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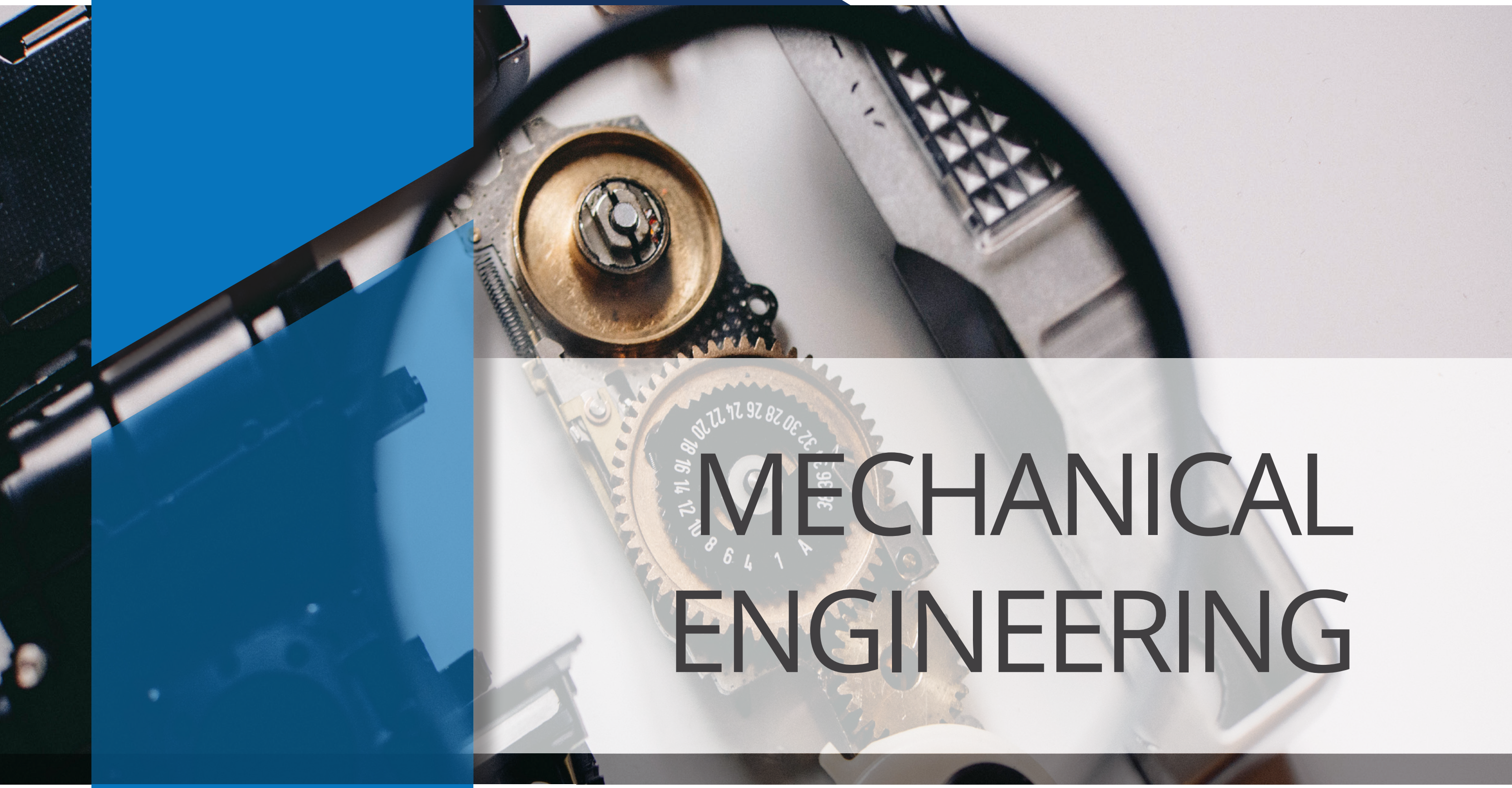

# MECHANICAL ENGINEERING

## Materials in machine industry

UNIVERSITY
OF APPLIED SCIENCES
UPPER AUSTRIA
VŠTE
EUROPEAN UNION

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# 1. INDUSTRIAL MATERIALS IN CURRENT PRACTICE

Generally, industrial materials are divided into construction materials, i.e. the materials for producing technical constructions (machine members, building parts, electrical and technical components, etc.), and auxiliary materials (oils, fuels, moulding substances, chemical reagents, coolants, etc.). It is necessary to systematise the quality properties of industrial materials. For this purpose, variables that make the basis for evaluation and measuring are used. These are atomic, mechanical, thermal, chemical, electrical, magnetic, acoustic, optical variables. In the production process, the behaviour of materials is evaluated by means of technological properties that determine the possibility of their processing into a desired shape or the possibility to achieve the required properties, such as castability, hardenability, etc. Similarly, technological properties must be assessed by standard measuring gauges based on standard methods and units [10], [12], [14], [71]. Currently, there are known about 20 000 alloys of industrial metals, out of which 12 000 are iron alloys with alloying elements, such as C, Mn, Si, Cr, Ni, Mo, V, Nb, Ta, Ti, Zr and impurities O, S, P, etc. There are about 2 000 aluminium alloys with additional metals, such as Cu, Mg, Si, Zn, Mn, Ni, Sn, Fe, Pb, Zr and O, H impurities. There are about 5 000 copper alloys with additional metals, such as Zn, Sn, Al, Mn, Ni, Fe, Pb, Zr and O, H impurities. Other metal alloys are used in various industrial sectors. The main groups of materials used in current practice are shown in Figure 1.1.

*Figure 1.1 Main groups of materials [71]*

**Legend: ocel – steel, liatina – cast, kovy – metals, zliatiny kovov – metal alloys, keramika – ceramics, oxidová – oxide ceramics, neoxidová – non-oxide ceramics, sklo – glass, elastoméry – elastomers, kaučuk – caoutchouc, guma – rubber, polyméry – polymers, plastoméry – plastomers, duroméry – thermoset, hybridní materiály – hybrid materials, kompozity - composites**

Another division of industrial metals are based on required physical properties, practical use and other perspectives of their use are shown in Figure 1.2.

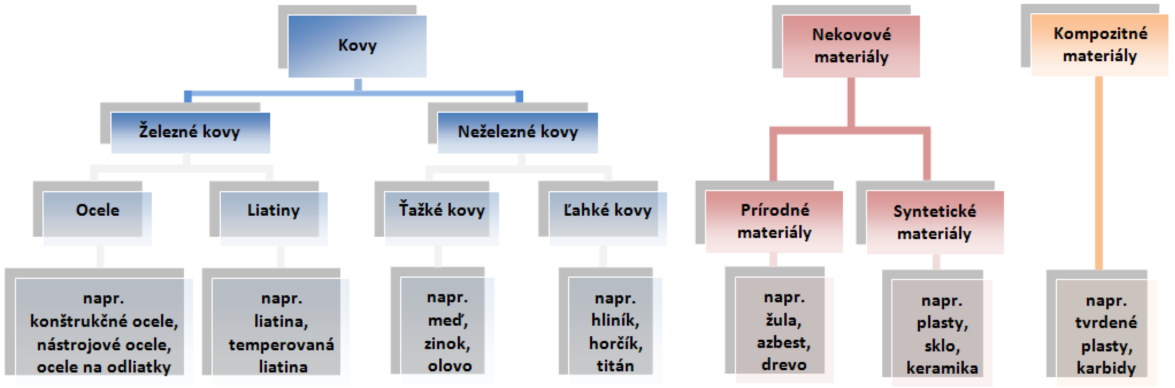


*Figure 1.2 Classification of materials [71]*

**Kovy – metals, železné kovy – ferrous metal, neželezné kovy – non-ferrous metals, ocele – steels, liatiny – cast iron, ťažké kovy – heavy metals, ľahké kovy – light metals, napr. konštrukčné ocele, nástrojové ocele, ocele na odliatky – e.g. structural steel, tool steel, steel for casting, liatina, temperovaná liatina – cast, malleable cast iron, meď, zinok, olovo – copper, zinc, lead, hliník, horčík, titan – aluminium, magnesium, titanium, nekovové materiály – non-metallic materials, prírodné materiály – natural materials, syntetické materiály – syntetic materials, žula, azbest, drevo – granite, asbestos, wood, plasty, sklo, keramika – plastics, glass, ceramics, kompozitné materiály – composite materials, tvrdené plasty, karbidy – hardened plastics, carbides**

## 1.1. Description of individual material groups

**Steel:** malleable iron alloys containing iron and a small amount of carbon whose content is smaller than 2.14 %, that is below the limit of solubility in austenite. Alloyed steels also contain noble metals. Steel is the main construction material for manufacturing machines, engines, constructions, especially for their mechanically stressed parts (shafts, gears, screws, springs, pins and camshafts [11], [19], [26], [27].

**Cast iron:** iron and carbon alloys (2.14 % - 6.67% C), with a good castability. They are used for casting components of a complex shape, e.g. engine boxes or their parts.

**Heavy non-ferrous metals:** (density $\rho > 5$ kg.dm$^{-3}$). This includes e.g. copper, zinc, chromium, nickel, silver, tin, tungsten. They are used either in pure form (for their specific properties), or in alloys.

**Light metals:** (density $\rho < 5$ kg.dm$^{-3}$). This includes aluminium, magnesium, titanium. They have relatively high strength and good corrosion resistance at relatively low density. Aluminium is used e.g. for manufacturing engine pistons and light car and aircraft parts.

**Natural materials:** granite, mica, diamonds, wood, ivory, cotton, wool, silk. In mechanical engineering, e.g. granite is used as a drawing board. It has low heat conductivity and compared to cast iron board, it has higher temperature.

**Synthetic materials:** they include a large group of macromolecular polymers of simple organic substances, called plastics, and also glass and ceramics. Plastics are light, water resistant, do not conduct electricity, thermal insulators, resistant to chemicals. They have various mechanical properties; some plastics are elastic, while some are rigid and brittle. Plastics have low thermal resistance. Plastics are used for a number of purposes, from production of tyres to gears. Due to their hardness and abrasion resistance, ceramic materials are used for nozzles, cutting tools, packing rings.

**Composite materials:** materials consisting of two or more kinds of materials. Fiberglass consists of artificial resin and glass fibre fabric. They are tough, light, and strong. They are used for manufacturing containers, kayaks, pools or printed circuit boards. Another type of composite material is cemented carbide. They combine carbide grand hardness and binder metals toughness. They are used for making cutting tools of machine tools.

**Production of materials:** materials are used mainly from natural raw materials. Raw materials are in the deposits of the Earth´s crust. Metals are obtained from metal ores, plastics are mostly produced from oil and natural gas. Materials from raw materials are obtained mainly by thermal and chemical processes. Materials come into engineering production in the form of semi-finished products, e.g. profiles, tin sheets or wires. Natural materials are obtained directly from natural deposits (e.g. granite from quarries).

**Auxiliary materials and energy:** in machine parts production and assembly, auxiliary materials and energy are necessary for powering machines and for thermal processes. E.g. in the case of turning the components, machining (cutting) fluid is necessary for cooling and lubricating the tool edge, lubrication for lubricating lathe bearings, and electric energy for powering engines and the control system.

# 2. GENERAL MATERIAL PROPERTIES

## 2.1. Physical properties of materials

**Density**

Material density is a ratio of its mass m and volume V. In the case of gases, density is given at normal atmospheric pressure [8], [10], [11].

**Melting temperature**

Melting temperature is the temperature at which the material starts to melt (under normal pressure). The highest melting temperature is for compound carbide (composed of four parts of TaC and one part of zirconium carbide) - 4000 °C, diamonds (3 816 °C) and graphite (3 530 °C). Pure metals have a precise melting temperature. Alloys, e.g. steels have only one melting temperature only at a certain composition (at eutectic point). In other cases they pass from solid to liquid state at a certain temperature range (between the solidus and liquidus curves in equilibrium diagram).

**Electric conductivity**

Electric conductivity is the ability to conduct electric current. It corresponds to the current at the unit voltage. Good conductors are e.g. silver, copper and aluminium. They are used as materials for manufacturing conductors. Materials that do not conduct electric current are called insulators. These include plastics, glass, and ceramics.

**(Longitudinal) thermal expansion**

Thermal coefficient of expansion in longitudinal direction α indicates expansion in the longitudinal direction Δl of a body of a 1-m length at the temperature change of Δt = 1 °C. Longitudinal thermal expansion Δl has to be considered e.g. in the case of measuring tools, built-in components or castings. Thermal shrinkage has to be compensated by allowances.

**Thermal conductivity**

Thermal conductivity is the degree of the ability of a material to conduct thermal energy. Materials with high thermal conductivity are metals, especially copper, aluminium, and iron or steel. Materials with low thermal conductivity are plastics, glass, and air. These are used for thermal insulation.

## 2.2. Material mechanical properties

Due to the forces acting on material (solid body), the material or solid bad deforms. Depending on the internal structure of the material, the resulting deformation is either permanent (plastic) or temporary (elastic). A saw made of hardened tool steel can be bent using increasing force and then it could be returned back to its original shape with acting of decreasing force, since it is elastic. Its structure is not changed by deformation, only the distances of the atoms in the crystal lattice change. Within certain deformation range, some materials behave as elastic for a certain period of time (as each material wears by periodically repeated stress). This property is called plasticity (malleability, ductility). Materials that are malleable or ductile include e.g. steel heated to forging temperature or pure iron [13], [14], [15].

**Elastic and plastic deformation**

A bar made of unalloyed structural steel shows both plastic and elastic deformation, when bent. In the case of large deformation, the bar returns only partially into its initial shape, and permanent deformation remains. Materials showing elastic and plastic deformation behaviour include e.g. non-hardened steel, alloys of copper and aluminium. Various materials can show elastic, plastic and elastic and plastic deformation behaviour.

**Toughness, brittleness, hardness**

Tough material is a material that could be deformed elastically and plastically, but the deformation is with great material resistance. Very tough materials include structural steel and stainless steel. Brittle materials can be only deformed slightly when using great force, as it is not possible to change the material crystal structure. In the case of larger deformation, the material breaks or breaks into more pieces. Brittle materials are e.g. hard materials, such as precious stones, glass, ceramic, and in some way also hardened carbon steel (with a large amount of martensite in its structure). Material hardness refers to the resistance of a material against penetration of a foreign body into it, and it is assessed by the size of the deformation made in the test body at certain pressure or impact energy. The hardest material is boron carbide $B_4C$ and diamond. Hard materials include sintered carbides, precious stones, and materials based on $Al_2O_3$ (corundum), carbides (carborundum SiC, TiC), glass, ceramic and hardened steel (with martensite in its structure). Soft materials include aluminium and copper. Hardness is required e.g. for tools, friction and sliding surfaces.

## 2.3. Technological properties of materials

Technological properties are characteristics of material processing by various technological procedures [16], [18], [19].

**Castability**: is the ability of material to make thin melt that completely fills the mould and do not form cavities during solidification. The materials with good castability are e.g. various types of cast iron, aluminium alloys for castings, copper and zinc alloys, and zinc alloys.

**Malleability:** is the ability of a material to make a plastic deformation by force. The hot-forming methods are e.g. hot rolling and forging. Cold-forming includes e.g. cold rolling, bending, brake bending and deep drawing. Materials that could be well formed are e.g. low carbon steel, aluminium alloys, copper alloys used for casting. Cast iron cannot be formed.

**Machinability**: machinable materials are suitable for cutting operation. In indicates whether and under what conditions the material can be cut, e.g. lathed, milled or grinded. The evaluation criteria for machinability are e.g. the quality of the machined surface, the conditions (difficulty) of cutting operation and the durability of the tool.
Metals are usually well machinable, especially non-alloyed and low-alloyed steels and cast iron, copper alloys, and aluminium alloys. Materials with worse machinability are e.g. elastic and tough materials, such as pure copper, pure aluminium, stainless steel, titanium, and hard materials, e.g. hardened steel.

**Weldability**: indicates whether the material is suitable for welding or tip welding. Well weldable materials are non-alloyed and low-alloyed steels with a low carbon content. By special procedures it is possible to weld high-alloyed steels, alloys, and copper alloys.

**Hardenability and refining**: it is the ability of material to increase hardness or strength of a material by suitable heat processing. Most steels can be hardened, refining is only possible in the case of some kinds of alloys and aluminium alloys.

## 2.4. Chemical properties

Chemical properties of materials are important in terms of the resistance to the influence of the environment, aggressive substances and high temperatures (in terms of supporting chemical effects of the environment) on the material.

**Corrosive behaviour** – describes the material behaviour in moist air, industrial atmosphere, water or in any other aggressive substances. Disruption of the material structure starting on its surface caused by chemical and electrochemical processes is called corrosion. Corrosion-resistant materials are stainless steel and most copper and aluminium materials. The materials which are not resistant to corrosion caused by moist air or industrial atmosphere include non-alloyed and low-alloyed steels and cast iron, and these materials corrode. Surface treatment using protective coating or any other protective coating helps prevent corrosion for a long time [21], [22], [23]. Another chemical property is the resistance to dross formation. It describes the behaviour of the material at high temperature of the air. In the case of some materials, e.g. plastics, it is necessary also observe flammability and when the materials are used, loss of strength as well as the ignition temperature shall be taken into account. Plastics also change their properties when exposed to sunlight, especial to its UV.

Michael F. Ashby [2] in his work Materials Selection in Mechanical Design made a set of material charts maps. They represent the dependencies of the most important material properties for the basic groups of materials: metals, ceramic, glass, polymers, elastomers, and hybrid materials (composites, foams, natural materials). In the set of material chart maps, he determined the following dependencies: Young´s modulus – material density, Young´s modulus – tensile strength, specific Young´s modulus – specific tensile strength, loss factor – Young´s modulus, thermal conductivity – electric resistance, thermal conductivity – variance heat, thermal expansion coefficient – Young´s modulus, strength – maximum operating temperature, dry friction coefficient to steel and Young´s modulus – relative cost per unit volume.

# 3.CRITERIA FOR CHOOSING MATERIALS

Primary requirement in choosing a suitable material is almost always its strength. It is important to combine the material characteristics (strength, toughness, resistance to cyclic loading, wear, temperature, corrosion, etc.) with required utility properties of a future component of system in the optimal way. [71].

Besides material characteristics, there are other criteria to be considered when choosing a suitable material:

**Production technology** – besides the viability of a technology for a given product, selection of material shall be based on the findings on the impact on the composition, structure, and mechanical properties. If possible in terms of other criteria, priority shall be given to non-waste technologies, e.g. powder metallurgy, precision casting, enabling to maximize the using of the material and minimize machining (which is a technology associated with the highest costs).

**Material and production costs** – the economy of the choice is a complex problem including the price of the selected material as well as its processing technologies. For example, replacing steel with aluminium alloy or polymer may appear to be less cost-effective. However, the calculation shall also include lower costs of transports, surface treatment, machining.

**Economy of the selected material use** – it´s also a complex problem. The impact of the selected material on the environment (direct or indirect) has many aspects and it is hard to quantify. In addition, it is also necessary to consider the possibility of recycling the selected material.

**Other criteria** – these include e.g. the necessity to consider the range of semi-finished products and available materials, limited available production equipment, the reliability of the input data (i.e. the extent to which the test defines material properties, the extent to which the sample corresponds to a real component, knowledge of load and environment, etc.).

The choice of a material is a complex process, and the great amount of available materials makes it even more complicated. However, this is not the main cause of its complexity. When choosing a material, it is necessary to take into account a large number of various aspects and their mutual relations and influences. For example, the relation of a material (its technological, mechanical, physical, and chemical properties, its price, assortment, etc.), technologies (especially rational production), and structure (shape and function of a product, requirements placed on it). Moreover, it is necessary to consider also material and production costs, energy and raw material demands, possible impact on the environment including e.g. material recycling [28], [32], [42].

The choice of a material for a given product cannot be independent of the technology that has to be used to manufacture the given product (its shape, surface, etc.). The product function, its structure, material, and technology interact (Figure 3.1). The product function (e.g. transmission of load, heat, energy storage, etc.) determines the choice of the material that would be able to meet the required criteria. The technology is influenced by the properties of the material used (its malleability, machinability, weldability, castability, heat treatment, etc.). the technology used influence the possibility to achieve the required shape, the precision of the shape, the surface quality, and price.

