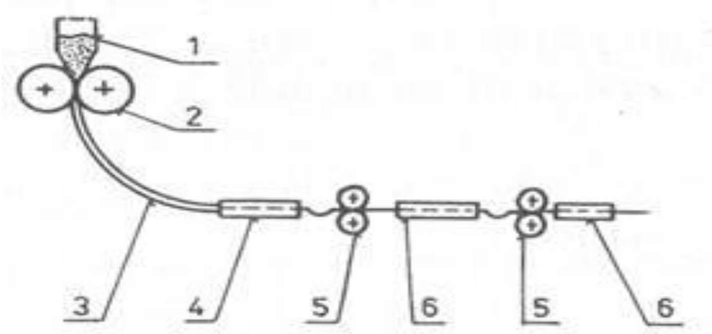


Diagram of semi-finished products manufacturing by rolling metal powders 1 – hopper, 2 – two-cylinder component, 3 – slide, 4 – sintering furnace, 5 – two-cylinder component, 6 – annealing furnace

Forging

- Forging is used to achieve better mechanical properties and eliminating residual porosity.
- The initial semi-finished product can be either pressing which sinters during the heating to the forming temperature, or semi-finished sintered product, which can be forget directly after its removal from the sintering furnace.
- Free forging is used mainly for large semi-finished products, die forging for product with high precision demands. Relatively small deformations are chosen.

5.5. Special consolidation methods

- Hot pressing, which includes both pressing and sintering, enables to achieve full density of pressings.
- Powder is pressed at relatively low pressure at temperatures almost 2500 °C in controlled atmosphere, vacuum, or air.
- Isostatic cold pressing is suitable for complex products. The vibration compacted powder is closed in a thin elastic shell and exposed to a gradual hydrostatic pressure of the fluid (up to 600 MPa).
- The advantage is high density and isotropic properties. Isostatic heat pressing is suitable to achieve non-porous state.
- The powder in metal container is subjected to pressure and temperature acting. As the pressure medium, argon is used.

- Hot pressing is used mainly for AL, Mg, Ag, etc.
- In special cases, hydro-impulsive pressing, magnetic field pressing, explosive pressing, injection molding, extrusion, casting, freezing casting, technology of very high pressure, etc. can be used.

Sintering

- Sintering is a method of heat processing of densified particles or powder pressing, during which the porous pressing turns into a compact body under the influence of temperature and pressure.
- The overall contact area of the particles is increased, porosity is reduced, physical and mechanical properties are improved, volume shrinkage occurs.
- Sintering temperature ranges between 0.6 – 0.9 of melting temperature.
- Sintering can take place under normal pressure or under external forces acting. Sintering occurs in electric furnaces with controlled atmosphere (reduction or inert gases, vacuum).
- The most important sintering parameters are temperature, sintering time, and controlled atmosphere.

6.THERMAL TREATMENT

6.1. Purpose and basic classification of thermal treatment methods

By proper use of metal and alloys properties, it is possible e.g. to reduce a machine or machinery weight, or to use cheaper materials. Both results in increasing the economy of production.

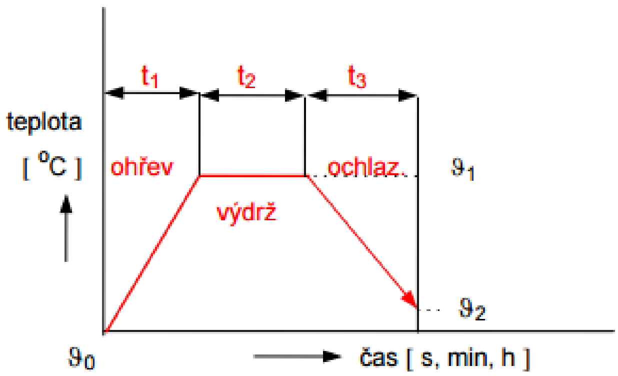
Thermal treatment includes all processes in which an object or material in its solid state is heated and cooled in a certain way in order to achieve desired properties.

It always includes the following processes:

- heating to a certain temperature
- maintaining this temperature
- cooling to a given temperature at certain speed

In some cases, these processes can be repeated several times under different conditions.

The cooling or heating speed is given at high speed in °C/s, at low speed in °C/min, or °C/h.



Legend: teplota – temperature, ohřev – heating, výdrž – maintaining the temperature, ochlaz. – cooling, čas - time

