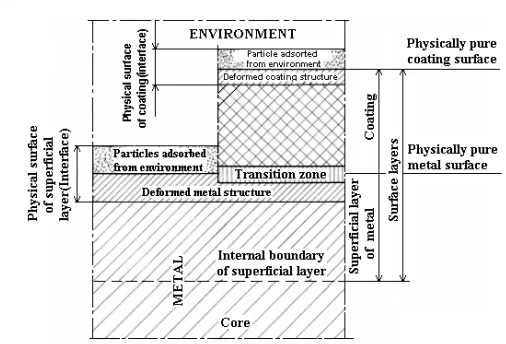
3.5 Structure and type of the coating

The cover of animals' bodies → given in the 1950s → no general terminological specification defining

⊙ 3.5.1 Definition of coating

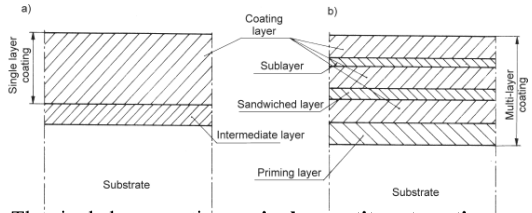
⊙ **Coating** - a layer of material, formed naturally or synthetically or deposited artificially on the surface of an object made of another material, with the aim of obtaining required technical or decorative properties.

Superficial layer < > coating



3.5 Structure and type of the coating

3.5.2 Structure of the coating



The single layer coating: – **single constituent coatings**;
– **multi-component coatings**

The multi-layer coating: – **multiple coating**;
– **sandwich coating**;
– **self-stratifying paint**

3.5 Structure and type of the coating

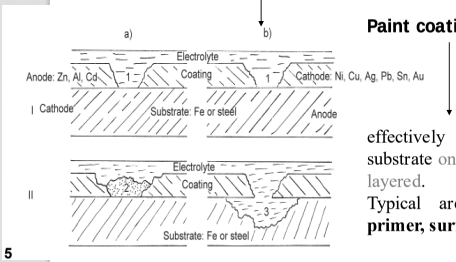
3.5.3 Types of coatings
Division of coatings by material
1) Metallic coatings
2) Non-metallic coatings

Paints	**Compounds of substrate metals**
Varnishes清漆	**Synthetics** (plastomers, plastic mixes)
Resins	
Oils	**Indiarubbers (latexes)**
Cements	**Rubbers** are products of vulcanization橡胶硫化
Waxes	
Lubricants	
Metal ceramics	
Ceramic materials	

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **1) Protective coatings**

Anodic coatings and Cathodic coatings



Paint coatings

effectively protect the metallic substrate only when they are multi-layered.
Typical are 4-layered coatings: **primer, surfacer, enamel, varnish**.

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **2) Decorative coatings**
- Decorative coatings, once called ornamental, serve predominantly to give the metal or non-metal object an aesthetic external appearance.

  This depends first of all on color, luster and resistance to tarnishing 变色.

  It is evident that decorative coatings, in many cases, make good protective coatings.

  Decorative coatings may be both metallic and non-metallic.

electroplated coatings paints

3.5 Structure and type of the coating

⊙ **3.5.3 Types of coatings**

⊙ **Classification of coatings by application**

⊙ **3) Protective-decorative coatings**

⊙ Regarding **electrolytic coatings**, the protective-decorative role is fulfilled by nickel, chrome, and copper-nickel-chrome coatings on condition that they are sufficiently thick. It is accepted that their thickness should not be less than 25 μm

⊙ The overwhelming majority of **non-metallic coatings** functions as both protective and decorative, **particularly those of plastic, enamel and paint**

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**
  Coatings which enhance tribological properties
- In the majority of cases, **better tribological properties are exhibited by harder than by softer metal coatings**.
- Most frequently, as resistance coatings wear, hard chrome-plated layers of 10 to 30 μm thickness are used. For high sliding velocities and high unit loads, electroplated silver or indium coatings of 500 to 1500 μm, as well as porous chrome coatings, are used.
- Among **non-metallic coatings**, very high hardness and excellent tribological properties are exhibited by **nitride, oxide, carbide and boride coatings**, deposited in vacuum by PVD and CVD techniques.