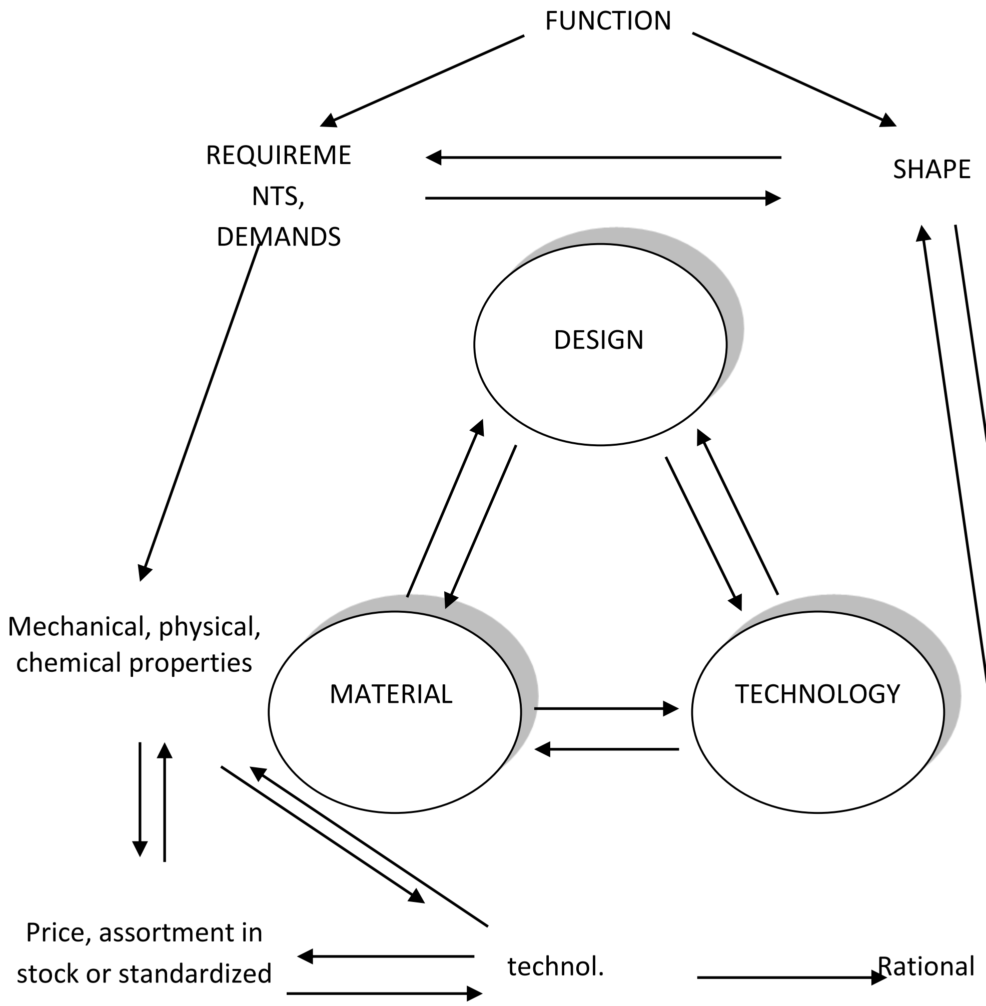


*Figure 3.1 Relation between product properties (shape, function), material, and technology [28]*

*The product design (its shape) limits the choice of a material and technology. The more complicated the design is, the narrower is the specification and higher interaction.*

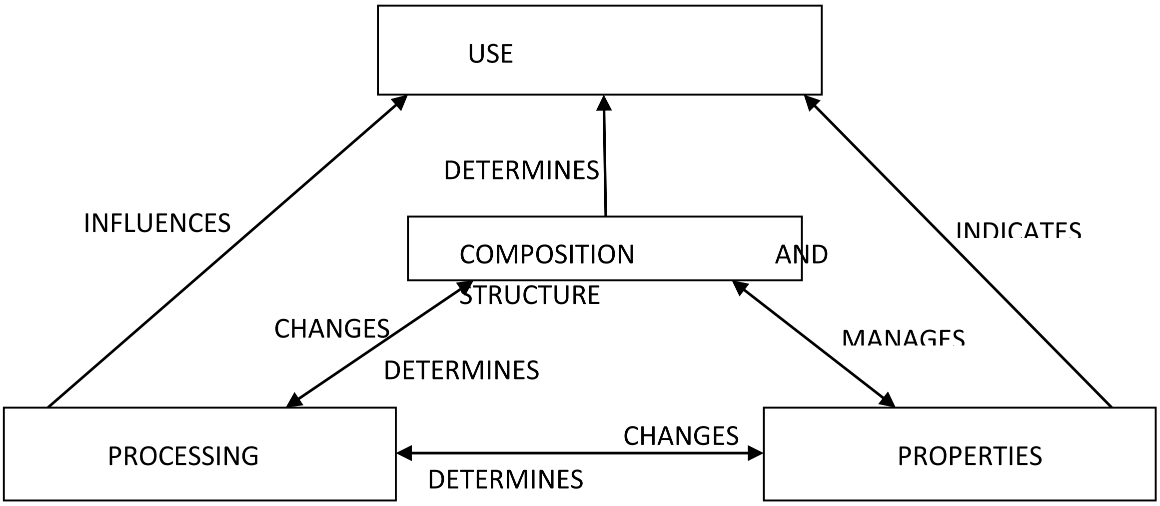


*Figure 3.2 Relation between material composition and structure, processing, properties and utility properties of product [28]*

It results from Figure 3.2, material properties are determined by its composition and structure influenced (changed) by the technology used (e.g. strengthening in cold forming) and vice versa, they determine using of specific technology. The composition and structure of materials is given by primary and secondary technologies and are limiting for achieving required utility properties of a product. Besides the structure and composition of a material, the product utility properties are influenced by the properties of the material used and its processing technology. The whole system of mutual interactions (utility properties – technologies – composition, structure, and properties of material) is also influenced by economic parameters, i.e. costs of material and technology used, as well as by theimpact of all reactive elements.

## 3.1. Selection of material in the product design process

Designing a new product is an interactive process starting with an idea and finishing with a resulting product that corresponds with the initial idea or market requirement (Figure 3.3). Between the beginning and end of this process there are three stages of designing: concept, embodying, and detailed design [33], [34], [35].

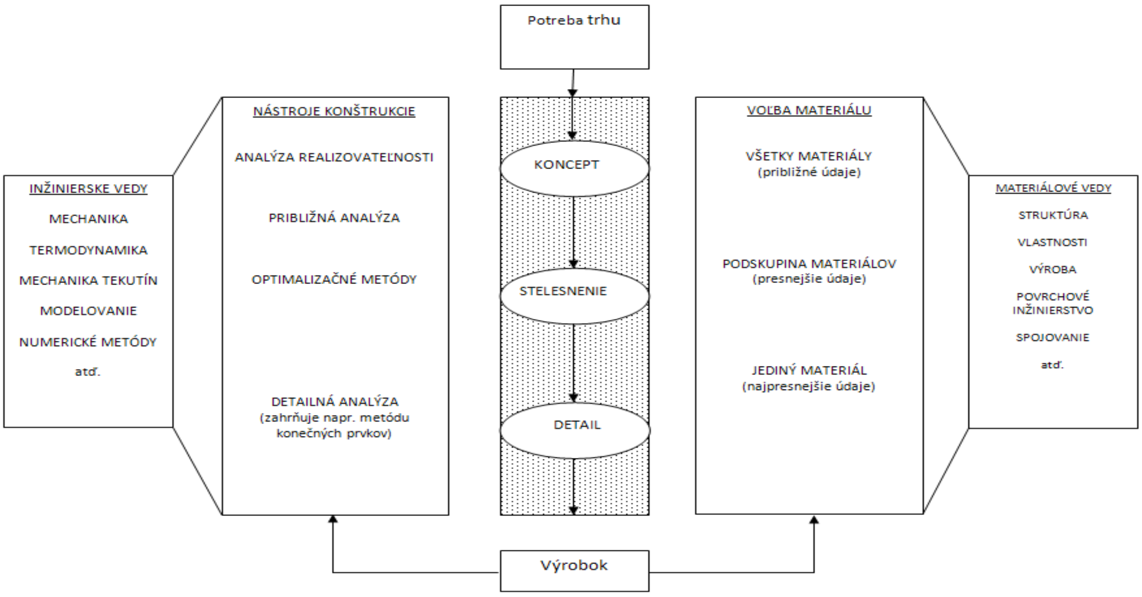


*Figure 3.3 Design of a new product – flow chart [28]*

**Legend: potreba trhu – market demand, koncept – concept, stelesnenie – embodying, výrobok – product, nástroje konštrukcie – construction tools, analýza realizovatelnosti – analysis of feasibility, optimalizačné metódy – optimization methods, detailná analýza (zahrňuje napr. Metódu konečných prvkov) – detailed analysis (includes e.g. finite element method, inžinierske vedy – engineering science, mechanika – mechanics, termodynamika – thermodynamics, mechanika tekutín – fluid mechanics, modelovanie – modelling, numerické metódy – numerical methods, volba material – selection of material, všetky materiály (približne údaje) – all materials (approx. details), podskupina materiálov (presnejšie údaje) – materials subgroup (more detailed data), jediný material (najpresnejšie údaje) – one material (the most precise data), materiálové vedy – material science, struktúra – structure, vlastnosti – properties, výroba – production, povrchové inžinierstvo – surface engineering, spojovanie – joining**

In the first stage of the conceptual design, the designer first considers all alternative work processes or scheme of functions the system will ensure. In the embodying stage, the designer examines the functional structure and analyses the individual activities, including the design of the individual parts dimensions. This stage ends with a project (drawing of the system) as a basis for a detailed design. The left part of the figure shows the tools and technologies the designer has at disposal, or which they use. The figure shows that the selection of the material is in line with a design in its three stages, with the aim to choose the material optimally ensuring the product utility properties. In the first stage (conceptual design), a wide range of materials are considered that could fulfil the basic conditions, e.g. working temperature, resistance to corrosion in the given environment, etc. Based on the required properties, it is decided whether the component will be made of metal, plastics, ceramic, or composite material. At the same time, it is also determined whether a metal component will be used in cast or formed state.

In the second stage, a more specified group of materials are used that would better meet the requirements, e.g. of the least expensive welding technology, suitable surface treatment, etc. Within the detailed design, list of materials is reduced into one (or a few materials in exceptional cases), the most suitable one(s) and also a suitable technology is used. Each of the stage corresponds with different demands on the level of material data. At the stage of the conceptual design, the designer needs only approximate data when considering different conceptual variants. In the second stage, the designer works with a more precise data provided by material databases.

At the stage of a detailed design, the designer needs as precise data as possible about one, or several materials. In some cases, the data from standards or from manufactures are not sufficient and more data, e.g. from laboratory tests, are required. However, it can happen that the product fails to operate (either in terms of function or inadequate material), and the whole design process is repeated (with the information about the failure) at one or more stages.

## 3.2. Material selection process

Material selection is carried out mostly for two reasons:

- Selection of material and technologies for a new product (original design)
- Considering alternative materials and production processes for an existing product

A new product usually brings new work principles; therefore for choosing the optimal material and technology, it is necessary to consider as wide range of materials as possible [44], [45], [46]. In the second case (alternative material), the situation is different. There is usually a wide number of reasons for changing or innovating the material or technology currently used, including:

- Need to adapt to required functions of parametric changes of the product in relation with the alternative design
- Effort to lower the price of the material
- reduction of production costs
- using the advantages of a new material or technology
- solving problems related to the material processing technology
- application of the recommendations resulting from a fractographic analysis of damaged products

In the case of choosing a material for a new product, the procedure shall be as follows:

- To define the function the product will have and translate it into the required material properties (strength, resistance to corrosion, etc.) and include other factors, such as price or availability of the material.
- To define requirements (size and shape of the component, required tolerance, surface quality, number of components, etc.)

- To compare the required properties with the parameters and properties of as large number of materials as possible; to choose several materials that could meet the requirements. It is also useful to determine minimum and maximum values the material shall have in terms of these properties
- To assess selected materials in more details (e.g. their availability in the given semi-finished product dimensions, price, behaviour in operation, etc.)
- To choose one material on the basis of the results of detailed materials analysis and determine the data and specificities for the construction

When choosing an alternative material for an existing product, the following procedure shall be used:

- To characterize utility properties, production requirements, and price of the material currently used
- To choose characteristics that shall be improved
- To find alternative material and (or) a technology the procedure is similar to the previous case – points 1-3) and compare its / their parameters in detail with those currently used.

## 3.3. Relation of material and technology

It is a very narrow and at the same time quite complicated relationship, since in most cases, there are several or a large number of production processes to manufacture a given component. The basis is to choose a material and technology to achieve the maximum quality of the component being produced at the lowest price possible. Choosing the optimal technology is complicated due to a number of factors that have to be taken into account, such as the quantity of the components manufacture, shape, requirements for surface roughness and precision, availability of production equipment, impact of technologies used on the environment, costs, etc. [40], [41], [42], [43].

The choice of material determines the technologies that could be used for the manufacturing of the given component. The overview of the most frequently used technologies for processing a certain material group is shown in Table 3.1, according to [80]. When choosing a material, it is also necessary to consider other aspects, such as the size of the component, its shape, complexity, tolerance, surface quality, and production costs. From these points of view, the key factors for assessing the suitability of individual technologies are mainly the cycle length (time necessary for manufacturing one piece), quality (required tolerance, surface roughness, lack of cracking, pores, dross, etc.), flexibility (the ability to adapt the given technology to the production of another product or its variant), usability of the material, and production costs.

*Table 3.1 Utilization of production processes for selected material groups [80]*

| **Technology** | Cast iron | Carbon steel | Alloyed steel | Stainless steel | Al and its alloys | Cu and its alloys | Zn and its alloys | Mg and its alloys | Ti and its alloys | Ni and its alloys | Refractory metals | Plastomer | Duromers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Casting / forming** | | | | | | | | | | | | | |
| Sand casting | ● | ● | ● | ● | ● | ● | - | ● | - | ● | - | X | X |
| Ceramic mould casting | - | ● | ● | ● | ● | ● | - | - | - | ● | - | X | X |
| Metal mould casting | X | X | X | X | ● | - | ● | ● | X | X | X | X | X |
| Die casting | X | X | X | X | X | X | X | X | X | X | X | ● | - |
| Investment casting | X | X | X | X | X | X | X | X | X | X | X | ● | X |
| Blow moulding | X | X | X | X | X | X | X | X | X | X | X | ● | X |
| Centrifugal casting | X | X | X | X | X | X | X | X | X | X | X | ● | X |
| Forging/bulk-forming | | | | | | | | | | | | | |
| Backward extrusion | X | ● | ● | - | ● | ● | ● | - | X | X | X | X | X |
| Cold heading | X | ● | ● | ● | ● | ● | | - | X | - | X | X | X |
| Die forging | X | ● | ● | ● | ● | ● | X | ● | ● | - | - | X | X |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |
| Pressing and sintering (PM) | **X** | ● | ● | ● | ● | ● | **X** | ● | - | ● | ● | **X** | **X** |
| Hot extrusion | **X** | ● | - | - | ● | ● | **X** | ● | - | - | - | **X** | **X** |
| Rotary swaging | **X** | ● | ● | ● | ● | - | - | ● | **X** | ● | ● | **X** | **X** |
| **Machining** | | | | | | | | | | | | | |
| Machining semi-finished products | ● | ● | ● | ● | ● | ● | ● | ● | - | - | - | - | - |
| Electrochemical machining | ● | ● | ● | ● | - | - | - | - | ● | ● | - | **X** | **X** |
| Spark erosion work | **X** | ● | ● | ● | ● | ● | - | - | - | ● | - | **X** | **X** |
| Wire cutting | **X** | ● | ● | ● | ● | ● | - | - | - | ● | - | ● | **X** |
| **Pressing** | | | | | | | | | | | | | |
| Sheet metal forming | X | ● | ● | ● | ● | ● | - | - | - | - | X | X | X |
| Forming of heated foil | X | X | X | X | X | X | X | X | X | X | X | ● | X |
| Metal spinning | X | ● | - | ● | ● | ● | ● | - | - | - | - | X | X |

## 3.4. Choosing material in relation to the environment

The impact of the material selected on the environment has many aspects and it is hard to quantify. The direct impact (e.g. toxicity) must be excluded. A number of both organic and inorganic elements have toxic properties. Toxic effects of various substances can be basically divided into *immediate* and *consequent*, in the later the classification is into *mutagenic, carcinogenic* and *toxic for reproduction*. The detailed study of metals effects on human body increases the set of the metals harmful to health. Besides recently identified toxic metals (Hg, Be, As and Pb), other twelve metals are considered harmful. The metals with provably harmful effect include As, Cd, Hg, Se and Th, while the toxicity of other metals (Co, Ni, Pb, V, Zn) depends on the size and number of doses. Recently, there have been discussions about the influence aluminium possibly has on senile dementia. Unlike some extremely toxic but degradable compounds (e.g. cyanides), the possibility of metal waste disposal is limited to metal extraction or binding metals to minimally soluble form. The issue of toxic elements in metals is given considerable attention, and consequences are immediately drawn from the findings [63], [64], [65].

The main indirect effects include:

- Raw materials, mining, processing of raw materials
- Energy intensity
- Safety and long-term reliability
- Possibility of recycling.

In the toxicology of polymers, the effects of residual monomers, additives, and substances generated by polymers disposal are considerable. Of the many harmful monomers (e.g. vinyl chloride, acrylonitrile, methyl methacrylate, etc.), the most important is the first mentioned carcinogenic monomers, whose content in polyvinyl chloride is limited to 1 mg/kg.

Metallurgy, chemistry, and other industries impose burden on the environment in the form of waste that cannot be recycled in basic technology. Most metallurgical processes generate all kinds of waste – gaseous (carbon oxides, nitrogen oxides, sulphur oxides), liquid (waste water, sludge), and solid (slag, dust). One of the environmental parameters for assessing the industrial gaseous emissions is specific primary energy consumption related to a certain range of products.

Of the individual material groups, steel is almost completely recyclable. However, this is associated with a number of problems and increased costs related to sorting and treatment of waste from chip machining or sorting returnable waste. A known problem of recoverable steel waste is the increasing content of copper and surfactants. Non-ferrous metals are about 90% recyclable, they do not contain any fillers (chalk, talc, glass, etc.), which are added in order to improve the mechanical properties. Thermosetting polymers cannot be recycled. Elastomers (natural rubber, rubber) cannot be recycled but additional application possibilities are sought for them.

For near future, products facilitating recycling are promising. Their production must follow several basic rules:

- To use materials that are recyclable or can be used for some other purpose,
- To minimize the number of materials used for manufacturing one product or to use materials that could be combined well in terms of recycling,
- To join non-combinable materials in a demountable manner,
- Mark plastics.

A new development trend is degradable, especially organic, materials, that is, plastics that could be incorporated into the natural cycle of substances. In the degradation process, hydrolytic, oxidation and photo degradation mechanisms are used, that lead to cutting the molecular chains into shorter structures that are readily subject to biodegradation by microorganisms.  Degradable plastics can decompose anywhere in the nature, preferably in landfills or at sea levels. Biodegradation is very effective when composting degradable plastics, which leads to creation of humus. Compost fertilizer can be used to grow some agricultural crops that are basic raw material for production of degradable plastics that is based on the combination of vegetable and synthetic raw materials. This way a suitable polymer material is incorporated into a closed natural cycle without any harmful effects on the environment. Some limitations of this trend can result from its contraction with the requirement for a long durability of a product.

*Figure 3.4 shows a typical material cycle. The aim is to use as little non-recyclable waste as possible*

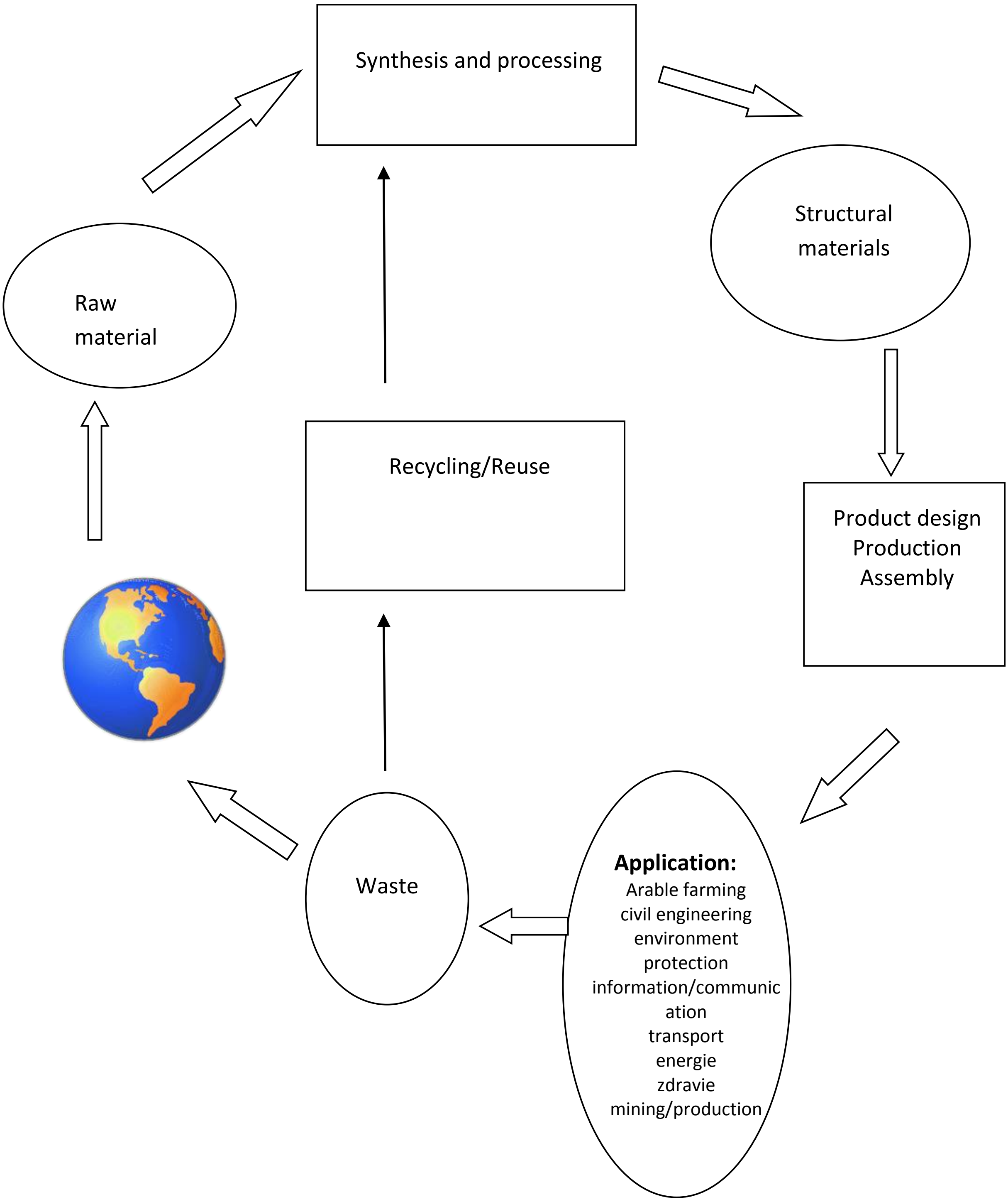


*Figure 3.4 Typical material cycle [71]*

Recycling of materials (products) has a number of practical forms, ranging from recovery procedures enabling repeated use and wear of a component (e.g. build-up welding of other layers onto worn parts), using the worn component as a raw material for making a new component, to energy recovery (e.g. combustion of plastics).

A classic material cycle with variant recycling steps in the production cycle (processing of primary waste in the primary cycle), or in product use (secondary cycle – regeneration processes), use of product after its end of life (tertiary cycle) to transformation of the product into another material or energy.

# 4. MARKING OF MATERIALS

Different types of materials are commonly designated with markings composed of either letters or numbers or a combination of both. In each country that produces it, steel is designated according to national technical standards as well as names (trademarks) of individual manufacturers. Trademarks are put on steel that has not yet been standardized in a given country or steel that has been normalized to recognize a manufacturer´s origin. Marking systems vary greatly in every country. Recently, however, individual EU countries have been increasingly adopting a marking system according to European standards (EN), which gradually makes the process more unified. Still, technical documentation from the above countries very often contains markings according to the national technical standards [51], [52], [53], [71].

## 4.1. Division and marking of steels according to European standards

Division and marking of steels in Europe are being unified on the basis of European standards (EN). All CEN members are required to comply with the standards, with the members being national standards organizations of 18 European countries, namely Belgium, Denmark, Finland, France, Ireland, Iceland, Italy, Luxembourg, Germany, Netherlands, Norway, Portugal, Austria, Greece, Spain, Sweden, Switzerland, Great Britain, thus virtually all Western European countries. However, other European countries, including the Czech Republic and Slovakia, are also gradually taking on the standards. In the Czech Republic, they are issued as CSN EN replacing the existing CSN standards. As a result, the EN will become European-wide standards, and it is therefore necessary for one to become familiar with them.

Division of steels is given by the European standard EN 10020-88 (ČSN EN 10020-94) which defines:

- the term forming steel,
- steel grades according to chemical composition and their division to unalloyed and alloyed,
- main quality classes of steels based on their properties and purpose of use.

Abbreviations related to steel marking systems are listed in the following standard:
EN 10027-1-92 and its supplement IC 10-93 (information circular) incorporated into ČSN as ČSN ECISS IC 10-95. Numerical marking systems are stated in EN 10027-2-92 (ČSN EN 10 027-2-95).

As regards forming steels, they are materials whose iron content by weight is larger than any other element, and which contain less than 2% C and include other elements. Although some chromium steels contain more than 2% C, the 2% mark is generally considered to be the borderline for distinguishing between steel and cast iron.