Although both speeds are not uniform (they depend on instantaneous temperature gradient), we mostly consider average speed, which is calculated as follows:

a) při ohřevu

$$c = \frac{\vartheta_1 - \vartheta_0}{t_1}$$

b) při ochlazování

$$c = \frac{\vartheta_1 - \vartheta_2}{t_3}$$

kde: ϑ_0 je výchozí teplota před ohřevem

ϑ_1 je teplota ohřevu

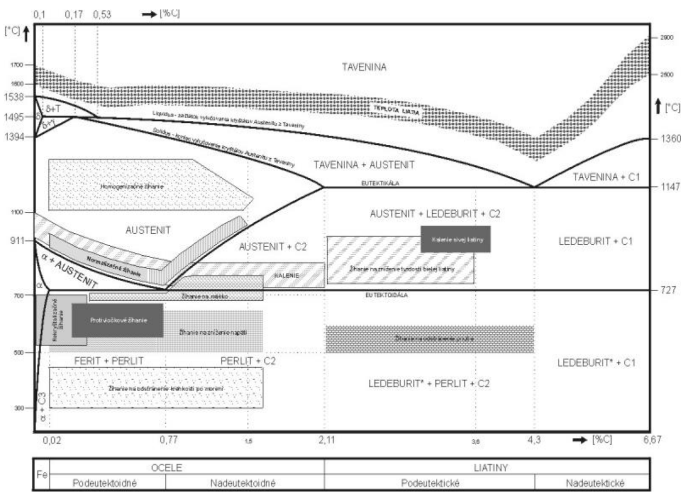
ϑ_2 je požadovaná teplota na konci ochlazování

Legend: při ohřevu – in heating, při ochlazování – in cooling, kde – where, výchozí teplota před ohřevem – starting temperature before heating, teplota ohřevu – heating temperature, požadovaná teplota na konci ochlazování – required temperature after cooling

Thermal treatment influences mechanical properties, such as strength, hardness, ductility, notch toughness, wear resistance, etc. In many cases, changes in structure occur; therefore knowledge of equilibrium diagrams and phase changes is required.

Since the equilibrium in phase changes in the solid state is completely determined by diffusion, for the result of thermal treatment it will be important what effect the diffusion will have. The course of diffusion is influenced both by temperature and the duration (period of time) at which the temperature is maintained. By the way of influencing diffusion, thermal treatment is divided into two basic groups:

- Thermal treatment methods enhancing the diffusion on hindering it just slightly. These methods are generally called annealing.
- Thermal treatment methods hindering significantly or stopping the diffusion completely. The non-equilibrium state of the alloy is generally the greater the higher the cooling speed is. The main method is quenching.



6.2. Annealing

The objective of annealing is mostly:

- To reduce residual stress,
- To eliminate the consequences of preceding mechanical processing,
- To improve technological properties (cold-forming, machining),
- To lower chemical and structural heterogeneity.

The decisive technological parameter of annealing is the temperature and the time at the temperature when cooling is very slow. The annealing temperatures of the individual procedures result from the equilibrium diagram of Fe-Fe3C.

All types of annealing can be divided by the annealing temperature:

Annealing to reduce residual stress. The purpose is to reduce internal stress in the material during the casting solidification, cooling after cold and hot-forming, and in surface layers after chip machining. At the annealing temperature of 450 - 650 °C the yield strength is so low that the residual stress can be reduced by local plastic deformation. Depending on the size, shape and material, 2 – 10h remaining at the temperature with slow cooling is necessary to prevent new residual stress.

Recrystallization annealing

It mostly refers to intermediate annealing in cold-forming of low-carbon steel, which removes the hardening and regenerates malleability and ductility. This is done by means of its heating to the temperature of recrystallization (550 – 700 °C), with a duration of 1 – 5 hours. Using this method, it is possible to change significantly the shape and size of grain. The purpose of annealing is usually to refine the grain.

Soft annealing

The surface tension causes spheroidization of eutectoid carbide particles. By changing lamellar perlite to grain perlite, it is possible to improve cold-forming possibility in low-carbon steel and machining possibility in steel with the C content over 0.4 %. Also, annealing enables to prepare a suitable initial structure for subsequent quenching, especially in the case of eutectoid and over-eutectoid steel. The uniform distribution of granular carbides in basic ferritic mass facilitates the subsequent austenitization and improves the general properties after quenching, which is successfully used especially in the case of bearing steels. The annealing temperature is close t eutectoid temperature.
Increasing the temperature above Ac1 or its fluctuation around this temperature facilitates and accelerates balling of carbide particles. The annealing time differs based on the type of the steel and on the previous heat treatment, ranging from 4 h for carbon steel to 16 h for high alloy steels. Annealing is finished by slow cooling in the furnace.

Anti-flake annealing

It is applied at supercritical hydrogen content in steel, when steel is susceptible to creation of internal cracks – flakes. Creation of flakes can be prevented by long-term heating (up to tens of hours) at the temperatures of 650 – 750 °C, where as the result of a significant increase of hydrogen diffusivity in ferrite, its content decreases under the critical value. Annealing must be performed immediately after casting or hot forming (before its cooling to the temperature of the ambient temperature), when the hydrogen present does not create molecules which are not capable of diffusion and thus of removing from steel. After remaining at the annealing temperature for a long time, it is advisable to cool to at least 500 °C very slowly.