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**
  Coatings which enhance electrical properties.
- These coatings serve first and foremost to enhance electrical conductivity of terminals and are used in electrical and electronics applications.
- Since very good electrical conductivity is exhibited by silver, very often silver coatings are deposited on copper, brass and bronze substrates

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**
- **Coatings enhancing solderability of joined surfaces**
- These are tin and copper coatings, as well as alloys: tinzinc or zinc-lead, less often cadmium and twin-layered cadmium-tin and copper-tin, deposited on brass and steel components.
- Copper coatings of 2.5 to 7 μm, often protected by a layer of varnish against tarnishing, are applied to components immediately before soldering.
- The thickness of tin coatings, which insignificantly oxidize and for that reason require the use of fluxes助熔剂, is 5 to 15 μm.
- Alloy coatings composed of 70% tin and 30% zinc are well suited for soldering and for service in tropical climates.
- The best proportion of tin to lead in tin-lead coatings is 40:60

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**

Coatings protecting against diffusion, particularly of carbon, nitrogen, and other elements in thermochemical treatment operations, are applied as electroplated or in the form of pastes.

They fulfill the role of a blockade封锁, stopping the passage of a given element to a given (coated) fragment of the component which is subjected to thermo-chemical treatment.

Electroplated coatings are usually copper or tin, as well as alloys of copper and tin with a thickness of up to 25 μm.

Paste coatings with varied chemical composition may reach thicknesses of over 1 mm

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**

Catalytic coatings.

- These coatings serve to **change the rate of reaction** in the gaseous environment with which it is in contact, as well as to raise or lower the temperature at which the reactions occur.
- Since **a large area of contact** between the coating and the surrounding gas is required, the real surface should be developed as much as possible.
- The coating material may be **metallic, metal ceramic and ceramic**

3.5 Structure and type of the coating

- **3.5.3 Types of coatings**
- **Classification of coatings by application**
- **4) Technical coatings**

Coatings enhancing selected thermophysical properties

Most often, these coatings are applied in order to **enhance resistance to the effect of elevated temperatures**, as well as **emissivity and thermal conductivity properties, themselves dependent on temperature**

- Coatings which enhance emissivity may be monolayer, but those which retard or enhance thermal conductivity, as well as heat-resistant coatings, are all multi-layered, most often comprising three layers, in order to improve adhesion to the substrate and thus to prevent cracking of the external layer due to excessive residual stresses which rise with a change in temperature.
- Metal ceramic and ceramic coatings are characterized by high emissivity, within the range of 0.6 to 0.95.

3.5 Structure and type of the coating

3.5.3 Types of coatings
Classification of coatings by application
4) Technical coatings
Ablation(烧蚀） coatings

These constitute one type of coating with special thermophysical properties.

They are most often produced by thermal spraying of ceramic refractory 耐火的难熔的 materials (the main constituents of which are Al_2O_3 and ZrO_2 as well as silicides $ZrSiO_4$ and $MoSiO_4$) onto metallic or non-metallic surfaces with good thermal insulation, in order to protect them against the effect of elevated temperatures at which the surface may melt.

Carbon ablation materials

3.5 Structure and type of the coating

3.5.3 Types of coatings
Classification of coatings by application
4) Technical coatings
Ablation(烧蚀） coatings

Under the influence of heat they undergo ablation, thereby protecting the substrate material.

Such coatings are deposited on **gas turbine blades**, **components of high temperature equipment and, primarily, on short and long range ballistic rocket heads, as well as on external surfaces of space vehicles**. In the latter case, they enable the vehicle to overcome the heat barrier during re-entry into the dense layers of the earth's atmosphere.

As an example, at a speed of 6000 km per hour, at an altitude of several kilometers, the temperature of the vehicle surface, due to friction from atmosphere particles, reaches approximately 1600 K.

3.5 Structure and type of the coating

3.5.3 Types of coatings

Classification of coatings by application
4) Technical coatings
Optical coatings

These coatings may have different tasks.

Steel and brass elements are coated with electroplated silver, chrome and rhodium, nickelchrome and copper-nickel-chrome layers to enhance surface luster.

Thin multi-layered anti-reflection coatings are applied by PVD techniques to surfaces of glass and plastics. These coatings may absorb or reflect selected bands of thermal radiation, especially in the visible range; they may transmit radiation in one direction and they may counteract(阻碍) the accumulation of dust, gases, vapours, etc

3.6 Potential properties of the coating

3.6.1 Geometrical parameters of coatings

(1) Thickness

Coating thickness is the basic parameter on which protective properties, decorative and technical properties significantly depend.

Porosity, tightness, corrosion resistance and mechanical strength all depend on the appropriate coating thickness.

In general

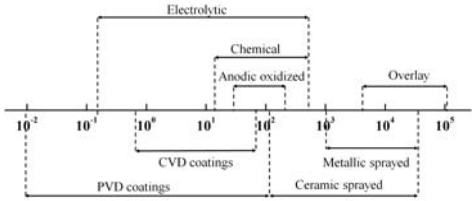
Protective properties of coatings increase with the rise of thickness, similarly to wear resistance.