Division of steels according to their chemical composition into unalloyed and alloyed is based on the minimum content of elements (as stated in the above standard) or delivery conditions. If only the maximum value of the content in melt is prescribed for the elements, 70% of the value is decisive (except for Mn) for dividing steels into unalloyed and alloyed. As for manganese, the limiting content is 1,80%, whereas the chemical composition of their base material is crucial for multilayer and clad products
***Unalloyed steels*** are those whose determining contents of individual elements in no way reach limit contents given in the table of limiting contents of alloying elements for the division of steels into unalloyed and alloyed.

***Alloyed steels*** are those whose contents of individual elements at least in one case reach or exceed limit contents given in the table of limiting contents of alloying elements for the division of steels into unalloyed and alloyed.

## 4.2. Unalloyed steels

### 4.2.1. Common quality steels

*Common quality steels* are steels with quality requirements that do not involve special precautions in production. However, they still have to meet the following conditions: they are not intended for heat treatment (where, according to EN 10020, no type of annealing, e.g. normalizing annealing, is considered as heat treatment); requirements to be met for unprocessed or normalized annealing state are in accordance with values given in the table of limit values for common quality steels. With the exception of the Si and Mn contents, no other contents of alloying elements are prescribed, [12], [71].

### 4.2.2. Unalloyed quality steels

They are all unalloyed steels not included in the grades of conventional quality steels and stainless steels. Such steels do not have a prescribed uniform heat treatment reaction or a required degree of purity with respect to non-metallic inclusions. In comparison with conventional quality steels, more stringent or additional requirements are imposed on them (e.g. their susceptibility to brittle fracture, grain size, formability). Thus, their production requires special care.

### 4.2.3. Unalloyed stainless steels

Unlike the aforementioned grade of steels, unalloyed stainless steels exhibit a higher degree of purity. They are mostly intended for refinement or surface hardening and are characterized in that they react more evenly to such treatment. The desired properties are achieved by accurately determining chemical compositions as well as production and testing conditions – often in combinations and within restricted limits (high or narrowly defined strength or hardenability in conjunction with high demands on formability, weldability, toughness, etc.).

Unalloyed stainless steels include:

- steels with impact requirements in a refined state;
- steels with requirements for a turbid layer depth or surface hardness in a turbid or opacified, or released, state;
- steels with very low non-metallic content requirements (including steels for which the content may be agreed);
- steels with a prescribed maximum content of P and S = 0.020% in the melt and 0.025% in the finished product (e.g. wires for highly stressed springs);
- steels with minimum impact forces of KV > 27 J on longitudinal samples at -50 $^{o}$C;
- steels for nuclear reactors with Cu = 0,10 %, Co = 0,05 %, V = 0,05 % for a finished product analysis;
- steels with prescribed minimum electrical conductivity of > 9 S m/mm$^2$;
- ferritic-pearlitic steels with a prescribed minimum content of C = 0,25 % which, as for non-alloy steels and for the purpose of hardening, still contain permissible contents of one or more micro-alloying elements, e.g. V, Nb;
- steels for prestressed concrete reinforcement.

## 4.3. Alloyed steels

### 4.3.1. Alloyed quality steels

This group involves steels intended for similar purposes to unalloyed quality steels, but in order to meet special conditions of their use, they contain alloying elements in certain contents that make them alloyed steels. These steels are generally not intended for refining or surface hardening and encompass:

- weldable fine-grained structural steels for steel structures, including pressure vessels and pipelines that meet the following requirements:

    - for t = 16 mm, the yield strength of Re < 380 MPa is prescribed,
    - contents of alloying elements must be below limit values given in the table

    - of limit contents for the division of alloyed weldable fine-grained structural steels into alloyed quality steels and stainless steels,
    - a minimum impact value of KV proportion is at -50 °C = 27 J,

- steels alloyed only with Si or Si and Al with special requirements for magnetic and electrical properties;
- steels intended for manufacturing of rails, brushes and mine supports;
- steels for hot-rolled or cold-rolled flat products which are intended for more advanced cold forming and which are alloyed individually or in combinations with B, Nb, Ti, V or Zr (similar to biphasic steels);
- steels alloyed only with Cu.

### 4.3.2. Alloyed stainless steels

They are steels where the required properties – often in combinations and within restricted limits – are achieved by determining precise chemical compositions as well as special production and testing conditions. They particularly include stainless steels, high-temperature resistant and refractory steels, steels for roller bearings, tool steels, steels for steel structures and machine construction, steels with special physical properties, etc., [71].

## 4.4. Abbreviations for steel marking system

Table 4.4 shows a specific steel markings system.

*Tab. 4.4 Steel marking system scheme according to EN 10027-1, EN 10 027-2 and IC-10 [71]*

<table>
<tr><td colspan="8">Marking of steel standards</td></tr>
<tr><td colspan="3">Basic symbols (EN 10027-1)</td><td></td><td colspan="4">Additional symbols IC-10</td></tr>
<tr><td rowspan="3">Letter</td><td colspan="2">Properties</td><td></td><td colspan="2">Steels</td><td>+</td><td rowspan="3">Steel products</td></tr>
<tr><td rowspan="2">Carbon content</td><td rowspan="2">Alloying elements</td><td rowspan="2"></td><td>Group 1</td><td>Group 2</td><td rowspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="8">Markings according to EN 10 027-1, Numerical markings according to EN 10 027-2</td></tr>
</table>

**Group 1** – Markings developed on the basis of their use and mechanical and physical properties of steels

**Group 2** – Markings developed on the basis of chemical compositions of steels

A – Examples of symbols for special requirements
B – Examples of symbols for coating types
C – Examples of symbols for processing statuses

# 5.NUMERIC SYMBOLS OF STEEL

For all steels included in the European standards, the number is assigned in accordance with the system in EN 10027-2. These numbers are additional to steel marking according to EN 10027-1. The authority competent to allocate numbers is the European Registration Office in Düsseldorf. A request for allocating a number to steel manufactured according to the national standards must be submitted via a competent authority. For the procedure of creating numerical symbols, see Table 5.1.

*Table 5.1 Creating numerical marking [71]*

| **X.** | **XX** | **XX(XX)** |
|---|---|---|
| Number of the main material group<br>1 - steel<br>2 - 9 – can be assigned to other materials | Number of steel class – marked in accordance with the table of numbers of steel | Serial number.<br>Currently, serial number consists of two digits, the remaining digits (in brackets) is intended for future use |

## 5.1. Marking of steel in some EU countries

Although the EU member countries are gradually starting to use a uniform system of steel marking in accordance with the European standards, it is still possible to encounter steel marked in accordance with the standards of other countries. Steel is marked in all countries that produce it, according to technical standards and also by the individual producers. The following part deals with the marking system in accordance with the technical standards in Germany, France, Great Britain, Italy, Spain and Belgium. There are also previously used symbols which are still possible to encounter in technical documentation.

Individual kinds of steel are marked by symbols consisting of letters, digits, or letters and digits. Various criteria are chosen to create a marking system. The most common is chemical composition. In some other systems it is e.g. tensile strength, and sometimes only a serial number with a symbol of steel used according to the purpose of its use, etc. The letters used in the marking of alloyed steel mean usually mainly alloying elements. As it results from Table 5.3, there used to be used different letter for individual elements in different countries. This has currently been unified in the EU countries.

*Table 5.3 Marking of steel in selected EU countries [71]*

| Element | Symbol | Germany | France | Italy | Spain |
|---|---|---|---|---|---|
| Aluminium | Al | Al | A | A | Al |
| Boron | B | B | B | - | B |
| Carbon | C | - | - | - | - |
| cobalt | Co | Co | K | K | Co |
| Chromium | Cr | Cr | C | C | Cr |
| Copper | Cu | Cu | U | - | Cu |
| Manganese | Mn | Mn | M | M | Mn |
| Molybdenum | Mo | Mo | D | D | Mo |
| Nitrogen | N | N | Az | Az | N |
| Niobium | Nb | Nb | Nb | - | Nb |
| Nickel | Ni | Ni | N | N | Ni |
| Phosphorus | P | P | P | - | P |
| Lead | Pb | Pb | - | - | Pb |
| Silicon | Si | Si | S | S | Si |
| Titanium | Ti | Ti | T | T | Ti |
| Vanadium | V | V | V | - | V |
| Tungsten | W | W | W | - | W |
| Zirconium | Zr | Zr | Zr | - | Zr |

Note: In the case of French and Italian steels, the symbols in the table were used until the mid-eighties. Currently, the symbols used correspond to the German ones.

## 5.2. Steel marking in accordance with German standard DIN

In Germany, steels are marked in two ways:

- By numerical symbol – this determines the number of the material (Werkstoffnummer),
- By combination of numbers and letters.

For the latter method, steels are divided into several groups (see Table 5.4).

*Tab. 5.4 Classification of steels [71]*

| Non-alloyed (carbon) steel | | | Alloyed steels | |
|---|---|---|---|---|
| Non-heat treated, except for normal annealing | Intended for heat processing | | Low alloy steels – content of alloying elements up to 5 % | Super alloy steels – content of alloying elements over 5 % |
| Common steel (including low alloy steels) | Quality steel | Stainless steel | | |

**Marking non-alloyed carbon steels**

- symbol – capital letter designating the method of casting
    - U – rimmed steel
    - R – killed or semi-killed steel
    - RR – fully killed steel

- symbol – letters St
- symbol – a two-digit number indicating the lowest tensile strength in kp/mm2
- symbol – number of group of grade; steels are divided into groups according to the P or S (or C) content,
    - the quality group number is separated from the number giving the lowest strength by a horizontal line.The four symbols make the basic marking of the steel. This could be completed by additional symbols:

**In front of the 1st symbol**

- E – steel manufactured in electric furnace
- M – steel manufactured in open hearth furnace
- Y – steel manufactured in converter

**Between the 1st and the 2nd symbol**

- Q – suitable for cutting
- Z – suitable for drawing of bars
- P – suitable for die forging or forging using forging machines
- Ro – intended for the production of pipes (after the last symbol)
- U – delivered after rolling
- N – delivered in normally annealed condition.

### Marking of non-alloyed quality steels

Marking of these steels indicates the mean carbon content.

- 1st symbol – letter C
- 2nd symbol – number indicating 100 times greater content of carbon.

### Marking of non-alloyed stainless steels

- 1st symbol – letters Ck
- 2nd symbol – number indicating 100 times greater mean content of carbon.

### Marking of low-alloy stainless steels

- 1st symbol – number indicating a 100times higher mean content of carbon
- 2nd symbol – chemical symbols of alloying elements arranged in successive order according to their mean content in steel. Only the elements important for marking steel or for distinguishing between the individual types of steels are given.
- 3rd symbol – mean content of alloying elements expressed by a multiple of the actual mean content in accordance with Table 5.5.

*Table 5.5 Content of alloying elements expressed by a multiple of the actual mean content [71]*

| Alloying elements | Coefficient |
|---|---|
| Cr, Co, Mn, Ni, Si, W | 4 |
| Al, Cu, Mo, Ti, V | 10 |
| P, S, N | 100 |

### Marking of super alloy steels

For these steels, the actual content of the main alloying elements is alleged. Unlike the low alloy steels, the first symbol is letter X.

- 1st symbol – letter X
- 2nd symbol – number indicating a 100times greater mean content of carbon.
- 3rd symbol – chemical symbols of important alloying elements.
- 4th symbol – number indicating the approximate mean content of the main alloying elements.

### World steel producers

In recent years, China has produced 567.8 million tons of steel, thus producing nearly half of the world´s production. The second largest producer is Japan followed by Russia, has surpassed the United States. The production of steel in North America fell by nearly 34 % (23 % in Europe). For more details, see Table 5.8 and Figure 5.12. [60]

The steel industry is beginning to recover from the crisis with a gradual recovery of the world´s economy. Steel production increased year-on-year by 30 % (to 106.4 million tons). However, compared to the 117 million tons of steel produced in the last period, the production has decreased according to Reuters. According to Accenture analyst, John Lichtenstein, world production and demand for steel should rise again by approx. 10 %, and the production will thus increase to the level from the years 2008 – 2010. [71]

Members of WorldAutoSteel:

- Arcelor Mittal – Luxembourg
- Baoshan Iron & Steel Co. Ltd. – China
- China Steel Corporation – China
- Hyundai-Steel Company – South Korea
- JFE Steel Corporation – Japan
- Kobe Steel, Ltd. – Japan
- Nippon Steel Corporation – Japan
- Nucor Corporation – USA
- POSCO – South Korea
- SeverStal – Russia/USA
- Sumitomo Metal Industries, Ltd. – Japan
- Tata Steel & Corus – India, UK, Netherlands
- ThyssenKrupp Stahl AG – Germany
- USIMINAS – Brasil
- United States Steel Corporation – USA
- Voestalpine Stahl GmbH – Austria

*Tab. 5.8  80 largest world steel producers in 2008, mmt – production in million tons [60]*

| 2008 | | 2007 | | | 2008 | | 2007 | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | mmt | Rank | mmt | Company | Rank | mmt | Rank | mmt | Company |
| 1 | 103.3 | 1 | 116.4 | ArcelorMittal | 41 | 6.9 | 40 | 7.4 | Jiuquan Steel |
| 2 | 37.5 | 2 | 35.7 | Nippon Steel[1] | 42 | 6.9 | 41 | 7.3 | Salzgitter[5] |
| 3 | 35.4 | 5 | 28.6 | Baosteel Group | 43 | 6.8 | 43 | 6.9 | voestalpine |
| 4 | 34.7 | 4 | 31.1 | POSCO | 44 | 6.5 | 39 | 7.8 | Jianlong Group |
| 5 | 33.3 | NA | 31.1 | Hebei Steel Group | 45 | 6.5 | 44 | 6.8 | BlueScope |
| 6 | 33.0 | 3 | 34.0 | JFE | 46 | 6.4 | 46 | 6.4 | Metalloinvest |
| 7 | 27.7 | 11 | 20.2 | Wuhan Steel Group | 47 | 6.4 | 47 | 6.4 | Beitei Steel |
| 8 | 24.4 | 6 | 26.5 | Tata Steel[2] | 48 | 6.1 | 60 | 5.2 | Guofeng Steel |
| 9 | 23.3 | 8 | 22.9 | Jiangsu Shagang Group | 49 | 6.1 | 51 | 6.1 | SSAB |
| 10 | 23.2 | 10 | 21.5 | U.S. Steel | 50 | 6.0 | 56 | 5.4 | Erdemir |
| 11 | 21.8 | 8 | 23.8 | Shandong Steel Group | 51 | 5.9 | 54 | 5.9 | AK Steel |
| 12 | 20.4 | 12 | 20.0 | Nucor | 52 | 5.9 | 52 | 6.1 | Mechel |
| 13 | 20.4 | 13 | 18.6 | Gerdau | 53 | 5.7 | 53 | 6.0 | Nanjing Steel |
| 14 | 19.2 | 15 | 17.3 | Severstal | 54 | 5.6 | 42 | 7.0 | Ilyich |
| 15 | 17.7 | 17 | 16.2 | Evraz | 55 | 5.4 | 61 | 5.0 | Tonghua Steel |
| 16 | 16.9 | 14 | 17.9 | Riva | 56 | 5.3 | 56 | 5.6 | Xinyu Steel |
| 17 | 16.0 | NA | 16.2 | Anshan Steel | 57 | 5.2 | 57 | 5.5 | HKM[6] |
| 18 | 15.9 | 16 | 17.0 | ThyssenKrupp[3] | 58 | 5.1 | NA | 4.5 | Sanming Steel |
| 19 | 15.0 | 18 | 14.2 | Maanshan Steel | 59 | 5.0 | 59 | 5.3 | CSN |
| 20 | 14.1 | 20 | 13.8 | Sumitomo Metal Ind | 60 | 4.7 | 63 | 4.6 | HADEED |
| 21 | 13.7 | 19 | 13.9 | SAIL | 61 | 4.5 | 68 | 4.4 | Tianjin Tiantie Group |
| 22 | 12.2 | 23 | 12.9 | Shougang Group | 62 | 4.4 | 72 | 4.0 | Hebei Jinxi Group |
| 23 | 12.0 | 21 | 13.3 | Magnitogorsk | 63 | 4.3 | 62 | 5.0 | Steel Dynamics |
| 24 | 11.3 | 30 | 9.7 | Novolipetsk | 64 | 4.3 | 69 | 4.1 | Pingxiang Steel |
| 25 | 11.3 | 26 | 11.1 | Hunan Valin Group | 65 | 4.3 | 65 | 4.5 | Ezz Group |
| 26 | 11.0 | 27 | 10.9 | China Steel Corporation | 66 | 4.0 | 71 | 4.1 | Nisshin |
| 27 | 10.4 | 22 | 13.1 | Techint[4] | 67 | 4.0 | 70 | 4.1 | Tianjin Steel |
| 28 | 10.0 | 28 | 10.1 | IMIDRO | 68 | 3.9 | 64 | 4.6 | Zaporizhstahl |
| 29 | 9.9 | NA | 11.6 | Industrial Union of Donbass | 69 | 3.8 | NA | 3.0 | JSW Steel |
| 30 | 9.9 | 29 | 10.0 | Hyundai Steel | 70 | 3.7 | 73 | 4.0 | Lion Group |
| 31 | 9.8 | 34 | 8.8 | Baotou Steel | 71 | 3.7 | 75 | 3.5 | AHMSA |
| 32 | 9.2 | 31 | 9.3 | Taiyuan Steel | 72 | 3.7 | NA | 3.0 | ICDAS |
| 33 | 9.0 | 33 | 9.0 | Anyang Steel | 73 | 3.6 | NA | 4.3 | SIDOR[6] |
| 34 | 8.2 | 32 | 9.1 | Metinvest | 74 | 3.6 | 78 | 3.5 | Hangzhou Steel |
| 35 | 8.2 | 37 | 8.1 | Celsa | 75 | 3.5 | NA | 2.7 | Hebei Jingye Steel |
| 36 | 8.1 | 38 | 8.1 | Kobe Steel | 76 | 3.5 | 77 | 3.5 | Chongqing Steel |
| 37 | 8.0 | 35 | 8.7 | Usiminas | 77 | 3.4 | NA | 2.7 | Commercial Metals |
| 38 | 7.5 | 45 | 6.6 | Panzhihua Steel | 78 | 3.4 | 74 | 3.6 | Essar Steel |
| 39 | 7.5 | 50 | 6.2 | Rizhao Steel | 79 | 3.4 | 79 | 3.5 | Tokyo Steel |
| 40 | 7.4 | NA | 7.6 | Benxi Steel | 80 | 3.1 | NA | 3.2 | Vizag Steel |

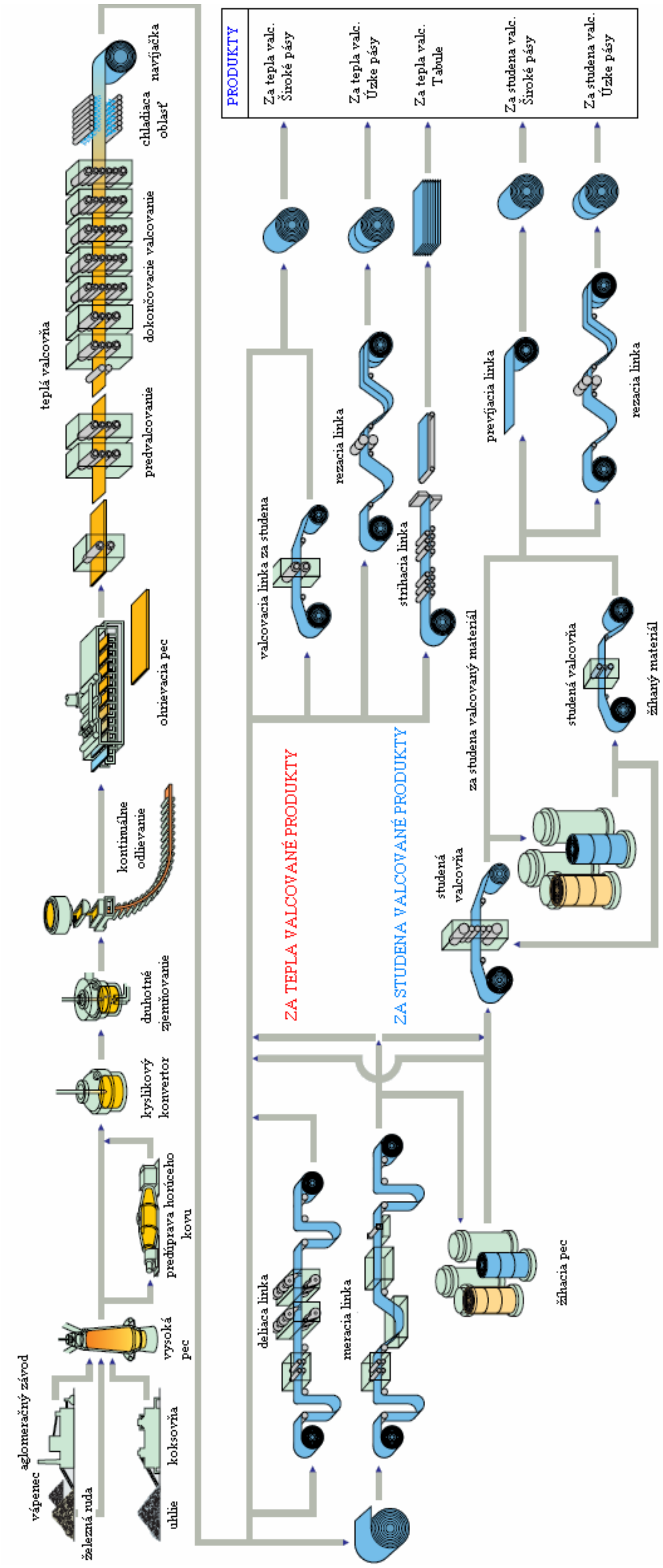


*Figure 5.12 Production processes of steel sheets [71]*

# 6.EVALUATION OF MATERIAL SURFACE

The surface of industrial parts and components or workpieces can be described as a physical borderline between a workpiece and the environment. The actual surface of the workpiece is defined by international standards (ISO) as a set of characteristic properties that physically exist and distinguish the workpiece from the surrounding environment. It shouldn´t be assumed that the workpiece surface has a purely mechanical character. In fact, the surface has also electromagnetic character. [92]

There are more definitions in accordance with the ISO:

- **The real mechanical surface** is a limit area determined by the ball contact with the radius *r*; the geometric location of the centres of the ideal ball contact, also with the radius *r*, rolling off the real surface of the workpiece.

- **The real electromagnetic surface** is a geometric location of effective reflection of the points of the real workpiece surface, electromagnetic radiation of the specified wavelength.

The ISO 4287 standard is currently the main valid international standard which specifies the terms, definition and parameters related to surface. These parameters correspond to various parts of a signal that is generated by the touch.

Parameters are marked by different letters:

**P** – primary profile,
**R** – roughness profile,
**W** – Waviness profile.

## 6.1. Material surface evaluation – main parameters

Height of profile Z(x) – is the value of the coordinate Z(x) at any location x. [92]
Local slope dZ/dX – it is a slope of the profile at the point x, Figure 6.1.