Annealing to remove brittleness after pickling

When removing skimming by means of pickling, in steel components, there is diffusion of hydrogen in the metal and subsequently hydrogen fragility. Since during the pickling, hydrogen penetration into steel is limited, hydrogen can be easily removed by annealing at temperature between 300 °C and 500 °C for 1 - 4 h

Normalization

It is one of the most widely used methods of steel heat treatment, as it ensures fine-grained and even structure after casting, forming, or long-term annealing at high temperatures. The classical procedure is used only for sub-eutectoid steels, when at a temperature of 30 – 50 °C and duration of 1 – 4 hours, a fine uniform austenitic structure is formed that after cooling transforms into fine-grained ferritic-perlitic structure with favorable mechanical properties. Exceptionally, it is applied in the case of over-eutectoid steels in order to achieve a better re-distribution of secondary cementite particles that was removed at grain boundaries in the form of grids as a result of slow cooling. By heating to the temperature above Acm, carbide meshes are dissolved in austenite and by its rapid cooling its repeated removing is prevented at grain boundaries.

Homogenizing annealing

It lowers non-homogeneity of the chemical composition of thick-walled castings in which significant dendritic segregation occurred. Long-term annealing at temperatures ranging from 1 100 to 1 200 °C (usually about 200 °C below solidus) causes sufficient diffusion speed of carbon and other elements to reduce segregation and unwanted heterogeneity. Remaining at the temperature depends on the size and thickness of the casting, usually resulting in a significant grain roughness, which requires subsequent normalization annealing.

Solution annealing

This type of annealing is used to dissolve carbides, nitrides and other inter-metallic phases, which increases the homogeneity of austenite and its saturation with alloying elements. It is most often used at high alloy austenite steels, where a pure austenite structure is obtained by annealing at temperatures of 1 050 - 1 150 °C with subsequent fast cooling that prevents repeated elimination of phases.

Isothermal annealing

By combining three types of annealing (normalization, soft, reducing internal stress) in one operation, it is possible to achieve more homogeneous fine-grained structure with improved machining. The process starts with normalization, after which the steel is cooled by a stream of air to the temperature of 700 - 650 °C, at which in isothermal delay the splitting of metastable austenite into fine spheroidized perlite occurs. Remaining at the temperature results from the knowledge of the IRA diagram for the relevant steel class. Finally, it is cooled by the air. The process is suitable for some kinds of medium-alloy steel that are difficult to soft anneal.

6.3. Quenching

The objective of quenching is to improve the hardness, strength and wear-resistance of steel. These properties are typical for partly or entirely non-equilibrium structures which can be obtained by cooling austenite at overcritical speed. Depending on the phase prevailing in the resulting structures, there is martensitic or bainitic quenching.

An important process parameter is the quenching temperature, at which steel is austenitised before cooling. The proper quenching temperature for sub-eutectoid steels is about 30 - 50 °C overAC3, where it ensures the homogeneous structure of austenite before decomposition. For super-eutectoid steels, the adequate temperature is only about 20 °C above AC1, where the initial structure consists of a heterogeneous structure of austenite and undissolved carbides that increase the wear-resistance after quenching. Improper quenching temperature results in increasing unwanted phases in the final structure (ferrite) or to thickening of grain, which may result in quenching cracks.

Quenchability is steel ability to achieve unbalanced state by austenitizing temperature lowering.

Quenching ability is determined by its maximum hardness after quenching; it depends on the carbon content in austenite. The resulting hardness is also affected by the quenching temperature, especially in the case of super-eutectoid steels.

Types of quenching

- **Basic quenching** is the simplest process. The temperature decreases steadily under *MS, when the austenite transformation into martensite starts. High residual stress and maximum deformations arise, therefore this type is not suitable for quenching products of complex shape.*

- **Discontinuous quenching** starts with supercritical speed in order to support perlitic transformation (e.g. in water) and continuous with cooling in moderate ambient (e.g. oil). This way the difference between the temperature on the surface and inside the product as well as thermal stress is reduced.

- **Isothermal quenching** is similar to thermal quenching, with the dwelling time in the bainitic transformation lasts until isothermal austenite decomposition is finished. Thermal and structural stress is minimal, there is no risk of deformation and cracks. The oldest isothermal quenching method is patenting used for production of high-strength wires.

- **Thermal quenching** enables to balance temperatures in the whole volume of the product quenched. It reduces the stress and deformation due to dwelling over the MS temperature. Cooling in the interval of martensitic transformation usually takes place in the air. The process is suitable for thin-walled steel products of complex shapes, whose bainitic area is shifted on the left.

- **Grain quenching by freezing** requires additional cooling in liquid nitrogen freezing baths that should prevent the stabilization of RA (residual austenite) for steels with low MS and Mf temperatures. It is applied to the products working at temperatures below zero, measurement tools, and bearing steel, where the shape stability is required.

- **Continuous bainitic quenching** is used for steels with bainitic area on the left. The resulting composition consists of bainite, martensite and residual austenite.

6.4. Tempering

Tempering is a steel heat treatment method usually following quenching. By heating quenched steel to temperatures not exceeding AC1, martensite decomposition and transformation of residual austenite occurs. The changes of structure and resulting changes of mechanical properties depend mainly on the tempering temperature. From technology point of view, we distinguish between:

- **Tempering at low temperatures (to 300 - 350 °C), which lowers the residual stress after quenching, reduces the RA content and stabilizes dimensions.**

- **Tempering at higher temperatures (above 450 °C), at which a complete decomposition of martensite occurs, which is shown by marked decrease of hardness and strength, but also by increase in plasticity and toughness.**