But thickness has the opposite effect on flexibility弹性, impact strength冲击强度, and sometimes even on adhesion strength.

3.6.1Geometrical parameters of coatings

(1) Thickness

Coating thickness varies over a very broad range - from hundredths of a micrometer to several millimeters. overlay



3.6.1Geometrical parameters of coatings

(2) Roughness Ra and Rz

(3) Three-dimensional structure defects

The three-dimensional structure of the coating is the result of the coating process, dependent on the **method or technique used**, on **defects** formed during the deposition and on **substrate roughness.**

Defects of the three-dimensional structure, which are simply **coating defects**, all have the same character as **those of the superficial layer**.
The most frequent defects, common to both surperficial layers and coatings, are blemishes斑瑕疵缺陷, scratches划痕, cracks裂纹裂缝and porosity.

Among the most important defects, common to all coatings, are non-uniform thickness (including object edges), delamination分层, exfoliation脱落, incomplete coverage, pits, blisters气泡, raising鼓起浮起of the coating, brittleness, chipping碎屑, and sagging松垂下垂[沉, 陷].

3.6.1Geometrical parameters of coatings

(3) Three-dimensional structure and defects

Each type of coating exhibits certain own, characteristic defects. Among the most frequently encountered are:

–for **metallic, electroplated coatings**: burns烧伤，灼伤, streaks条纹条斑，striation条痕，条纹状，haziness朦胧之性质或状态，roughness (here understood as major build-ups 积累,叠加；复合；(壳型)结垢现象or surface contamination inclusions), spots 污点, decoloration去色, excessive matting无光粗糙表面 and runs条纹

–for **organic paint coatings**: bleaching漂白，browning褐变，blushing雾浊发白, spots, pinholing, uneven color, uneven luster, pock-marking麻点, orange peel桔皮漆病, crocodile skin, fading and runs;

–for **sprayed inorganic coatings**: irregularity of coating thickness (resulting from "spitting分散" by the spray gun), varying degree of melting of coating material particles

3.6.2 Geometrical – Physico-chemical parameters of coatings

Among the most important **geometric and physico-chemical parameters** are those which describe coating properties, such as:

– relating to energy, mainly **surface energy**,

–relating to radiation, mainly **reflection and emissivity**, and significantly less often (only for selected types of coatings): radiation辐射 transmittance透过系数,

–**catalytic** (dependent on degree of surface development and coating components which accelerate or retard chemical reactions),

–**thermophysical**, mainly thermal conductivity and solderability可焊性

3.6.3Physico-chemical parameters of coatings

(1) **Residual stresses**

The kind of stresses depends on **the coefficients of thermal expansion of substrate and coating layers** and on **the character of structural defects**.

Residual stresses are formed in coatings as the result of differences in thermal expansion coefficients of substrate and coating materials (stresses of the **I kind**), as well as significant defects in the structure of the coating material (stresses of the **II and III kind**)

Compressive stresses and **tensile** stresses:

If the layer contains **more atoms** in **interstitial positions than there are vacancies in the lattice**, **tensile stresses** are formed, while **the reverse situation leads to the formation of compressive stresses**

3.6.3Physico-chemical parameters of coatings

(1) **Residual stresses**

Residual stresses may be reduced by the **selection of appropriate materials and process parameters**.与材料及制备工艺有关

For examples in chrome-plated coatings, residual stresses may vary from –800 to 1000 MPa.

Brighteners, in particular, significantly affect the rise of residual stresses, mainly in nickel coatings, in which an addition of saccharin糖精 or other organic compounds of sulfur **reduces tensile stresses**.

Without the use of brighteners, tensile stresses are generated in nickel, cobalt, iron, palladium, manganese and chrome-plated coatings, while compressive stresses are generated in zinc and cadmium coatings.

3.6.3Physico-chemical parameters of coatings

(1) **Residual stresses**

Values of residual stresses vary, depending on **layer thickness**, e.g., in chrome and nickel plated coatings; stresses diminish with a rise in layer thickness and achieve a constant value when the layer thickness reaches 30 μm.

In order to reduce residual stresses of the I kind, **multi-layered coatings are deposited**, comprising a composition of layers with successively changing thermal expansion coefficients, relative to the substrate material.

Coatings with **big tensile stresses**, e.g., chrome and nickel-plated, **exert an unfavorable effect on some mechanical properties** of coated objects, especially on **fatigue strength which may decrease by 20 to 70%** as the result of coating deposition.