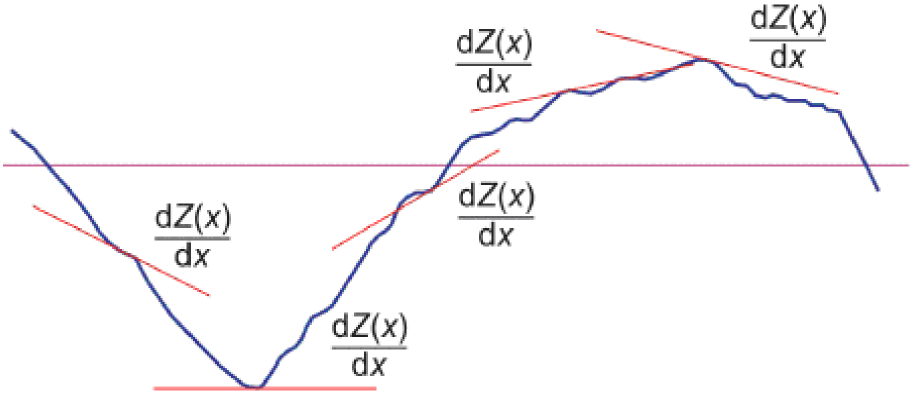


*Figure 6.1 Local slope [92]*

**Profile peak** – it is a part of the profile connecting its adjacent intersegments with the middle line of the profile outwards the material.

**Profile valley** – it is a part of the profile connecting its two adjacent intersegments with the middle line of the profile inwards the material.

**Profile element** – it is a peak of the profile and the connected profile valley, Figure 6.2.

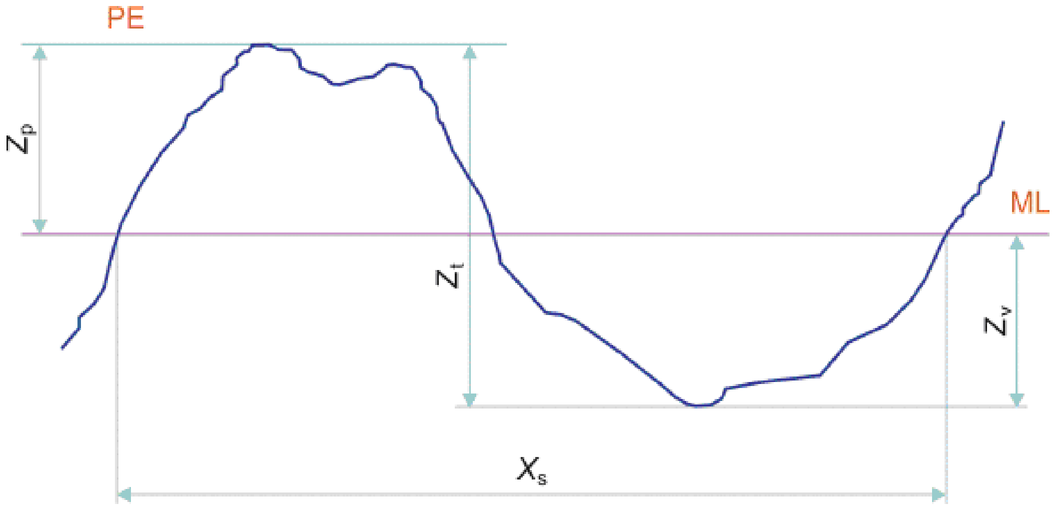


*Figure 6.2 Profile element [92]*
*PE – profile element, ML – middle line*

Height of the profile peak Zp – is a distance between the middle line of the profile and the highest point of the profile, Figure 6.2.

The depth of the profile valley Zv – is a distance between the middle line of the profile and the lowest point of the profile valley, Figure 6.2.

Height of the profile element Zt – it is the sum of the peak height and valley depth, Figure 6.2.
Profile element spacing Xs – it is the length of the segment of the profile middle line containing the profile element, Figure 6.2.

Material length of the profile, level c Ml(c) – it is the sum of the lengths of the segments created by a cut parallel with the middle line of the profile at the level c by separating the profile peaks in the sampling length, Figure 6.3, [92].

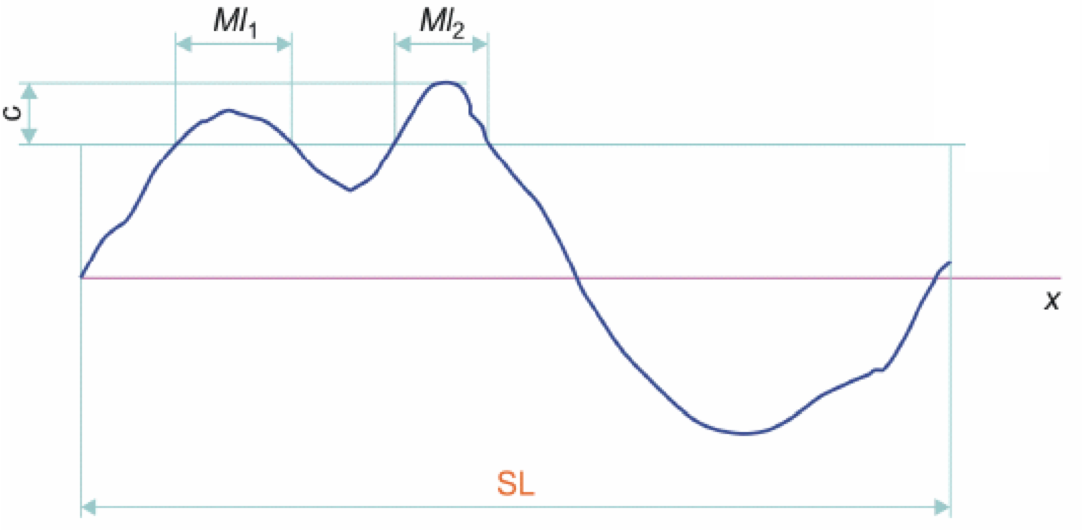


*Figure 6.3 Material length [92]*
*Ml(c) = Ml1 +Ml2, SL – sampling length*

The peak of the highest profile peak Pp, Rp, Wp – it is the highest height of the profile peak Zp in the sampling length, Figure 6.4. [92]

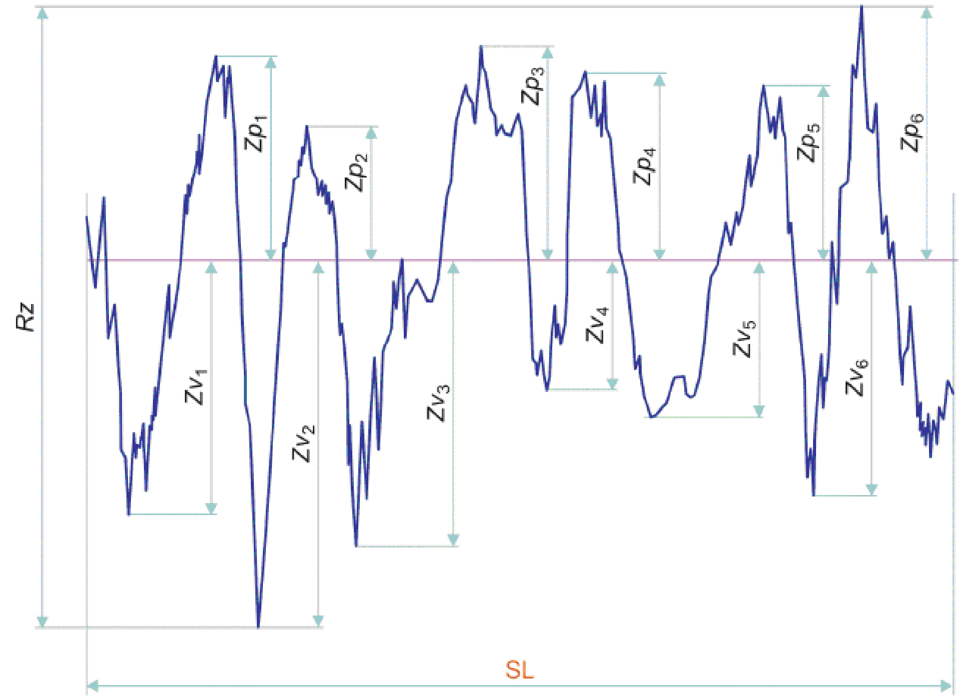


*Figure 6.4 Sampling length (example of roughness profile) [92]*

The depth of the deepest valley in the profiles Pv, Rv, Wv – the deepest valley of the profile Zv in the sampling length.

The highest profile Pz, Rz, Wz – it is the sum of the peak of the peak Zp and the deepest valley of the profile Zv in the sampling length.

Medium height of the profile element Pc,Rc, Wc – it is the medium value of the heights of the profile elements Zt in the sampling length.

$$P_c, R_c, W_c = \frac{1}{m}\sum_{i=1}^{m} Zt_i \qquad (6.1)$$

The total height of the profile Pt, Rt, Wt – it is the sum of the height of the highest profile peak Zp and the depth of the profile valley Zv in the evaluated length. [92].

The medium arithmetic deviation of the profile Pa, Ra, Wa – it is the medium arithmetic value of the absolute profile deviations Z(x*)* in the sampling length.

$$P_a, R_a, W_a = \frac{1}{l}\int_0^l |Z(x)|dx \qquad (6.2)$$

## 6.2. Parameters for evaluation of 3D surface roughness

**Amplitude parameters** used in 3D evaluation derived from 2D parameters according to ISO 4287:

- $S_a$ – average arithmetic deviation of surface
- $S_q$ – mean square deviation of surface
- $S_t$ – total height of profile
- $S_p$ – maximum peak height
- $S_v$ – maximum valley depth
- $S_z$ – ten point surface height
- $S_{sk}$ – skewness of height distribution curve
- $S_{ku}$ – sharpness of the surface heights

**Area and volume parameters:**

- $S_{mr}$ – ration in a given depth (areal material ration) – it is given with a limit value and reference data.
- $S_{dc}$ – height difference of the surface cuts – determined by two limit values (in %). [9]
- $S_{mvr}$ – the mean value of the empty space radius – the volume of the surface material obtained by measuring the space between the imaginary horizontal plane folded at the largest depth of the surface profile and the surface points.
- $S_{mmr}$ – mean value of the material volume portion – the total volume of the material surface obtained by measuring the space between the imaginary horizontal plane folded at the largest depth of the surface profile and the surface points, [12], [92].

**Spatial parameters:**

- $SP_c$ – number of peaks on the surface – density of peaks between two levels c1 and c2, where c1 and c2 are limit planes defined in relation to the median plane 0. c1 must be lower than c2. The peak is taken into account only if it exceeds c2 and passed under c1. The parameter is expressed by the number of peaks per $mm^2$ . [9]
- $S_{ds}$ – summit density – number of summits per mm. summits are derived from peaks. A peak is a summit that is higher than 8 nearest points.
- $S_{al}$ – auto-correlation length – length corresponding to the fastest decrease in autocorrelation function. It expresses the number of wavelengths of the surface profile. High values indicate high wavelengths.
- $S_{tr}$ – texture aspect ratio – ratio of the shortest drop to the largest length. It ranges from 0 to 1. If the value approaches to 1, the surface is isotropic, if it is close to 0, the surface is anisotropic.

- $S_{td}$ – texture direction – it determined the main angular direction of the surface texture. It is meaningful if the value is lower than 0.5. The angular direction is expressed in degrees between -90°and 90°.
- $S_{fd}$ – fractal dimension of surface – it indicates the shape complexity of the surface profile using the theory of fractal geometry. The surface dimension varies between two values for a planar surface and three values for a complex shape of a plane. For some surface shapes, fractal dimension cannot be determined, [92].

**Hybrid parameters** – combine both amplitude and spatial parameters:

- $S_{dq}$ – quadratic slope of the surface
- $S_{sc}$ – arithmetic mean of the summits curvature
- $S_{dr}$ – developed interfacial area ratio

**Functional parameters** – characterize functional aspects of the surface:

- $S_k$ – core roughness depth – extended 2D parameter $R_k$
- $S_{pk}$ – reduced peak height – extended 2D parameter $R_{pk}$
- $S_{vk}$ – reduced valley depth – extended 2D parameter $R_{vk}$
- $S_{r1}$ – upper material ratio
- $S_{r2}$ – lower material ratio
- $S_{a1}$ – upper area (of a triangle, corresponding to peaks)
- $S_{s2}$ – lower area (of a triangle, corresponding to valleys)

**Parameters $R_k$**

- $S_{bi}$ – surface bearing index
- $S_{ci}$ – core fluid retention index
- $S_{vi}$ – valley fluid retention index

**Parameters SURFSTAND**

- Vm(h) – material volume at a given depth
- Vv(h) – void volume at a given depth
- Vmp – peak material volume
- Vmc – volume of the material of the core
- Vvc – core void volume
- Vvv – valley void volume

**Flatness parameters** for the surface smoothed using the least squares method and filtered by low pass filter:

- FLTt – peak to valley flatness deviation
- FLTp – peak to reference flatness deviation
- FLTv – reference to valley flatness deviation

- FLTq – root mean square flatness deviation [12], [92].

**Comparison of 2D and 3D**

Currently, 2D and 3D methods of surface evaluation have been developed and upgraded. In terms of 2D evaluation, parameters Ra and Rz are still being widely used because of easy measuring of the mean roughness values, international standards or due to their clarity and the fact that the metrology has been based on these parameters from the very beginning. In terms of measuring roughness, parameters Ra, Rz are still very important, but practically impossible to use in evaluating functional properties.

The reason is that different surfaces can have the same roughness value but the prerequisites for performing the function are different, e.g. upper profile (Figure 6.16) can better perform the sliding bearing function than the lower profile. [10]

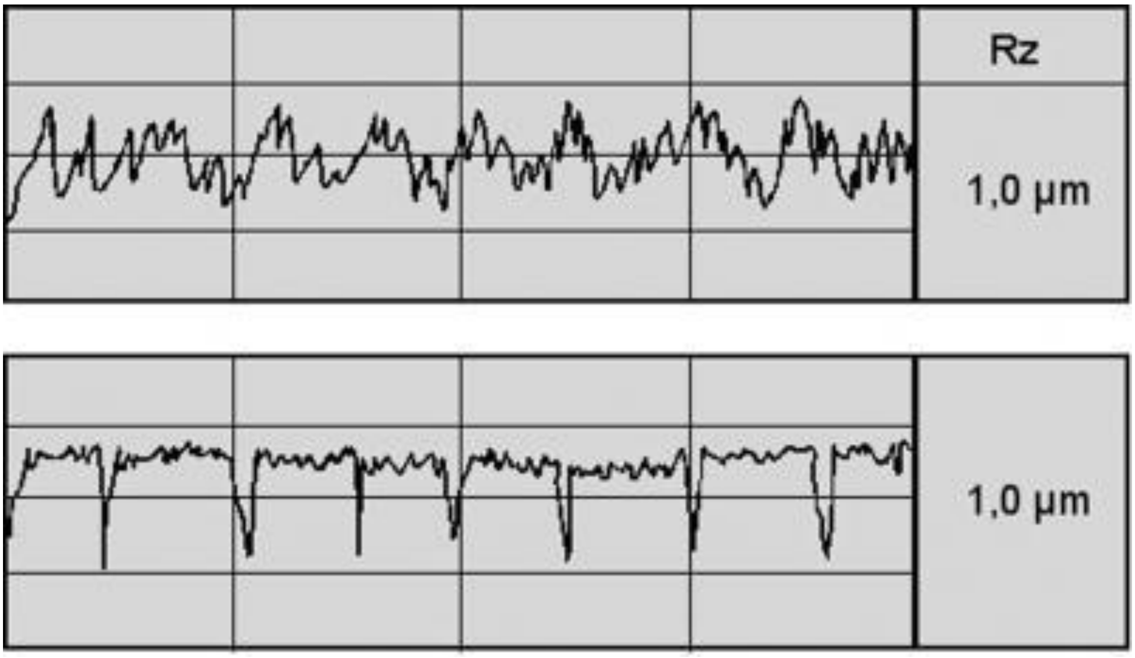


*Figure 6.5 Measuring with contact profilometer – Rz values with different functions [7]*

2D parameters cannot provide information about the wear rate of the individual surface textures, about the ability to retain lubricant or about the proneness to cracking caused by machining. For a full application, some parameters need other information than only numerical value, as e.g. the direction of the machining marks is. The parameter describing this direction is more a vector than a scalar. For two surfaces with peaks of the same height, out of which one surface peaks point to the right and second to the left, the parameters Ra, Rq will be the same. However, the direction of the relative movement will be different due to the edges loaded. If such surfaces are mounted in a wrong direction, it could cause malfunction. It is important of pay attention not only to one surface but the whole system, which consists of several surfaces. Evaluation of the surface function thus cannot be separated from the whole system. [10]

The main disadvantage of the 2D evaluation is the fact that the results are limited and dependent on the position of the controlled section. Measuring often shows a location with more pronounced height surface deviations. However, it is not possible to evaluate the character and the extent of bigger deviations, which represent defects or surface damage, based on one profile only. 3D measuring provides much more data, which increases the objectivity of the surface evaluation. Axonometric evaluation enables to specify the extent of the more pronounced deviations.

In practice, when analysing a larger surface defect, it is recommendable to combine a 2D and 3D evaluation. In the case of a 3D analysis of a deep cracking, whose depth cannot be measured precisely, it is recommendable to record one section profile, which enables to evaluate the cracking dimensions and record in detail its shape, which enables to obtain more detailed information for identifying the cracking effect on the surface function Figure 6.17.

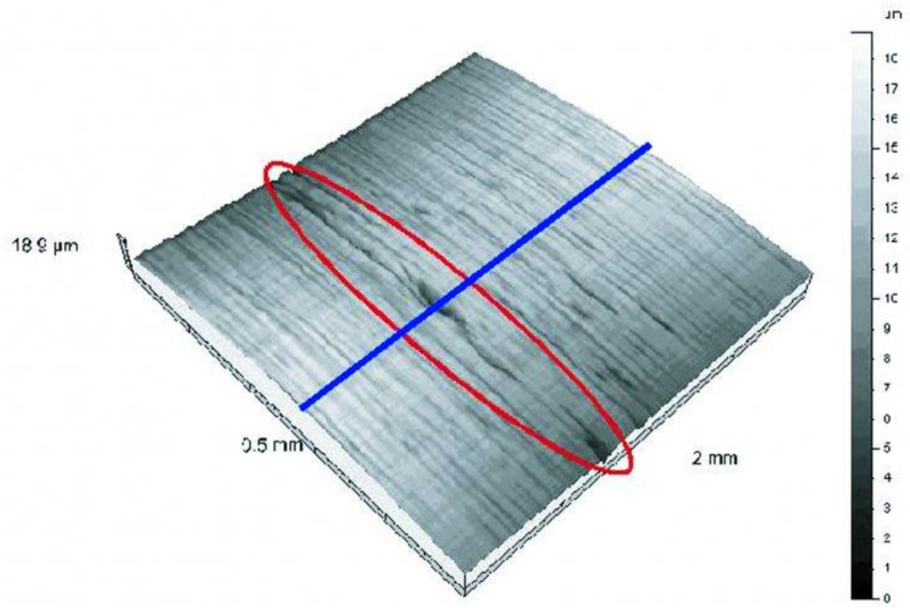
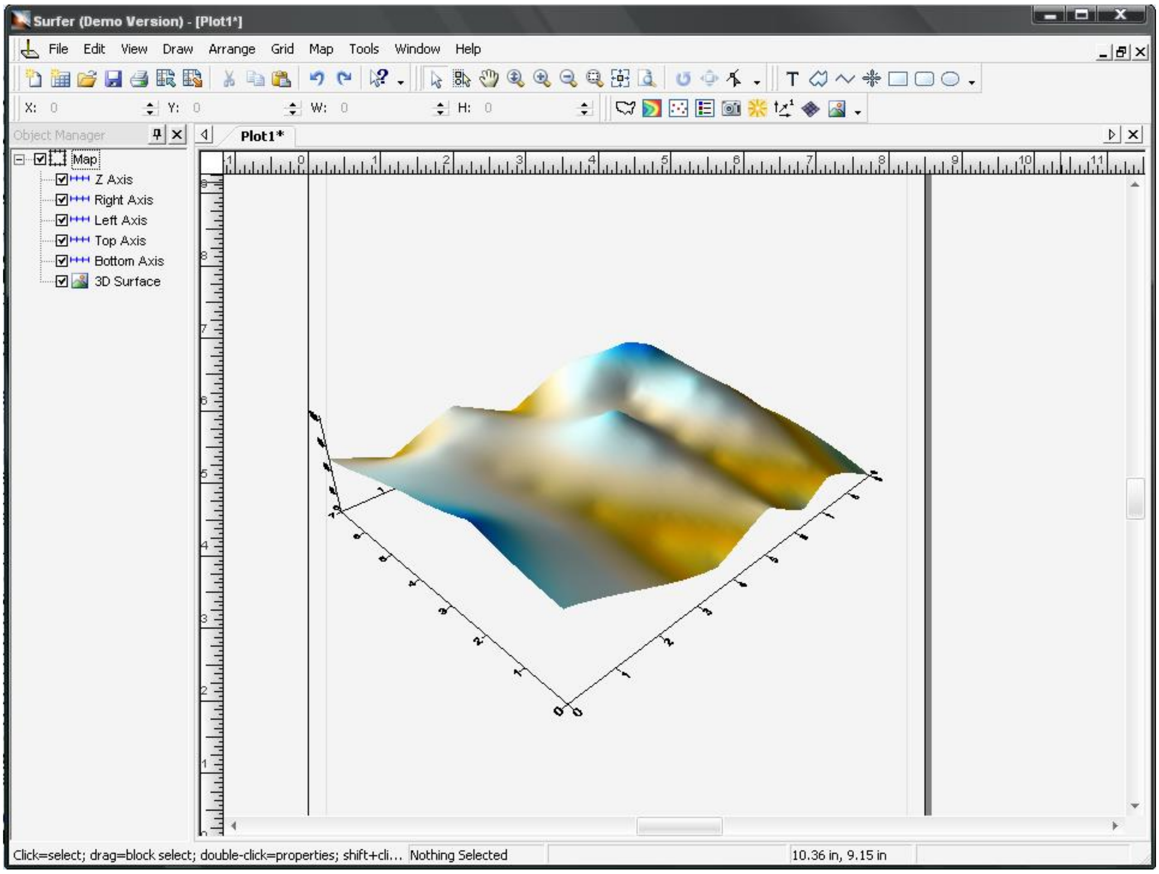


*Figure 6.6 3D viewing of surface with cracking with marked subsequent 2D section [10]*



Click=select; drag=block select; double-click=properties; shift+cli... Nothing Selected 10.36 in, 9.15 in

*Figure 6.7 Example of 3D view of surface in programme Surfer 9 [92]*

# 7. MEASUREMENT EQUIPMENT AND PROGRAMMES

In developing new products, producers of measurement equipment put great emphasis on processing of the data measured. Measurement equipment is thus delivered with modern special computer programmes. These programmes are often compatible only with a concrete measurement device and vice versa. Such solutions are characteristic for the systems in which the software not only evaluates the data measured, but performs also control and monitoring functions.

## 7.1. Optosurf QS 500

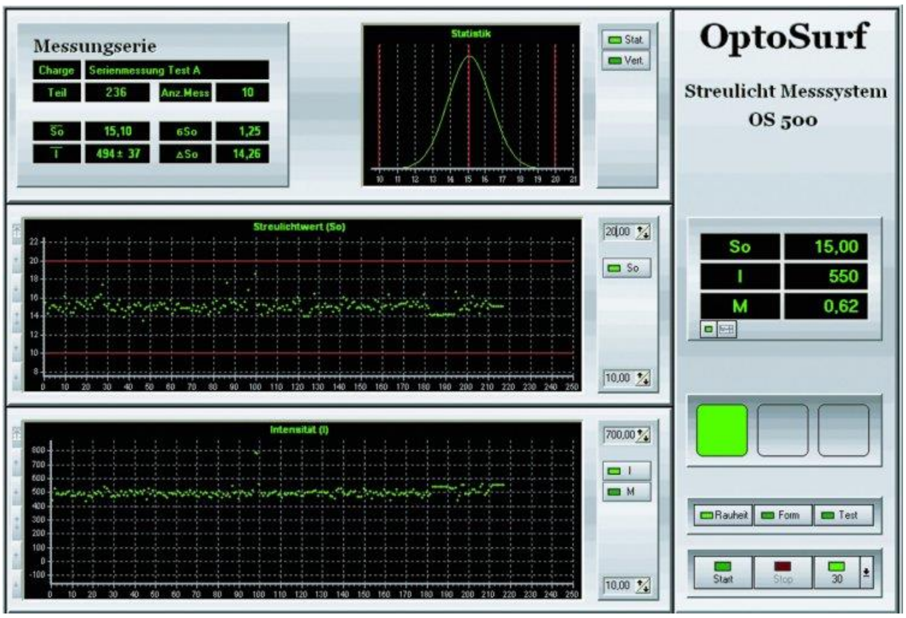
Optosurf QS 500 (see Figure 6.18) uses light scattering methods. The principle of this method consists in lightning the surface with a light spot of a 0.9-mm radius. Reflected scattered light is sensed by a sensor. Scattering is statistically evaluated and by calculation, the optical parameter of roughness S0 is obtained that roughly corresponds to the parameter of the. Measurement does not depend on the surface reflection, which means that dark surfaces have the same roughness value as light surfaces. It is possible to measure all functional components surfaces. The sensor is able to measure reliably even in unfavourable operational conditions and is also able to handle vibrations.

*Figure 6.18 Measuring using sensor QS 500 [7]*

This measurement is used as an additional measurement to conventional contact measurement methods, but its measurement speed is much higher – over 1000 measurements per second. However, measurement speed is not the main parameter that sets the light scattering method before the contact methods. In practice, it is often necessary to know the direction of the marks after machining or to recognize the machining method. An example can be e.g. grinding and finishing of crankshafts in engines manufacturing.  The result of grinding is the structure of engravings with profile tips. During finishing, the tips are party removed, which significantly improves the functional properties, reduces friction and wear. The light scattering method enables to distinguish grinded surfaces from finished, while in the case of contact methods there is an overlap in which these surfaces cannot be distinguished from each other. [7]

## 7.2. Software SW 500

Sensor QS 500 is used with the software SW 500 (Figure 6.19), which is intended for collecting the data measured, it operates the sensor and stores the data in SQL database.


Messungserie
Charge Serienmessung Test A
Teil 236 Anz.Mess 10
$\overline{So}$ 15,10 6So 1,25
$\overline{I}$ 494± 37 ΔSo 14,26

So 15,00
I 550
M 0,62

*Figure 6.19 SQL database for storing results of measurement [7]*

Establishing limit values enables fully automated production, where the components exceeding the limit values are automatically discarded. Simple statistical functions calculate mean deviation, standard deviation, and maximal deviation based on the values measured. Also the statistics of all tools used in production is kept, thus enabling to document the production process. The scattered light sensor controls the production process and provides continuous information on the machine status.

This enables detection of problems, such as cooling failure, bearing damage, wear of the production tool, etc.

## 7.3. Taylor Hobson Talysurf CLI

Measuring system designed for fast spatial measuring and evaluation of the surface with high resolution. It enables to measure in three axes by contact and contactless method and subsequent analysis of the data from one profile section and surface area section. In the case of the contact method, an inductive touch sensor is used, while in the case of contactless method it is a laser triangular probe and CLA confocal sensor. These methods provide almost unlimited possibilities in measuring the surface structure in terms of quality, accuracy and type of material. The device is equipped with automatic feed in all axes with the speed not exceeding 30 mm/s. In the case of contact induction measuring tool it is 3 mm / s. For measuring, it is possible to use four different measuring heads. Although this device is specially designed for 3D measuring, it contains also mechanical and analytical tools for a complex 2D measurement. This enables to use one device for monitoring research and development, conduct study analyses, routine inspections or manage production processes, (Figure 6.20). [9]

*Figure 6.20 Talysurf CLI 2000 [92]*

## 7.4. Talymap

Talymap is designed to process spatial characteristics from the data obtained by contact and contactless measuring. It enables to view the monitored surface in more ways, e.g. in axonometric projection with an optional angle, colour resolution, and adjustable increase of a part or the whole surface. It is possible to measure in three axes, display profile inversion or simulation of surface wear. One of the greatest advantages of this programme is its versatility in terms of processing the data obtained from different measurement equipment (Figure 6.21).

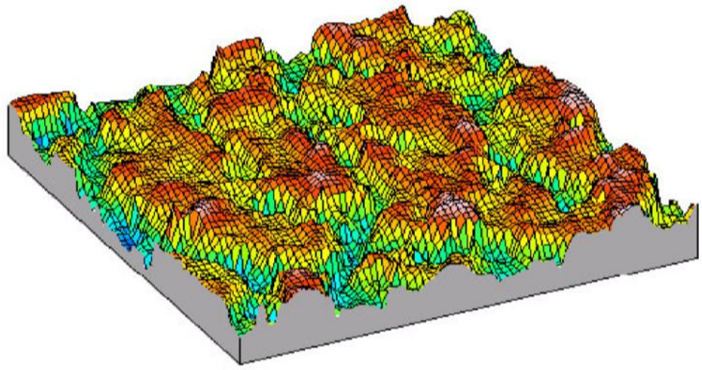


*Figure 6.21 Surface in programme Talymap [92]*

For spatial evaluation of surface, amplitude parameters, parameters describing the material surface, parameters related to unevenness, and volume parameters. In total, it is possible to use 120 parameters in 2D view and 40 parameters in 3D view. In 3D profile it is possible to choose one profile that can be evaluated by 2D functions.

There are also a number of progressive specialized modules that are intended for evaluating surface parameters and properties important for a specific function, such as wear, damage, surface erosion.

## 7.5. Module Textured Surfaces

This module is intended for 3D evaluation of a complex material surface. It calculates areas and volumes, maximal and minimal peak heights and valley depths in relation to height limit established by user. The data are important in terms of determining the ability of the surface to retain lubrication or for predicting the durability of functional surface in wear. [9]

For graphical representation of the results, the function "Coloured Binary Image" is used, which uses 256 colours to create a height scale or 2 colour for dividing a surface into the areas above and below the selected height limit.

## 7.6. Talymap Wear

It is used for 3D analysis of surface wear. It allows 3D data filtering before the analysis using Gaussian method, spline method, three-point method or the least squares method. Filtration consists in removing short wavelengths, which improves stability and repeatability. Surface wear is evaluated by means of comparing the surface before wear and after wear (Figure 6.22).

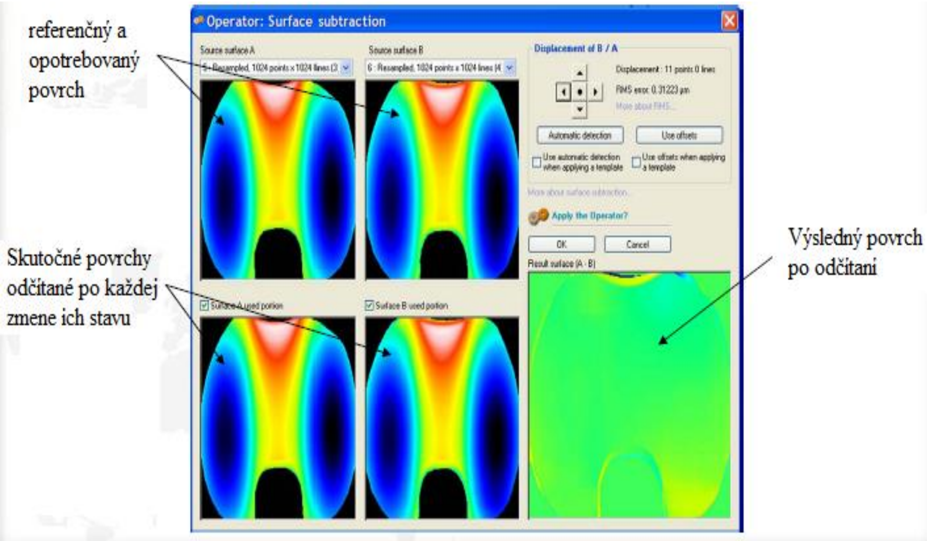

Operator: Surface subtraction
Source surface A: 5 : Resampled, 1024 points x 1024 lines (3
Source surface B: 6 : Resampled, 1024 points x 1024 lines (4
Displacement of B / A
Displacement : 11 points 0 lines
RMS error 0.31223 µm
☐ Use automatic detection when applying a template
☐ Use offsets when applying a template
☑ Surface A used portion
☑ Surface B used portion

*Figure 6.22 Analysis of surface wear using Talymap Wear [92]*

**Legend: referečný a opotřebovaný povrch – reference and worn out surface, skutočné povrch odčítané po každej zmene ich stavu – actual surfaces removed after each change of their state, výsledný povrch po odčítání – final surface**

## 7.7. Step Height Analysis programme

It is used to determine and evaluate the vertical dimensions, e.g. thickness of thin coatings, elevation or shallow depth. This analysis is important in the application or removal of material using mechanical, chemical or other methods. The programme can calculate the average height of a selected area or the difference between heights of more areas. When selecting two points of a surface, it determines their horizontal distance, mutual elevation and slope. For the calculation, several methods can be used, including interactive manual method.

## 7.8. Twist programme

It is a programme for analysis of spatial surface texture used for evaluation of roughness and roundness. After obtaining a sufficient amount of data, a spatial surface map is created. The texture analysis itself is divided into filtration and determining the parameters. By analysing the dominant wavelength, filter type and the size of the limiting wavelength is determined. If no dominant wavelength is found, Gaussian filter is used and the users choose their own limiting wavelength. After evaluating the dominant wavelength, the data are processed by ZBP (Zero Band-Pass) filter. The value of the limiting wavelength is equal to the dominant wavelength (Figure 6.23). [92]

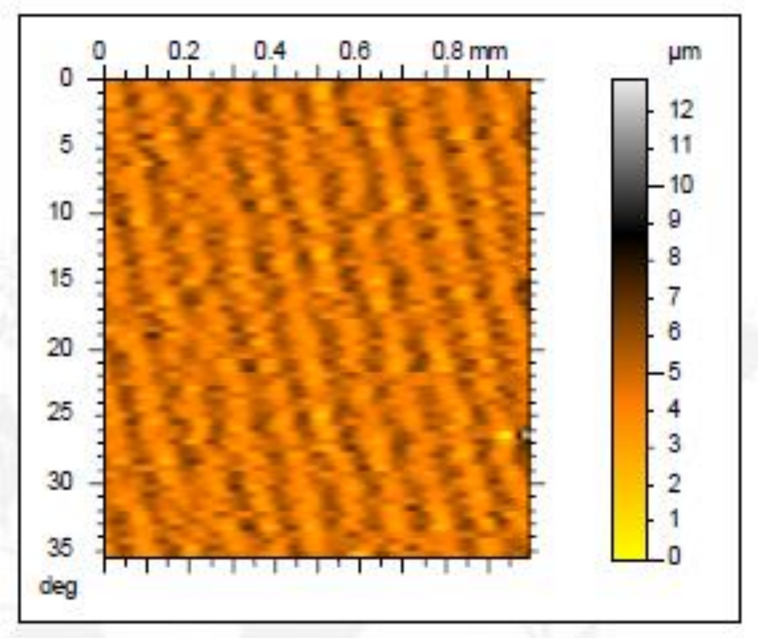


*Figure 6.23 Example of filtered surface [92]*

The surface profile data are then processed by Fourier transform, which evaluates the following basic parameters: wavelength of the surface tracks in the axial direction, the frequency and direction of the tracks in the circumferential direction, the average amplitude. Other parameters are derived from the basic parameters: the average value of the cross-section, gradient, and angle. The analysed surface can be viewed in axonometry (Figure 6.24).

*Figure 6.24 Axonometric continuous image of machined surface [92]*

## 7.9. Mitutoyo Surftest SJ-400

In this case, it is a manual tool designed for measuring roughness, waviness, and primary profile. It has its own display for displaying the selected parameters. It also enables automatic calibration, adjustment of the inclination, upside down measurement, setting the measurement conditions. It contains integrated statistical functions for evaluation, but there is also a possibility of a connection to Surfpak-SJ (evaluation software – Figure 6.25).

*Figure 6.25 Surftest SJ-400 [92]*

## 7.10. Software Surfpak SJ/SV/PRO

Surftest is supplied with the software Surfpak SJ/SV/PRO, which ensures controlling of the device, evaluation of the values measured and processing of the documentation. This programme is able to process a large number of roughness parameters included in the standards DIN, ISO, JIS, Motif, etc. It enables various types of graphical analyses, SD topography, displaying a profile cross-section, etc. (Figure 6.26).

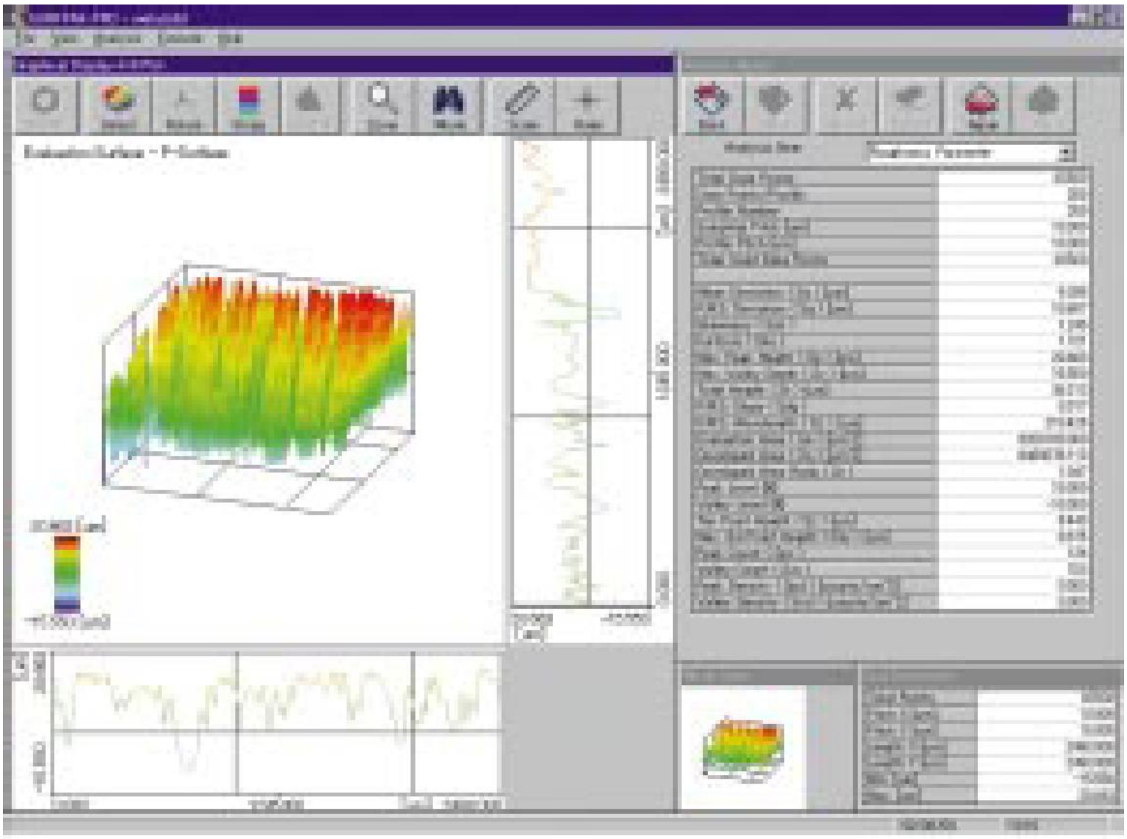


*Figure 6.26 Example of evaluation of measurement by Surfpak-PRO [92]*

## 7.11. Surfer 9 programme

Unlike the previous programmes, Surfer 9 is not connected to any measurement device nor it is primarily specially designed for evaluating the roughness or waviness parameters. It can transform XYZ date into outline maps, 3D surface maps, 3D wireframes, terrains, post maps, vector maps or basic maps. It is also able to calculate various sections, areas, or volumes. Input data can be imported from a large number of various types of sets, Figure 6.27.

# 8.MATERIALS IN CURRENT PRODUCTION OF AUTOMOBILES I.

New trends in the development of automotive consist in the following principles: increasing the safety of the crew, reducing fuel consumption, increasing the comfort and convenience. In terms of developing the mid-size cars, the trend set by economic studies is to achieve the fuel consumption of 2.6 l/100 km in 2020. Meeting such contradictory requirements is only possible by reducing the car weight. While the weight of a mid-size car in 1960 was about 2400 kg, in 2000 it was about 1450 kg. This value shall be 870 kg by 2020, which is, compared to 2000, a 40% reduction.

The analysis of the current mid-size car weight showed the following proportional weight distribution of basic groups and equipment: bodywork – 26 %, chassis 23 %, engine 21 %, liquid media 5 %, electrical equipment 8 % and others 17 %.

The average weight of a European car in 2000 was 1100 kg with the following material composition: steel and cast iron (62 %), non-ferrous metals (Al, Mg) and their alloys (8 %), plastics (10 %), rubber (5 %), glass (3 %), textile and noise insulation (4 %), liquids and other materials (8 %).

It follows from the analyses that 62 % of the overall weight falls on steel, or cast iron, and 30 % of a passenger car production costs are material costs. As a result, the attention of automotive designers focuses mainly on the reduction of the most widely used material – steel, which is the basis of the structural parts (bodywork, chassis, engine, etc.). Chrysler has future intentions of reducing its cars weight: bodywork (-50 %), chassis (- 50 %), engine (- 10 %), fuel system (- 55 %).

Metallurgy reacted to the challenges resulting from the economic studies as well as the requirements of automotive designers and manufactures by research and development of materials and technologies in two basic directions: developing materials and technologies for manufacturing lightweight aluminium / steel based (ultralehký) bodyworks. Given that regarding the necessary energy consumption needed for primary metallurgical production technologies, the global trend is in favour of research and development of steel materials, the following part will be focus on this trend.

The development of automotive, automation of production processes focuses on reducing the weight, increasing of safety and corrosion resistance of bodyworks while increasing the production efficiency and reduction of production costs. In terms of construction and utility properties of the resulting product, the objective is to reduce the thickness of sheet metal, which means to increase its strength and dynamic load bearing capacity. Currently, steel sheets and strips produced can be divided from different points of view:

- by the method of steel production:
    - cast,
    - continuous casting,
    - vacuum casting,

- by the method of rolling:
    - hot rolling,
    - cold rolling,
- by surface protection:
    - non-surface treated,
    - surface treated,

- by use:
    - structural,
    - suitable for forming,
    - for packaging,
    - for engineering industry,

- by strength and plastic properties, chemical and structural composition:
    - textured low-carbon zinc-killed steels (LC, ULC, SULC),
    - interstitial free steels (IF steels),
    - bake hardenable steels (BH steels),
    - dual-phase steels (DP steels),
    - complex phase steels (CP steels),
    - high-strength low-alloy steels (HSLA),
    - transformation induced plasticity steels (TRIP steels),
    - martensitic steels ( M steels) [71].

Structural steel materials for automotive are constantly developed. In the 1980s, classic high-strength cold-formed steels (ZStE) were supplemented with phosphor-alloyed steels ZStE–P and dual-phase steels (DP). In the mid-eighties, IF (interstitial free) steels and BH (bake hardening) steels were developed. Since the 1990s, also CP (complex phase) steels have been developed, as well as RA (residual austenite) steels with TRIP effect, SULC (super ultra-low carbon) steels and MS (martensitic) steels. [71], [82].

The requirements for steel sheets for automotive can be summarized in the following points:

- Strength and plastic properties
- Technological malleability
- Weldability
- Corrosion-resistant
- Suitable surface for surface treatment
- Low weight

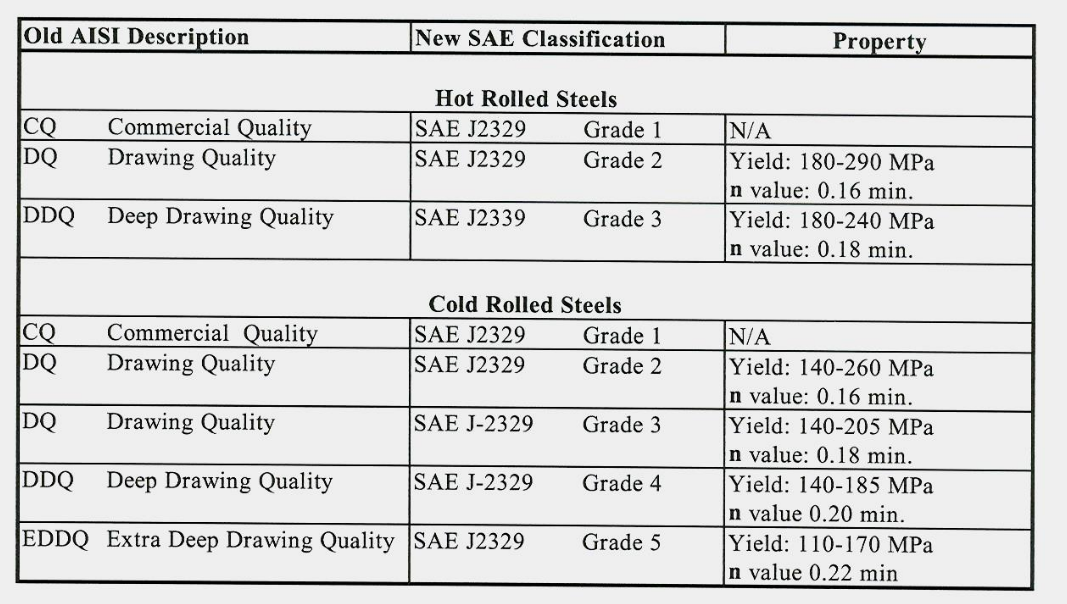
## 8.1. Low carbon steel sheets and strips for cold drawing

Steel sheets are produced by both hot and cold rolling. In terms of the processed amount, the prevailing are cold-rolled steel sheets. They are available in the form of coils and sheets of a 0.20-2.00-mm thickness. According to the degree of suitability for forming, cold-rolled sheets are divided into five groups [76]:

- MT – common quality steel (CQ)
- ST – drawing quality steel (DQ)
- HT – drawing quality steel (DQ)
- VT – deep drawing quality steel (DDQ)
- ZT – extra deep drawing quality steel (EDDQ)

New classification of low carbon steel sheets for automotive SAE J2329 is shown in Table 1. The steel sheets in the Table are classified by the production method: hot rolled steel and cold rolled steel, together with the minimal required properties that represent yield strength and minimum value of the strain hardening exponent n.

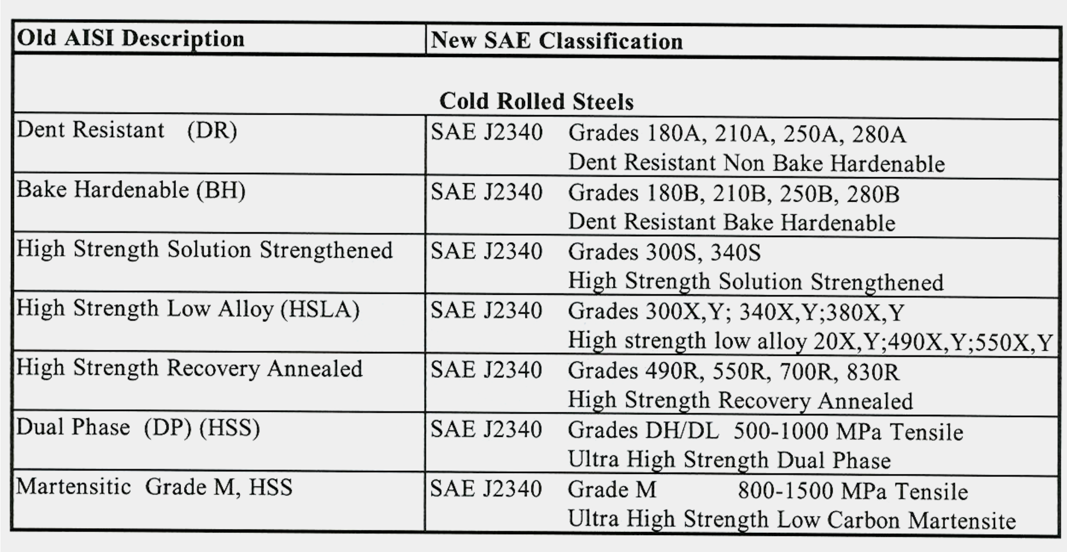
*Table 1 Classification of low carbon steel sheets for automotive [71]*



| Old AISI Description | | New SAE Classification | | Property |
|---|---|---|---|---|
| | | **Hot Rolled Steels** | | |
| CQ | Commercial Quality | SAE J2329 | Grade 1 | N/A |
| DQ | Drawing Quality | SAE J2329 | Grade 2 | Yield: 180-290 MPa<br>**n** value: 0.16 min. |
| DDQ | Deep Drawing Quality | SAE J2339 | Grade 3 | Yield: 180-240 MPa<br>**n** value: 0.18 min. |
| | | **Cold Rolled Steels** | | |
| CQ | Commercial Quality | SAE J2329 | Grade 1 | N/A |
| DQ | Drawing Quality | SAE J2329 | Grade 2 | Yield: 140-260 MPa<br>**n** value: 0.16 min. |
| DQ | Drawing Quality | SAE J-2329 | Grade 3 | Yield: 140-205 MPa<br>**n** value: 0.18 min. |
| DDQ | Deep Drawing Quality | SAE J-2329 | Grade 4 | Yield: 140-185 MPa<br>**n** value 0.20 min. |
| EDDQ | Extra Deep Drawing Quality | SAE J2329 | Grade 5 | Yield: 110-170 MPa<br>**n** value 0.22 min |

New classification of other steel sheets for automotive according to SAE J2340 is shown in Table 2.

*Table 2 Classification of other steel sheets for automotive [71]*



| Old AISI Description | New SAE Classification | |
|---|---|---|
| | **Cold Rolled Steels** | |
| Dent Resistant (DR) | SAE J2340 | Grades 180A, 210A, 250A, 280A<br>Dent Resistant Non Bake Hardenable |
| Bake Hardenable (BH) | SAE J2340 | Grades 180B, 210B, 250B, 280B<br>Dent Resistant Bake Hardenable |
| High Strength Solution Strengthened | SAE J2340 | Grades 300S, 340S<br>High Strength Solution Strengthened |
| High Strength Low Alloy (HSLA) | SAE J2340 | Grades 300X,Y; 340X,Y;380X,Y<br>High strength low alloy 20X,Y;490X,Y;550X,Y |
| High Strength Recovery Annealed | SAE J2340 | Grades 490R, 550R, 700R, 830R<br>High Strength Recovery Annealed |
| Dual Phase (DP) (HSS) | SAE J2340 | Grades DH/DL 500-1000 MPa Tensile<br>Ultra High Strength Dual Phase |
| Martensitic Grade M, HSS | SAE J2340 | Grade M 800-1500 MPa Tensile<br>Ultra High Strength Low Carbon Martensite |

## 8.2. Physical and metallurgical properties of steel for automotive

The properties of thin low carbon steel sheets and strips depend on their chemical composition, method of steel and sheet production. Strict requirements are imposed on steel sheets not only in terms of their mechanical properties but also thickness tolerance and surface quality. These factors influence the structure, mechanical, and technological properties of ductile thin steel sheets.

Ductile thin steel sheets are produced from low carbon steels (up to 0.1 %). Besides carbon, the steels contain other elements that penetrate into the steel due to imperfect metallurgical process or are added to steel on purpose in order to improve the sheets properties (Mn, Si, P, S, Cu, Ni , Cr , Mo , O , N , Ti , etc.) [90], [91].

The structure of ductile low carbon steel consists of ferrite and cementite. Ferrite in the binary system Fe – C is bounded by a solid carbon solution in iron δ. However, ferrite in steels dissolves also other elements, thus creating a substitution solution (Si, Mn, Cr, Ni, Mo, W), or an addition solid solution (N, H, O). Ferrite is a soft structural stage; therefore low carbon steels (ferritic) are soft, with low yield strength, low strength, and high ductility and contraction values. These are steels with high resistance to fracture and good plastic properties. Plastic properties of these steels depend on the size and shape of the ferritic grain, the amount and distribution of impurities. In the case of steel sheets, the ferritic grain size is a compromise between the plasticity and smoothness of the product surface.

## 8.3. Interstitial free steels (IF steels)

IF steels are used for deep drawing and for components of a complex shape. They are characterized with high plastic properties; therefore they are suitable for deep drawing. High ductility is achieved due to low content of interstitial atoms, size of ferritic grain and texture created in recrystallization annealing (Figure 1) [71].

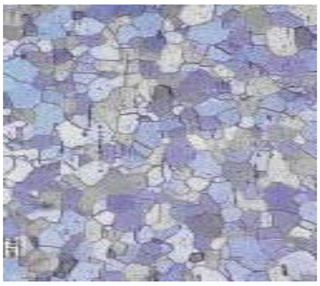


*Figure 1 IF steel structure [92]*

In these steels, interstitial elements (carbon, nitrogen) are bound to carbide, nitride or carbon-nitride forming elements (Al, Ti, Nb, V). Elimination of interstitial elements by binding them to elements that have high affinity during liquid steel processing results in achieving excellent compressibility of sheets on the final pressing. Free carbon in IF steels as well as in the steels containing free carbon (e.g. phosphorized steel) can be used e.g. for bake hardening (BH) effect [71], [76], [82].
In terms of metallurgy, IF steels require high purity and control of inclusions morphology. Due to non-existent interstitial reinforcement, they have low yield strength (below 160 MPa) and are fully non-aging.

## 8.4. Bake hardening (BH) steel

In the case of sheets for producing complex-shaped pressings by cold pressing and the subsequent surface treatment by vanishing, the properties required in terms of technology are good compressibility and uniformity of properties also in terms of a product utility properties (stiffness and constructions safety), high strength and dynamic load capacity. These requirements are to great extent met by BH steel pressings [71].

BH steels before pressing have low values of yield strength and high plasticity. After pressing and application of varnish, deformation-thermal aging occurs during baking, which results in increasing the yield strength by 30 - 70 MPa and increase in strength. This way the sheet is more resistant to deformation. In order to enable BH effect, especially physical and metallurgical conditions have to be met, BH effect control by controlling carbon dissolved in ferrite require that nitrogen is fully bound to AlN. The precipitation of AlN is controlled by Al and N content, coiling temperature, recrystallization annealing and the accompanying elements (Figure 2).

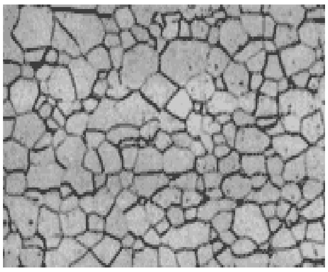


*Figure 2 BH steels structure [92]*

## 8.5. HSLA steels

Low alloy steels (HSLA Ductile Low Alloy) with ferritic-perlitic structure are fine-grain steels with low content (max 0.15 %) of one element of combination of Al, Ti, Nb, and V. The effect of low alloy elements consists in their affinity to carbon and nitrogen with solubility of carbides, nitrides, and carbonitrides in austenite and ferrite and strengthening mechanisms (Figure 3) [71].

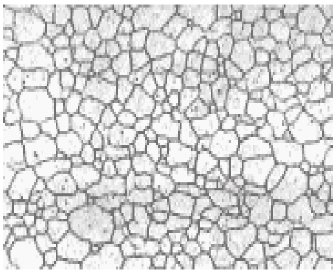


*Figure 8.3 HSLA steel structure [92]*

Low alloy steel sheets are characterized by a fine structure and higher cold weldability. Low alloy steels have significant grain boundaries (grain refinement) and dispersion reinforcement of intermediate compounds (carbide, nitride, and carbonitride compounds) of micro alloying elements

# 9. MATERIALS IN CURRENT AUTOMOTIVE II.

## 9.1. Multi-phase steels (CP, TRIP steels)

Steels with Transformation Induced Plasticity (TRIP) are a promising material in automotive. They have good strength properties and excellent ductility in cold forming. During their plastic deformation, austenite is converted into deformation-induced martensite, which significantly contributes to the overall material strength. As a result, the deformation is gradually redistributed evenly over the entire deformed zone, thus preventing the local accumulation of the deformation at critical points. Similarly, the formation of deformation-induced martensitic plates can slow the propagation of cracking and thus improve fatigue properties (Figure 1) [71].

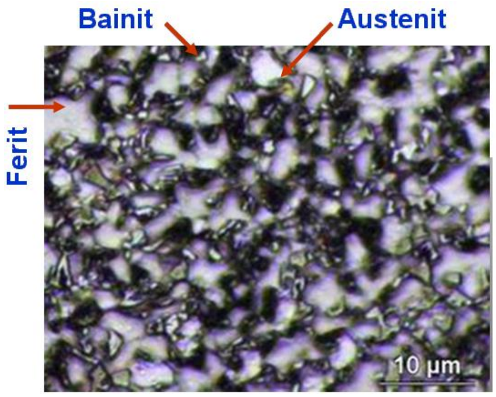


*Figure 1 TRIP steels structure [92]*

**Legend: ferit, bainit, austenit – ferrite, bainite, austenite**

## 9.2. Dual-phase steels (DP steels)

The structure of currently produced dual-phase steels used for steel sheets manufacturing for cold forming most often consists of ferrite and martensite. Recommended carbon content in these steels is not higher than 0.13%. Other elements are Mn, Si, Mo, Cr or V (Figure 2).

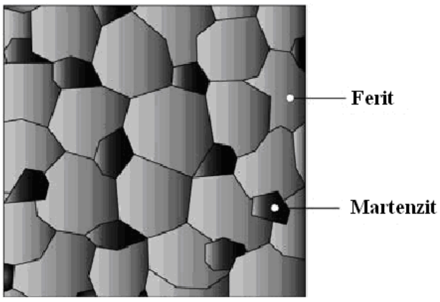


*Figure 2 DP steels structure [92]*

Dual-phase ferritic-martensitic steels are manufactured using the intercritical annealing or controlled cooling method. The method of intercritical annealing consists of heating the material after cold rolling to the temperature in the interval of AC1 - AC3, with a required holding time 5-15 minutes, and subsequent controlled cooling at supercritical speed, which ensures the required volume fractions of ferrite and martensite, [71]. Another method of producing dual-phase ferritic-martensitic steels consists in adjusting technological conditions of hot rolling process, or choosing chemical composition of these steels so that the required dual-phase ferritic-martensitic steels structure is achieved immediately after hot rolling.

## 9.3. Maraging steels

The name is a combination of two successive phase transformations causing reinforcement (martensitic and aging). They are low carbon steels with the carbon content C<0.03%, Mn<0.1%, Si<0.1%, S<0.01%, P<0.01%. Highly undesirable additives are C, S, N, because their presence increases the density of the dislocation grounding points formed by carbides and nitrides, which are mainly discharged at the grain boundaries. This results in reduced plastic properties. Similar effect is caused by sulphur-based inclusions (Figure 3) [71].

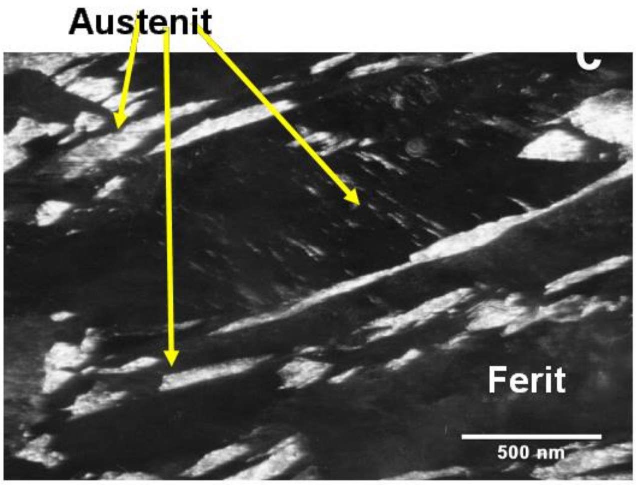


*Figure 3 Martensitic steels structure [92]*

These conditions ensure the dissolution of the particles in austenite and at the same time the relaxation of potential stress caused by the previous processing. After hardening, the structure is formed by almost carbon-free nickel martensite, which is characterised by high plasticity, relatively low hardness (30-35 HRC), and tensile strength about 1000 MPa and good machinability. During the aging process, dispersion particles of intermetallic phases, containing mainly Mo and Ti, are discharged in martensite. They enable to achieve the hardness of up to 62 HRC. These steels have a lot of important technological properties that can be characterized as follows: high dimensional stability during heat processing and long-term operation; low strain hardening exponent, and good plasticity, which enables to use all kinds of hot and cold forming with high degrees of deformation; good machinability of especially in hardened condition; suitability for various curing methods; good weldability.

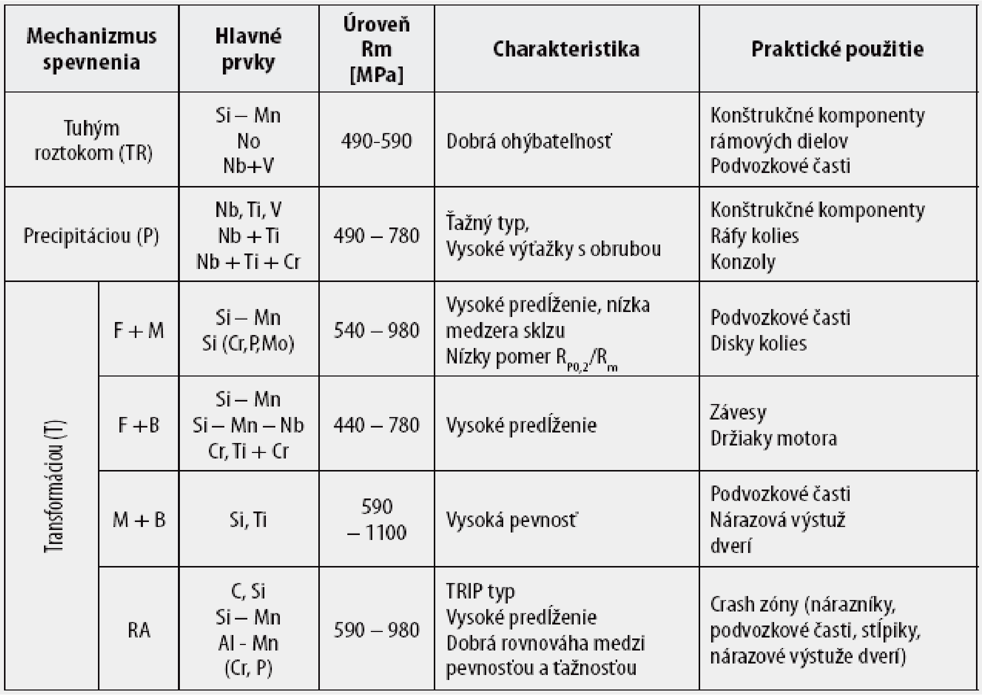
## 9.4. Hot rolled sheets

Their common thickness is 2 – 15 mm, rarely 1.5 – 25 mm. Breaking load can change in the range of 5 – 50 %. Besides high strength in static and dynamic load, other required properties are good cold compressibility and weldability. They are made from structural and drawing steel.

Structural steel sheets are used for load bearing elements with lower requirements for cold formability. The range of strength and plastic properties is determined by the following values: Re min = 200 – 360 MPa, Rm = 300 - 650 MPa, A5min = 22 - 26 %.

Drawing steel sheets are used for manufacturing structural elements; very good cold compressibility is required. The range of their mechanical properties is determined by the following values: RP0.2 max = 250 - 360 MPa, Rm = 250 - 450 MPa, A5min = 29 - 45 % (Table 1).

*Table 1 Hot-rolled high-strength steels for automotive [71]*



| Mechanizmus spevnenia | | Hlavné prvky | Úroveň Rm [MPa] | Charakteristika | Praktické použitie |
|---|---|---|---|---|---|
| Tuhým roztokom (TR) | | Si – Mn<br>No<br>Nb+V | 490-590 | Dobrá ohýbateľnosť | Konštrukčné komponenty rámových dielov<br>Podvozkové časti |
| Precipitáciou (P) | | Nb, Ti, V<br>Nb + Ti<br>Nb + Ti + Cr | 490 – 780 | Ťažný typ,<br>Vysoké výťažky s obrubou | Konštrukčné komponenty<br>Ráfy kolies<br>Konzoly |
| Transformáciou (T) | F + M | Si – Mn<br>Si (Cr,P,Mo) | 540 – 980 | Vysoké predĺženie, nízka medzera sklzu<br>Nízky pomer $R_{P0,2}/R_m$ | Podvozkové časti<br>Disky kolies |
| | F +B | Si – Mn<br>Si – Mn – Nb<br>Cr, Ti + Cr | 440 – 780 | Vysoké predĺženie | Závesy<br>Držiaky motora |
| | M + B | Si, Ti | 590 – 1100 | Vysoká pevnosť | Podvozkové časti<br>Nárazová výstuž dverí |
| | RA | C, Si<br>Si – Mn<br>Al - Mn<br>(Cr, P) | 590 – 980 | TRIP typ<br>Vysoké predĺženie<br>Dobrá rovnováha medzi pevnosťou a ťažnosťou | Crash zóny (nárazníky, podvozkové časti, stĺpiky, nárazové výstuže dverí) |

**Legend: mechanismus spevnenia – hardening mechanism, tuhým roztokom – by solid solution, precipitáciou – by precipitation, transformáciou – by transformation, hlavné prvky – main elements, úroveň – level, charakteristika – characteristics, dobra ohýbatelnosť – good bendability, ťažný typ – drawing, vysoké výťažky s obrubou – high drawings with trim, vysoké predlženie – high extension, nízká medzera sklzu – low slip gap, nízky pomer – low ration, vysoká pevnosť – high strength, TRIP typ – TRIP type, dobra rovnováha medzi pevnosťou a tažnosťou – good balance between strength and tensility, praktické použitie – practical use, konštručné komponenty rámových dielov – structural components, podvozkoé časti – chassis parts, ráfy kolies – wheel rims, konzoly – brackets, disky kolies – wheel discs, závesy – hinges, držiaky motora – motor holders, nárazníky – bumpers, sloupky – pillar, nárazová výstuž dveří – door impact reinforcement**

## 9.5. Cold rolled sheets

For practical use, they are produced in the thickness ranging between 0.50 – 2.00 mm, or exceptionally 0.30 – 3.00 mm. Tensile strength of cold-rolled sheets ranges between 300 – 1000 MPa, yield strength 150 – 800 MPa and ductility A80= 15 - 50 % (Table 2) [84].

Properties of steel for automotive can be adjusted by choosing a chemical composition and steel Hardening mechanisms, including the following ones:

- Strengthening of solid solution by interstitial and substitution elements,
- Dislocation strengthening,
- Grain boundary strengthening,
- Precipitation hardening,
- Transformation hardening.

The analysis of the influence of individual strengthening mechanisms to formability and properties of the resulting ferritic matrix, based on the literature, points to the following: transformation hardening shows the strongest influence on steel properties; the resulting steel properties depend on more hardening and strengthening mechanisms at the same time, and these contributions are depending on the chemical composition of steels, [5], [6], [84].

If only high strength with minimal plasticity is required, it can be achieved e.g. by combining solid solution strengthening and transformation hardening of martensitic steel. However, more often also good plastic properties are required. This can be achieved only by combining various strengthening and hardening mechanisms.

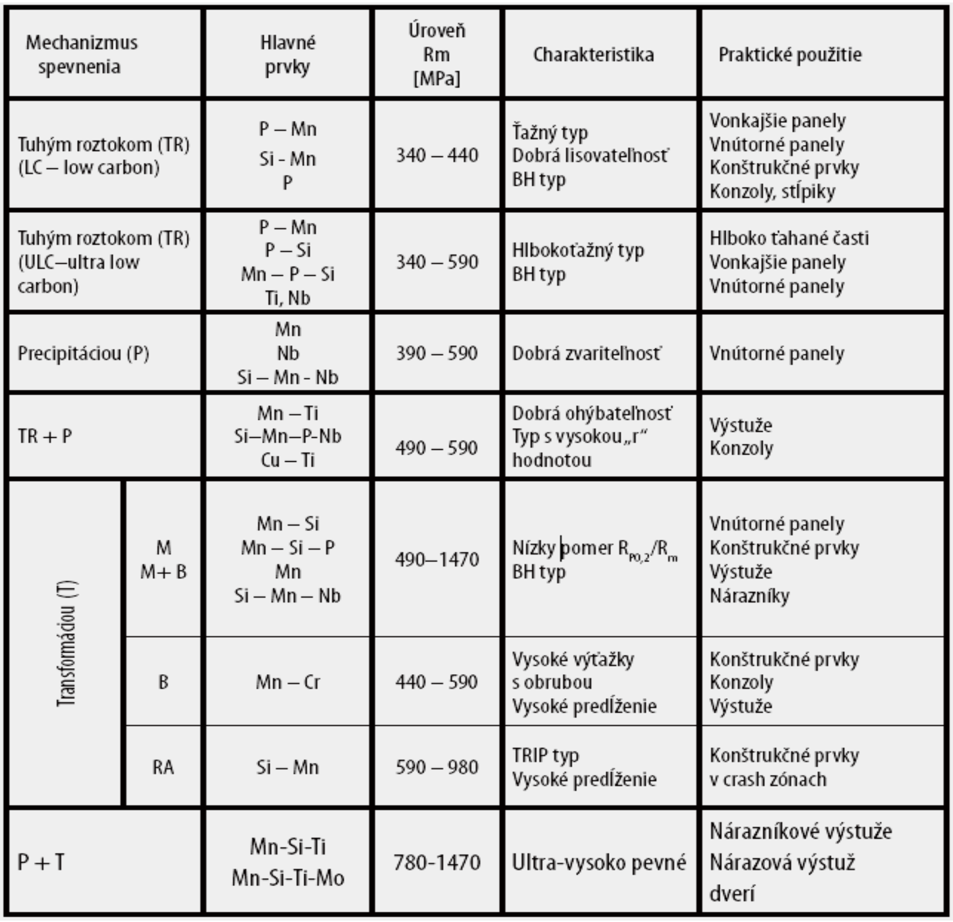
The most efficient strengthening mechanism is structural strengthening achieved by controlled phase transformation, which could be combined with other strengthening mechanisms (TR, P and grain refining). Structural hardening by means of controlled phase deformations can be carried out as follows:

- In the processes of hot plastic deformations,
- By means of controlled rolling (RV) and controlled cooling (RO),
- In the processes of cold plastic deformation,
- Using thermal processing.

Carbon causes decrease in plasticity of cold-rolled steels and deteriorates weldability, therefore there is a clear tendency to focus on minimizing its content in the steels intended for use in automotive. Until the introduction of vacuum technology, the C content was C > 0.05 %. Introducing vacuum technology in steel production technologies enables to manufacture low carbon steels, which are further classified according to the C content as follows: [82]:

- LC steels (low carbon) 0.03 – 0.2 % C
- ELC steels (extra low carbon) 0.01 – 0.03 % C
- ULC steels (ultra low carbon) 0.01 – 0.003 %C
- SULC steels (super ultra low carbon) < 0.003 %

*Table 2 Cold-rolled high-strength steels for car components [71]*



| Mechanizmus spevnenia | | Hlavné prvky | Úroveň Rm [MPa] | Charakteristika | Praktické použitie |
|---|---|---|---|---|---|
| Tuhým roztokom (TR) (LC – low carbon) | | P – Mn<br>Si - Mn<br>P | 340 – 440 | Ťažný typ<br>Dobrá lisovateľnosť<br>BH typ | Vonkajšie panely<br>Vnútorné panely<br>Konštrukčné prvky<br>Konzoly, stĺpiky |
| Tuhým roztokom (TR) (ULC–ultra low carbon) | | P – Mn<br>P – Si<br>Mn – P – Si<br>Ti, Nb | 340 – 590 | Hlbokoťažný typ<br>BH typ | Hlboko ťahané časti<br>Vonkajšie panely<br>Vnútorné panely |
| Precipitáciou (P) | | Mn<br>Nb<br>Si – Mn - Nb | 390 – 590 | Dobrá zvariteľnosť | Vnútorné panely |
| TR + P | | Mn – Ti<br>Si–Mn–P-Nb<br>Cu – Ti | 490 – 590 | Dobrá ohýbateľnosť<br>Typ s vysokou „r“ hodnotou | Výstuže<br>Konzoly |
| Transformáciou (T) | M<br>M+ B | Mn – Si<br>Mn – Si – P<br>Mn<br>Si – Mn – Nb | 490–1470 | Nízky pomer $R_{P0,2}/R_m$<br>BH typ | Vnútorné panely<br>Konštrukčné prvky<br>Výstuže<br>Nárazníky |
| | B | Mn – Cr | 440 – 590 | Vysoké výťažky s obrubou<br>Vysoké predĺženie | Konštrukčné prvky<br>Konzoly<br>Výstuže |
| | RA | Si – Mn | 590 – 980 | TRIP typ<br>Vysoké predĺženie | Konštrukčné prvky v crash zónach |
| P + T | | Mn-Si-Ti<br>Mn-Si-Ti-Mo | 780-1470 | Ultra-vysoko pevné | Nárazníkové výstuže<br>Nárazová výstuž dverí |

**Legend: mechanizmus spevnenia – strengthening mechanism, tuhým roztokom – solid solution, precipitáciou – by precipitation, transformaciou – by transformation, hlavné prvky – main elements, úroveň – level, charakteristika – characteristics, ťažný typ – drawing steel, dobra lisovatelnost – good compressibility, BH typ – BH type, hlbokoťažný typ – deep drawing steel, dobra zavritelnost – good weldability, dobra ohýbatelnost – good bendability, typ s vysokou "r" hodnotou – type with high "r" value, nízky pomer – low ratio, vysoké výťažky s obrubou – drawings with a trim, vyoské predlženie – extension, TRIP typ – TRIP type, ultra-vysoko pevné – ultra high strength, praktické použitie – practical use, vonkajšie panely – external panels, vnútorné panely – interior panels, konštručné prvky – structural elements, konzoly - brackets, stlpiky - pillars, hluboko ťahané časti – deep drawing components, výstuže - reinforcement, nárazníky - bumpers, crash zóny – crash zones, nárazníkové výstuže – bumper reinforcement, nárazová výstuž dveří – door impact reinforcement**

## 9.6. Galvanized sheets in automotive

**Classification of galvanized sheets.**

Galvanized steel sheets are not a new material. The development of their use in various areas of engineering production makes them a very progressive commodity. The use of galvanized sheets between 1975 and 2000 was double, while the sales of untreated sheets decreased almost by half. The sector processing the largest amount of galvanized steel sheets is primarily automotive [71].

In steel sheets surface treatment by metal coatings, zinc is primarily used due to its relatively low price and great corrosion properties. The durability of the coating is proportional to its thickness and the environment in which the zinc coating is applied [7], [9], [29].
The demands placed on galvanized materials are the following: low weight, resistance to corrosion, technological formability, easy weldability, surface suitable for surface treatment, above-average strength and plastic properties.

### 9.6.1. Hot dip galvanized steel sheets

Hot dip galvanization is the most widely used method of protecting steel products against corrosion. Most of them (more than 50%) are used by automotive and construction industry. To improve corrosion properties, Al and Si is sometimes added in the coating. Galvanization, especially hot dip galvanization is one of the most cost-effective processes of steel strips surface treatment. Single-sided and double-sided galvanized sheets with the same of different coating thickness are produced and intended both for external and internal bodywork parts.

An important requirement that hot dip galvanized sheets must meet in terms of its use in automotive is avoiding the formation of flowers of zinc, which is an accompanying phenomenon of hot dip galvanization.

Meeting these requirements can be ensured as follows:

- Increasing the cooling rate of liquid zinc coating,
- Increasing the number of crystallization centres during the coating solidification process,
- Reduction of lead content in galvanic bath below 0.08 %
- Use of electrolytic zinc in the bath,
- Easy rolling of galvanized strip (0.8 – 1.5% removal).

## 9.6.2. Electrolytically galvanized sheets

Electrolytic galvanizing has been used since 1917. The production of electrolytically galvanized sheets is less common in the world than the production of hot dip galvanized sheets, accounting for about 10 – 15 % [71], [76], [82].

Compared to hot dip galvanized sheets, the advantages of electrolytically galvanized sheets are the following:

- The possibility to prepare very thin zinc coatings (starting from 0.4 μm),
- Relatively thin zinc coating ensures sufficient protection against corrosion
- Galvanization process does not influence the original mechanical properties of the basic material, especially its capacity of deep drawing,
- Zinc coating with a conversion layer ensures good adhesion of organic coating,
- Differentiated and single-sided galvanized sheets can be produced relatively easily

The usual thickness of the electrolytic coating required in automotive is below 7.5 μm. Electrolytically galvanized sheets use alkaline or acid electrolyte; the galvanization process is thus carried out in two types of bath:

- **In alkaline bath** – zinc is bound in the form of alkali zinc and in the form of complex zinc alkali cyanide. The bath has very good depth efficiency, fine-grained and quality structure of the coating and it is easy to recover. Due to these properties, cyanide baths have become widespread. According to the composition of the bath, brighteners, and operating conditions, more types of coatings are created: matt, semi-bright, and bright coatings. The basic composition of alkali zinc baths is zinc cyanide, sodium cyanide, sodium hydroxide, sodium sulphide, and brighteners. The cathode current density of the bath is 1 – 6 A.dm2, bath temperature 20 – 35°C.

- **In acid bath** – the most important ones are sulphated and fluoroborate baths. Acid baths have very low depth activity and poor hiding power. The bath composition is more stable than in the case of cyanide baths. It is possible to use high current density at which baths with high cathode ore extract are operated. They are used for galvanizing wires, sheets, strips and products of a simple shape.
  The basic component of acid bath is zinc sulphate, aluminium sulphate, ammonium chloride, and boric acid. The cathode current density is 1 – 6 A dm2, the cathode current yield is 95 – 100 %, bath temperature 20 – 30°C. The coating formation rate in acid galvanization baths is about 8 times higher than in the case of alkaline bath.
  With a constant development of cyanide-free acid baths for galvanization, results have been achieved that enable to replace nickel and chrome plating in many

cases. These are mainly:

- non-toxic bath,
- Glossy surface
- Durability and cost-effectiveness

# 10. STAINLESS MATERIALS

There are several grades of steels according to various criteria. According to processing method, there is a class of steels for forming in the form of semi-finished products, according to the use – structural steel, according to the chemical composition guaranteed by supplier – quality steels (producers guarantee their chemical composition, i.e. the minimal and maximal content of elements), according to chemical composition – alloy steels, which contain one or more alloying elements. All the steels mentioned above represent stainless steels of class 17 [4], [70], [71].

In Europe, classification and marking of steels is unified based on European standards (EN) (ČSN EN in the Czech Republic). Steels classification is given by the European standard EN 100020, which defines:

- The term “steels for forming”,
- classification of steels according to their chemical composition,
- dividing into main groups based on the properties and use.

Steels for forming are referred to as materials in which the iron proportion by mass is higher than that of any other element, containing less than 2 % of C and containing also other elements.

## 10.1. Classification of steels based on their chemical composition

- **Non-alloyed steels** – the content of the individual elements does not achieve these limit values:

Mn = 1.65 Si = 0.60 Cu = 0.40 Ni = 0.30
W = 0.30 Co = 0.30 Al = 0.30 V = 0.10
Mo = 0.08 Ti = 0.05 Bi = 0.10 Nb = 0.06
Zr = 0.05 Pb = 0.40 B = 0.008

Proportion by mass is given in %.

- **Alloyed steels** – the content of individual elements in at least one case achieves or exceeds the above-mentioned limit values of the alloying elements content.

**Classification of steels by quality according to the properties and use:**

- Alloy quality steels – the properties are achieved by prescribed chemical composition and special processing conditions. This group includes alloy structural steel, alloy steel for pressure lines and vessels, steels for rolling bearings, tool steels, high speed steel, steels with special physical properties – ferritic Ni steels.

**According to the content of alloying elements, they are divided into the following subgroups:**

- Stainless steels with the content of $Cr_{min} \geq 10.5$ % a max. C content 1.2 %,
- High speed steel with the content of $C \geq 0.60$ % and Cr = 3.0 – 6.0 %, and besides other elements, they contain at least two elements of this group: Mo, W, V (overall content over 7 %).

### 10.1.1. Stainless steels

Stainless steels are chromium alloys with iron, containing about 12 - 30 % of chromium, up to 30 % of nickel or up to 2.4 % manganese at a certain amount of Mo, Si, Cu, Ti, Ni, N, etc. (max. a few percent). Chromium ensures the passivity of these alloys, which makes it the most important element for achieving resistance against corrosion. Stainless steels are in some environments prone to localized corrosion (pitting, crevice, intergranular, stress corrosion cracking). However, this can be avoided by choosing a suitable type of steel of given conditions. Although chromium, nickel, manganese and other alloying elements amount is quite large in stainless steels, the basic element is iron and its alloy with carbon, i.e. steel. Stainless steels are divided into several groups based on their chemical composition and structure [71]:

- austenitic
- martensitic (hardenable)
- ferritic
- austenitic-ferritic (duplex)

### 10.1.2. Austenitic steels

They have the highest resistance against corrosion of all basic types of steels. This can be even increased by adding Mo and Cu. An important property is ductility and strength. In order to obtain different properties, the basic composition is changed by adding other elements in order to increase:

- overall resistance to corrosion (chromium, molybdenum, copper, silicon, nickel)
- quality of mechanical properties (nitrogen)
- machinability (sulphur, selenium, phosphorus, lead, copper)
- resistance against weld cracking (manganese)
- resistance against pitting and crevice corrosion (molybdenum, silicon, nitrogen)

- resistance against corrosion cracking (reduction of the phosphorus, arsenic and antimony content)
- creep strength (molybdenum, titanium, niobium, boron)
- heat resistance (chromium, aluminium, silicon, nickel)

### 10.1.3. Martensitic steel

Its resistance to corrosion is low. It can be used in combination with nitric acid, boric, acetic, benzoic, oleic, picric acid, with carbonates, nitrates, and lye. However, their resistance decreases with increasing temperature. The resistance against atmospheric corrosion is sufficient on in very clean air.

### 10.1.4. Ferritic steels

They are magnetic and sufficiently ductile. Higher chromium content increases their resistance against corrosion, which is higher than that of martensitic steels in oxidizing environments. They can be used in chemical industry, in nitric acid, in transport, for air conditioning, architecture. However, they are not suitable for some industrial atmospheres. They are not suitable for welded structures.

### 10.1.5. Austenitic – ferritic (Duplex) steels

They are derived from classic austenitic steels. Due to high chromium and molybdenum content, they have excellent resistance against fracture and corrosion. The microstructure of duplex steels ensures high resistance against stress corrosion cracking, stress corrosion, and erosion. Weldability of duplex steels is good. [71].

## 10.2. General characteristics of stainless materials

**Corresponding qualities in ČSN**

- Ferritic steels 17020, 17021, 17022, 17023, 17024, 17040
- Austenitic steels 17240, 17249, 17352, 17350, 17349, 17248, 17348
- Austenitic-ferritic 17381

### 10.2.1. Cold-rolled stainless sheets

- They are produced according to **DIN 17441/EN 10088-2**, with a tolerance **DIN**

**59382**.

- Surface:
    - **2R (IIId)** cold-rolled, bright annealed, brilliant polish.
    - **2B (IIIc)** cold-rolled, pickled, annealed, fine rolled, opaque polish.
    - **2G** cold-rolled, grinded (various kinds of grinders P80 - P400) or grinded and brushed.
    - **2J** cold-rolled, brushed (Scotch-brite)

### 10.2.2. Hot-rolled stainless sheets

- They are produced according to **DIN 17440/EN 10088-2, AD-W2**. Tolerance **DIN 59382, EN 10029**.

### 10.2.3. Decorative steel sheets

- Quality: 1.4016, 1.4301, 1.4404 (AISI 430, 304, 316L)
- Surface treatment 2B (annealed, pickled), 2R (bright annealed);
- Other surfaces at request
- Dimensions: thickness 0.5-2.0 mm
- Formats: 1000×2000 mm; 1250×2500 mm; 1250×3000 mm; 1500×3000 mm
- Other formats at request

### 10.2.4. Flat-rolled sheets

- Quality: 1.4016 ; 1.4301 ; 1.4404 (AISI 430 ; 304 ; 316L)
- Surface treatment: 2B (annealed, pickled) ; 2R (bright annealed) ; R13 ;
- brushed; colored;
- other surfaces at request
- Dimensions: thickness 0.5-2.0 mm
- Formats: 1000×2000 mm; 1250×2500 mm; 1250×3000 mm; 1500×3000 mm ;
- Other formats at request

### 10.2.5. Sheets with special surface treatment

Colored, brushed, chased, and etching decorative surfaces (various patterns).

### 10.2.6. Floor (tear) sheets

Further information about types, formats, and surface treatment can be obtained from producers at request.

# 11. SSAB (SWEDISH STAINLESS) STEELS

There are many properties of steel. It can be hard or soft, tough or brittle, thick or thin, or extra strong to resist wear. There can also be a combination of all these properties, where the steel properties are determined by the technological process in steel works, by rolling and subsequent processing. [81].

Swedish producer specializes in production of high-strength steel. In steel manufacturing they focus on car manufacturing, steels for household, products for free time, internal equipment, large buildings, bridges, means of means transport, industrial plants or health care facilities. In steel production, there are about 500 kinds of steel to choose.

The share of progressive SSAB steels is steadily increasing with the growing number of customers discovering its advantages and the possible application of these steels. In order to achieve the optimal results, it is necessary to combine technologies and innovations.

There are two different procedures in steel manufacturing:

- Steel produced from ore – pig iron from iron ore is in Sweden produced from iron ore pellets in blast furnace in Lulel and Oxelösund. A small amount of ferrous scrap is added when pig iron is refined into crude steel in LD. Sweden also produces steel sheets and heavy steel.

- Steel produced from ferrous scrap – i tis produced in the USA, where the steel works recycle ferrous scrap in electric arc furnaces and crude steel is produced only from ferrous scrap. The USA produce heavy sheets.

In both cases, the resulting composition of steel is in line with the SSEB procedures of refinement before the melted steel is cast and cooled to BRÁMY in continuous casting line. High strength steels gain their strength by adding alloying elements, and the production methods, e.g. hardening in extremely fast hardening processes. High accuracy is the main condition.

## 11.1. Type of SSEB steels

Swedish steels producer, SSEB, focuses on solving complex problems. The producer´s experts have excellent knowledge and experience in all areas of steel production, starting from various steel properties (strength, production engineering aspects, forming, joints) to wear and surface treatment.

A good example is European automotive, which has increased the purchase of modern high-strength steel in the last ten years. As a result, vehicles achieve good results in crash tests, lower fuel consumption, and contribute to reduction of carbon dioxide emissions. The producer of Swedish steels has a leading position in the market of the most progressive hardened and refined steels. Docol products (cold-rolled) are often used for passenger cars. Customers often choose combinations of HARDOX, WELDOX, DOMEX and Docol steels in heavy vehicles, trucks, trailers, truck superstructures, containers, and cranes in order to optimize their products. This results in increasing the load bearing capacity, durability, and reduction of maintenance costs. There are also other possibilities of application. TOOLOX is a special type of steel used for manufacturing compressing tools [81].

Technical support specialists are engaged in the preparation of new products and projects from the very start. The producer often develops new types of steel intended for a specific purpose. Developing new products in this way has clear advantages.

## 11.2. The current product range of SSSEB steels:

DOMEX ® are hot-rolled sheets used for ships manufacturing, buildings, machines, vehicles, lifting equipment, containers.

HARDOX ® is hardened, tempered, and wear-resistant steel used tipper superstructures, containers, shredders, mills, buckets.

DOCOL ® is cold-rolled steel sheet, in the forms of soft steel for compressing and bending to ultra high-strength steel.

DOGAL it is a kind of DP steel, with good formability and strength.

Dogal 600 D and 800 DP are extra and ultra high-strength steels, hot-dip galvanized.

**WELDOX®**
**HIGH STRENGTH STEEL**

WELDOX ® is high-strength structural steel used for lightweight products with the same or higher strength compared to the products made of common steel. It is used e.g. for crane manufacturing, trailers, and vehicles.

**PRELAQ®**
**COLORFUL BUILDING**

PRELAQ ® is coated steel sheet for construction industry. It is used for roof covering products, facades, roofs, rainwater pipes, forgings.

**ARMOX®**
**PROTECTION PLATE**

ARMOX ® is steel used as a protection in transporting e.g. teller windows, mine clearing vehicles, personal protection, etc.

**TOOLOX®**
**PREHARDENED TOOL STEEL**

TOOLOX ® are modern tool steels for compressing tools and machine elements.

**QSTE** – high-strength steel sheets, hot-rolled, for cold-forming.
QSTE steels are fine-grain, micro-alloy thermally and mechanically ™ rolled steels, whose higher strength make them suitable for cold bending.

## 11.3. Environment and recycling

Natural resources are limited. Therefore saving resources and using them as effectively as possible is very important. First of all, it is important to recycle materials such as iron that has already been extracted from its natural deposits.

During its lifetime, about 90 % of all waste iron and steel is reused or recycled. Steel scrap, such as old vehicles, machines, and rail transport equipment is melted, refined, and new steel for new products is manufactured. Steel is a part of a cycle in which everything can be renewed. About one third of the world steel production is based on scrap recycling. Since the demand for steel is still increasing and exceeds the available scrap supply, new steel has to be manufactured from iron ore. Swedish producers´ blast furnaces are among the most energy efficient in the world.

By means of steam turbines, process gases are used as a source material for production of electricity in combined heat and power (CHP) plants. This satisfies about a half of electric energy SSEB producers need for their three production plants. In the next stage, steam from steam turbines is used for heating water in a district heating system for 35.000 households supplied with water from district heating system. About 40.000 other households use a district heating system from process gas, where the heat is obtained from blast furnaces gas.

From the holistic point of view on industry and energy industry, the overall emissions of carbon dioxide can be reduced. In addition, other energies can be renewed in steel making industry. Therefore, if coal is used, it shall be used primarily for steel manufacturing.

Production facilities in Sweden and the USA use natural gas for heating in the processes of scrap recycling before scrap is melted in electric arc furnaces. Natural gas is also used for heating BRÁM in plate mills.

These producers´ production plats achieve lower emissions in the air and water, especially due to using side products, effectively separating energy gases, dust, slag, wet sludge, cooling liquid, they process water, OKOVINY, sulphur, tar, benzene, etc. The materials are gathered and separated. A great number of these materials are recycled. Side products of steel manufacturing industry are assets that could be processed and used by new users as raw material.

Merox, a steel producers company, focuses on the use of side products. It processes products and raw materials for a wide range of applications, such as construction materials, materials for roads, horse riding path, raw material for producing cement, fertilizers, ferrite for magnets and pigments for paints. Using side products as new raw materials means an important protection of natural resources.

Blast furnace soot, dust, and sludge from water treatment plants from production plants can be mixed with fine fractions of scrap and pellet debris, and serve as a new raw material for blast furnace, e.g. in the form of briquettes.

Blast furnace slag is an excellent construction material for construction of roads, as well as for cement manufacturing industry. High Ca content (30 %) is a great advantage. If slag is used for roads construction, Ca binds it in a continuous in load unit. At the same time, Ca binds other elements in the slag and prevents acidification due to pH increasing. Blast furnace slag is a good example of possible application of a closed cycle in steel works.

Continuous sampling of air, water, and fish and their analysis ensure the minimum impact on the environment. Environmental organizations create and perform extensive programmes for controlling and monitoring all emissions, which ensures that those do not exceed the allowed limits.

Swedish steel producer has their working environment policy, where safety is a priority, since it has a vital importance for job satisfaction, employees´ development and company profitability. The primary goal is that there shall be no accident, injury or occupational diseas, both on the side of employees and suppliers or visitors. It guarantees a systematic approach to the working environment and safety at work.

# 12. COMPOSITE MATERIALS I.

A qualitative change in solving the contradiction between the required properties and the actual properties of homogeneous materials are composites, whose component are able to perform the functions that are not compatible within one material. Composite materials include a wide range of diverse materials [59], [60], [61], [62].

According to properties, composite materials can be divided into:

- Composites with good mechanical properties;
- Composites with special physical and chemical properties.

Composites are materials that are combinations of existing homogeneous materials. The basic material, matrix, has a function of a binder. The second component, fibres, layers, or dispersion particles, are reinforcing phases. The properties of a composite compound from material A (reinforcing component) and B (matrix) are influenced especially by the following parameters:

- volume fraction of the components A and B (Va, Vb),
- geometry of the system, which is characterized by:

    - one-dimensional continuous phase (fibre, stick),
    - two-dimensional continuous phase (plate, board),
    - three-dimensional continuous phase (spatial network),

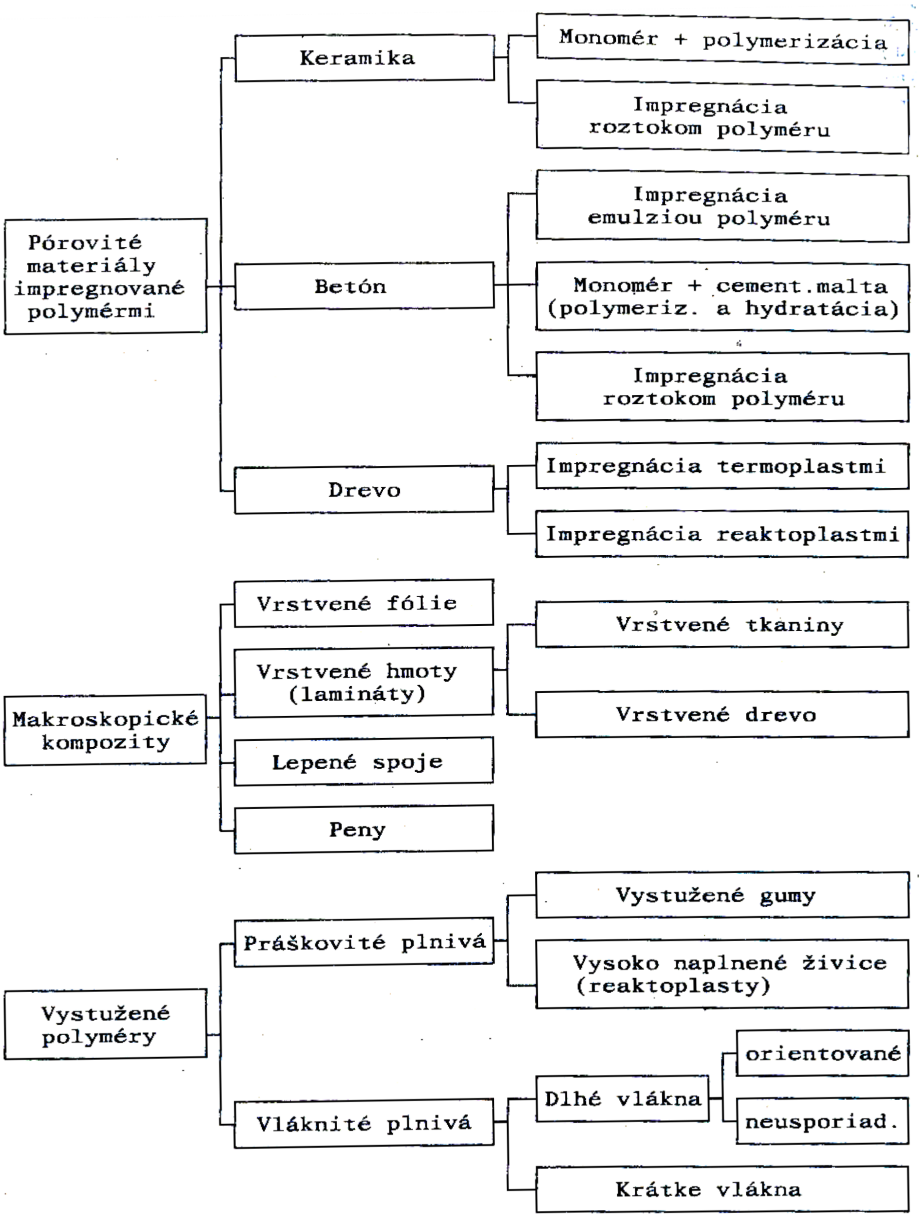
- degree of continuity (from total continuity to dispersoids),
- arrangement of phases (parallel and serial arrangements are extremes).

Mechanical properties are most influenced by the arrangement of the phases. Composite properties can be considered additive, which means they can be derived from the properties of the starting materials. [61]

## 12.1. Polymer-based composites

Almost all biological systems consist of polymers, which either perform mechanical functions (wood, bones, skin), or influence chemical reactions in the nature (leaves, cells). People have been using polymers for thousands of years, but synthetic polymers were developed in the last century. Simple synthetic polymers have higher strength than metal materials, but also than wood or bones. It is because wood and bones are composites: their polymer matrix is reinforced by fibres or particles. For this reason, also the development of plastics later focused on composite materials. Currently, there is a large number of polymer-based composite materials that increases every year. Table 1 shows their classification [59], [60], [61], [62].

*Table 1 Polymer-based composites [61]*



**Legend: pórovité materiály impregnované polymery – porous materials impregnated by polymers, markoskopické kompozity – macroscopic composites, vyztužené polymery – reinforced polymers, keramika – ceramics, beton – concrete, drevo – wood, vrstvené fólie – laminated foil, vrstvené hmoty – laminated materials, lepené spoje – glued joints, peny – foams, práškovitá plniva – powdered sinters, vláknitá plniva – fiber sinters, monomér + polymerizácia – monomer + polymerization, impregnácia roztokom polyméru – impregnation with polymer solution, impregnácia emulziou polyméru – impregnation with a polymer emulsion, monomér + cementová malta (polymerizace a hydratácia) – monomer + cement mortar (polymerization and hydration), impregnácia termoplastmi – impregnation with thermoplastics, impregnácia reaktoplastmi – impregnation with thermosetting plastics, vrstvené tkaniny – laminated fabrics, vrstvené dřevo – laminated wood, vystužené gumy – reinforced rubber, vysoko naplnené živice - resins, dlhé vlákna – long fibers, krátke vlákna – short fibers**

**Macroscopic composites** are composites in which macromolecular material creates a macroscopic continuous phase. The most important macroscopic composites are laminated materials (laminates), which are formed by joining more layers of polymers and reinforcing material. Reinforcement is not in the matrix but the individual fibres are joined in the form of a fabrics with various bound or in the form of mats or rovings (strand of fibres). The individual layers are saturated by liquid or powdered resins that are reinforced in the next stage. The most widely used laminated plastics according to the type of reinforcement include **glass laminates**. Laminates are used for manufacturing parts of a bodywork of some vehicles (bodywork of Trabant is from polyphenol resin reinforced by mats of short cotton fibres). Glass laminates are also used for manufacturing of sports aircrafts (airframes and wings).

**Impregnated porous materials** are composites based on ceramics, concrete, and wood. These materials are filled with polymers.

**Laminated safety glass** prevents glass fragments from dispersing when broken. It is manufactured by joining two or more glass panes with plastics. [61].

**Lightweight materials, foams**, are polymers containing cavities of different shapes and sizes. They are manufactured from plastics and natural rubber. Technically the most important lightweight materials are PS (polystyrene), PVC (polyvinyl chloride) and foam thermoset. They are used e.g. for the interiors of means of transport (seats) and as a packaging material [59], [60], [62].
A special case of laminated plastics are **sandwiches.** They are laminated or aluminium coatings with lightweight plastics core, intended e.g. for manufacturing bodyworks of refrigerator trucks and caravans.

**Reinforced polymers** are materials created by joining a reinforcement material (filler) and a macromolecular material, mostly in order to improve the mechanical properties. The polymer component is the basic continuous matrix of a composite. Filler can be organic or inorganic. The base of reinforced polymers are thermosets, e.g. PTFE (polymer of fluorinated ethylene – Teflon) filled with graphite and powdered bronze used for movable, non-lubricated gasket and sliding bearings. [62].

## 12.2. Composites with metal matrix

Composites with metal matrix can be divided into:

- **Disperse reinforced materials** – metal matrix + non-coherent dispersoids,
- **Fibre composites** – metal matrix + thin wires or monocrystalline fibres.

**Disperse reinforced materials** are composites with matrix reinforced by disperse continuous phases. They are mostly produced by means of powder metallurgy technologies. They have polycrystalline matrix with disperse particles, most often of oxide, carbide, and nitride type. Reinforcement can be both direct (this consists in inhibiting the movement of matrix dislocations) and indirect (this consists in the fact that in forming, dispersoids increase the density of dislocations and refine the grain and subgrain structure). Theoretical studies and experiments showed that the maximum reinforcement is achieved by means of following structural parameters:

- dimensions of the reinforcing particles of the secondary phases (dispersoids) shall not exceed 50 nm,
- medium distance between the reinforcing particles shall range between 0.1 – 0.5 μm and their distribution shall be even.

The parameters mentioned above indicate the real volume fractions of dispersoids.

**Aluminium SAP (Sintered Aluminium Powder)**, i.e. aluminium reinforced by $Al_2O_3$ particles is the oldest disperse reinforced material. For its preparation, surface oxidation of aluminium powder is used during the milling process. Hard oxides on the surface of the aluminium particles crack, peel off, and pure metallic grains are welded. The result of these repeated processes is the formation of aluminium grains that are reinforced by oxide particles inside. The resulting aluminium powder is compressed, sintered and hot extruded. The advantage of SAP are very good mechanical properties, low density, good resistance to corrosion and good thermal conductivity [59], [60], [61], [62].

**Dispal** is a new material with the properties similar to SAP. In this case, it is aluminium reinforced by $Al_4C_3$ particles prepared by mechanical alloying of the mixture of aluminium and graphite powder. This powder is subsequently hot-compacted. Like SAP, Dispal is also used as a construction material especially in automotive and air transport. It is characteristics with high resistance to recrystallization and high ŽÁRUPEVNOST between 300 - 500 °C.

**TD Nickel** (98 % Ni, 2 % $ThO_2$) is nowadays considered a traditional, disperse reinforced material. Nickel reinforced by thorium dioxide has a high strength and is suitable for application at the temperatures of 1100 $^{o}$C and higher.

**Disperse reinforced ŽÁRUPEVNÉ alloys** are currently most often reinforced by $Y_2O_3$, as $ThO_2$ is radioactive. It´s mostly NiCrAl-$Y_2O_3$ alloys prepared by mechanical alloying. They are used for gas turbines of aircraft engines. They are characteristics with high ŽÁRUPEVNOST to the temperature of 1200 °C and for a short time up to 1350 °C.

**Disperse reinforced stainless and ŽÁRUPEVNÉ steels**, austenitic and ferritic steels (reinforced by Al, Ti, or Th oxides) have higher resistance to radiation brittleness; therefore they are used at reactors construction. Due to their high strength (also at high temperatures – for a short time up to 1200 °C) at acceptable toughness and corrosion resistance, they are used also in aerospace and rocket technology. Their disadvantages include high costs, proneness to heat brittleness, problems with weld strength, frequent anisotropic properties and proneness to stress corrosion cracking. [61].

## 12.3. Fibre-reinforced composites

**Fibre-reinforced composites** with metal matrix ca diameter of 2 - 250 μm), fibres (short thin wires) and whiskers (short single-crystal fibres with a diameter of about 1 μm*).*

**Fibres** (or wires) have a tensile strength of about 2000 - 4000 MPa. Materials reinforced with fibres are mostly shaped; therefore the composite material has a significant anisotropy of properties. They are manufactured using powder metallurgy, embedding the fibres with the basic material, or rolling of matrix metal foil interlaced by fibres. When considering plastic deformation at higher temperatures, the optimal ratio *l/d* is increased to about 50.

**Composites with aluminium matrix** are one of the most widely used materials reinforced by fibres. The most common material are *carbon fibres* that are either compressed between aluminium foils or coated with a Ti and B layer and aluminium. Important fibres are the *B* and *B* fibres + *SiC* (boron fibres covered with SiC layer).

**Composites with titanium matrix** are also used in aerospace (blades of air engine fans). Borsic and beryllium fibres are suitable for titanium reinforcement. Composites with a titanium alloy matrix of VT6 type achieve the fibre strength of 1 000 - 1400 MPa.

**Heat-resistant composites** are mainly on nickel super-alloys base with tungsten and corundum fibres, as well as graphite fibres. The proportion of the fibres is between 20 - 70 %, strength at the temperature of 20 °C is 1 400 - 2 100 MPa, creep time (1 000 h) at the temperature of 1 100 °C is 200 - 300 MPa, which is much higher than in the case of conventional heat-resistant_alloys. They can be used at the temperatures of up to 1650°C.

**Whiskers** are short single-crystal fibres with a diameter of about 1 μm. They are usually prepared by crystallization from liquid and gas phase. The most convenient production is the production of sapphire ($\alpha$-$Al_2O_3$) whiskers. They are prepared by heating aluminium oxide to 1 300 – 1 500 °C in hydrogen atmosphere containing water vapour. Oxide is reduced, aluminium evaporates and re-oxidates. Aluminium oxide then deposites in the form of whiskers in the cooler part of reaction space [59], [60], [61], [62]. Composites reinforced with whispers are easy to form and can achieve high strength. For example, aluminium with SiC whiskers has a tensile strength of up to 600 MPa. There have also been developed $Al_2O_3$ or $B_4C$ whiskers in silver and niobium. Composites with niobium matric appeared to be extremely suitable materials for stress at the temperature of 1100 °C. The main disadvantage of whiskers is their high price.

# 13. COMPOSITE MATERIALS II.

## 13.1. Sintered metal ceramic materials

Powder metallurgy enables to produce more types of new materials that cannot be obtained by using conventional technological procedures. This includes also sintered materials made of the mixture of metal and ceramic powders. These are mainly sintered carbides to cutting tools and friction materials for manufacturing brake linings.

**Sintered carbides** belong among sintered micro-heterogeneous materials. They represent an advanced stage of hard tool materials. Powder metallurgy enabled to create materials, in which the high hardness of hard carbides is used, which are very brittle when cast. The basic material for currently used sintered carbides are particles of high strength carbides of tungsten and titanium, which are joined by means of cobalt. Sufficient hardness and reduction of sintered carbides brittleness is achieved if the individual carbide particles do not exceed the size of a few μm. Increasing cobalt content increases the bending strength and reduces hardness. Hardness (without reduction of toughness) can be further increased by the application of hard coatings on sintered carbide plates [61], [62].

**Metal and ceramic friction materials** are sintered heterogeneous materials for clutches and brake lining for very efficient means of transport (aircraft, trams), machines, and transportation mechanisms. For these, conventionally used non-metallic friction materials are not suitable, as high friction coefficient is necessary at high temperature, good heat conductivity (for conducting heat generated by friction). [61], [62].

## 13.2. Composite materials with ceramic matrix

New kinds of ceramic materials have been developed. Those are called “third-generation materials” and are used e.g. in mechanical engineering, electrical engineering, and electronics.

There are two groups of ceramic materials:

- Monolithic ceramic materials,
- Composite materials.

## 13.3. Monolithic ceramic materials

The basic element of these materials are aluminium oxides, silicones, and inorganic materials of various types. Along with the development of these materials, new technologies of their production and processing were also developed. New ceramic materials are referred to as *structural ceramics*, which is produced from refined or synthetic raw materials. For processing of raw materials, special chemical processes and mineral and technical treatment are used.

Structural ceramics has specific properties that enable to use it:

- In the areas with prioritized **electrical and mechanical properties**, i.e. in electronics and heavy current electrical engineering.
- As a **cutting material.** Sintered aluminium oxides, silicon ceramics, and zirconium-aluminium ceramics are more advantageous for cutting than tungsten carbides.
- for components working at **high temperatures**, where especially the ceramics stability at the temperatures up to 1 300° C is used. Ceramics is used e.g. for turbine engines blades, rotor covers, vents and their hoists in combustion engines.

## 13.4. Ceramic composite materials

Their properties are obtained by a suitable arrangement of their structure – filler matrix and fibres. They have higher strength and hardness than other materials. This is achieved by reinforcement by *fibres* and *whiskers*. While polymer composites can be used only at temperatures not exceeding 300° C and in the case of metal composites 600° C, ceramic composite materials are stable even at much higher temperatures.

There are two types of preparation of ceramic composite materials:

- Powder processing of the basic material and infiltration of fibres strands suspensions. They are reinforced by fibres or whiskers, compacting is ensured by hot pressing;
- Chemical processes – thermal decomposition, reaction binding, and chemical infiltration technology. High working temperatures are not required. Chemical processes are slow compared to the previous ones.

Ceramic composites are produced using technologies similar to metal composites. Surface coating of fibres is used in order to achieve the proper phase boundary between a fibre and filling [61], [62].

## 13.5. Carbon fibres composites

The starting raw material for production of carbon fibres are three materials:

- cellulose – created fibres have imperfect structure, they are used as insulation material at high temperatures.
- polyacrylonitrile (PAN) – standard fibres, since 1980
- pitch, a costly method of fibres production, whose final price is very favourable considering the low price of the starting material. It has a high value of the E-modulus and very good thermal and electrical properties. Their compressive strength is significantly lower compared to the standard fibres, since the bonds between the individual graphite layers are reduced. They have relatively small market share, HM (with high flexibility) fibres, HT (with high strength) fibres are used for special purposes.

In general, the production of composite fibres ranks among more advanced production technologies. Currently, the most frequently used method of production is fibres pyrolysis by PAN. They are stretched after heating in order to achieve the required orientation of molecules. Subsequently, carbonization stabilization is required for up to 10 hours at the temperatures of 220-230°C. The next step includes stretching the fibres in an inert atmosphere at temperatures of 1000-1500°C and the carbonization continues. Such fibres are referred to as HS fibres (high strength). When heating temperature exceeds 2500°C in an inert atmosphere, graphitisation causes the formation of a structure similar to graphite. Such fibres are referred to as HM (high modulus) fibre.

Currently, it is possible to adjust the fibres according to the customer. These include e.g. high-modulus graphite fibres, hollow fibres, fibres with high modulus of flexibility or nanofibers [59], [60], [61], [62].

**Figure 1 shows the overview of carbon fibres utility properties**

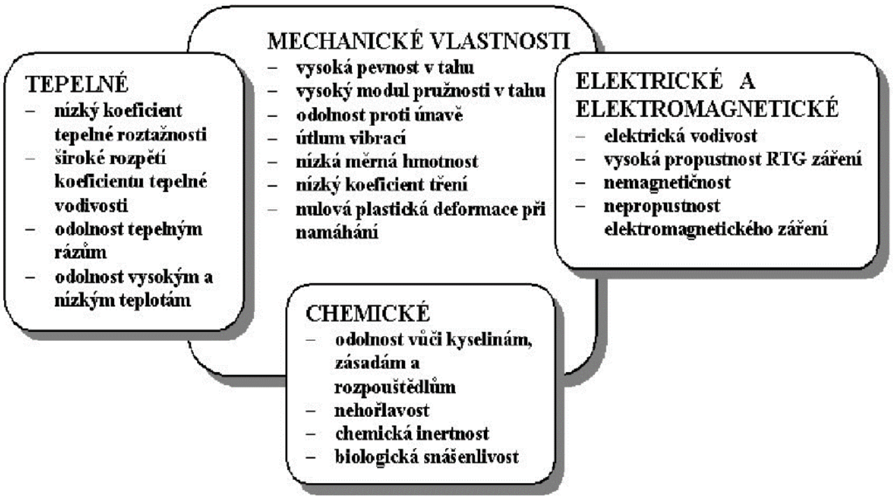


*Figure1 Properties of carbon fibres and composites [60]*

**Legend: tepelné vlastnosti (thermal properties): nízký koeficient tepelné roztažnosti (low thermal expansion coefficient), široké rozpětí koeficientu rázů (wide range of coefficient of restitution), odolnost vůči vysokým a nízkým teplotám (resistance to high and low temperatures)**
**Mechanické vlastnosti (mechanical properties):vysoká pevnost v tahu (high tensile strength), vysoký modul proužnosti v tahu (high tensile flexibility modulus), odolnost proti únavě (fatigue resistance), útlum vibrací (vibration attenuation), nízká měrná hmotnost (low specific weight), nízký koeficient tření (low friction coefficient), nulová plastická deformace při namáhání (zero plastic deformation at stress)**
**Elektrické a elektromagnetické (electrical and electromagnetic): elektrická vodivost (electric conductivity), vysoká propustnost RTG záření (high X-ray transmittance), nemagnetičnost (non-magnetic), nepropustnost elektromagnetického záření (non-transmittance of electromagnetic radiation),**
**Chemické (chemical): Odolnost vůči kyselinám, zásadám a rozpouštědlům (resistance to acid, bases, and solvents), nehořlavé (inflammable), chemická internist (chemical inertness), biologická snášenslivost (biocompatibility)**

Fibres produced by graphitization create strands that are coiled onto roving. Coils are than placed on a loom where fabric is made.

By increasing the number of fibres in the warp, various types of fibres crossings are created. These are called bindings [59], [60], [61], [62]. The advantage of fabrics compared to unidirectional reinforcement is its easy processing. Figure 2 shows the classification of fibre composites on a schematic diagram from geometric perspective.

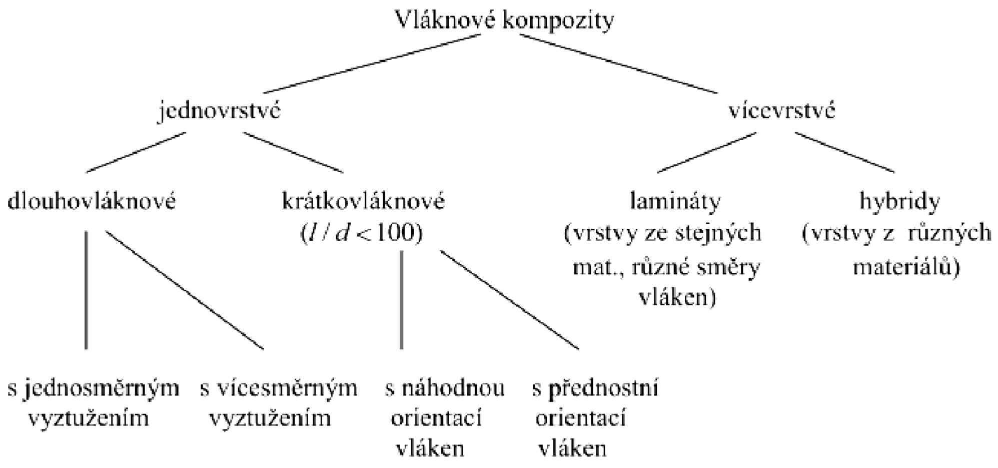


*Figure 2 Classification of fibre composites from geometric perspective [61]*

**Legend: vláknové kompozity – fibre composites, jednovrstvé – single layer, vícevrstvé - multilayer, dlouhovláknové – long fibre, krátkovláknové – short fibre, s jednosměrným vyztužením – with unidirectional reinforcement, s vícesměrným yztužením – with multidirectional reinforcement, s náhodou orientací vláken – with random fibre orientation, lamináty - laminates (layers of the same materials, with different fibre orientation), hybrids (layers of different materials)**