Compressive stresses in coatings **do not exhibit any significant effect on fatigue strength**

3.6.3Physico-chemical parameters of coatings

(2) **Adhesion**

Adherence of coatings to the substrate or of layers of multi-layer coatings to each other, described by the force necessary to detach the coating from the substrate or layers from each other, reflects the character of the dominating bond:

-**metallurgical** - consisting of **melt-mixing** of the coating and subsurface zone materials;

-**epitaxial**- consisting in the formation of coating crystals, similarly oriented relative in each other, on the crystals of the substrate, on condition that the difference in lattice parameters will not be bigger than approx 10%.取向附生的, 外延的

-**adhesive** - consisting of the utilization of adhesion of the coating to a well-cleaned substrate ;

3.6.3 Physico-chemical parameters of coatings

(2) **Adhesion**

-**diffusion** - consisting of mutual displacement, through diffusion of components of the coating and the substrate.

-**mechanical** - consisting of creation of conditions in the substrate for mechanical anchoring of coating material. This version occurs in some thermal spray techniques.

Naturally, combinations of the above types of bonding are also possible

3.6.3Physico-chemical parameters of coatings

(2) **Adhesion**

Influencing factors

1)The **condition essential for good adherence** of coatings is **high purity** of the **substrate surface** prior to deposition of coating.

Better adherence can only be achieved **2) when** the distance between the coating and the substrate is comparable to lattice parameters; **3)when** the formation of thin diffusion layers

4)Furthermore, residual stresses, degree of **surface development** (higher roughness -better adherence), as well as by differences in the ductility of surface and substrate materials.

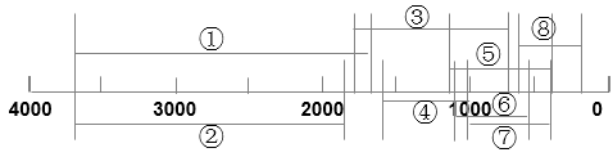
Good adherence of coatings prevents their scaling剥落 and detachment due to temperature, strong internal interaction of a mainly mechanical character and residual stresses

3.6.3Physico-chemical parameters of coatings

(4) Hardness

Hardness of various coatings[HV0.005(HK0.0025)]

For different coatings, it obviously differs and depends on the coating material and its structure. It varies within a very broad range, from the hardness of soft rubber to that of diamond.



①PVD ②CVD ③Overlay
④Ceramin sprayed ⑤Electrolytic
⑥Chemical ⑦Metallic sprayed
⑧Anodic oxidation

3.7 Service properties of coatings

3.7.1Anti-corrosion properties

The same object, coated with the same type of coating, exhibits different corrosion resistance in different environments.

For that reason, a generalization of the problem of **corrosion resistance** is extremely difficult.

It depends most significantly on:

composition, structure of the coating,

three-dimensional structure of coating surface,

on defects, residual stresses, type and condition of the substrate,

on type and intensity (temperature and concentration) of the corrosive medium and time of exposure.

3.7 Service properties of coatings

- (2) **Decorative properties**
- ***External appearance***
- The basic criterion of a coating's decorative value is its external appearance. Of all the properties of coatings, external appearance is the easiest to evaluate because it can be done immediately, by visual means.
- The **most important factors taken into consideration** when evaluating the external appearance of coatings are **color, luster, smoothness (opposite of roughness) and the ability to cover the substrate (Coverability).**
- These properties can be not only evaluated visually but also measured in an objective way, similarly to the resistance of coatings to intense ultraviolet and infrared radiation, as well as to tarnishing(沾色锈污).

3.7 Service properties of coatings

- (2) **Decorative properties**
- ***Color***
- The following color characteristics are distinguished:
- – the **color** itself - dependent on the wavelength of light radiation, reflected by the coating. This is a qualitative characteristic, described by a name, e.g., green, red, etc.
- – **saturation** - dependent on the degree to which the color is closer to white or black;
- – **purity** - dependent on the width of spectral band, i.e., on additions of other colors. The purity of a color is highest when the coating reflects radiation monochromatically (as one color);
- – **brightness** - dependent on the intensity of radiation reflected by the coating.

3.7 Service properties of coatings

- (2) **Decorative properties**
- ***Color***
- Coating colors stem from
- – **the nature of the components forming the metal or ceramic coating**, be it electroplated or deposited chemically, by immersion, spraying or overlaying.
- – **pigmentation of paint materials or ceramic enamels**, i.e., introduction of pigments into the coating composition.
- Besides offering aesthetic sensations, colors have their own way of affecting the human psyche心灵, as well as the physiological and physical changes which take place in the human organism. The force of color action is called ***color dynamics***.

3.7 Service properties of coatings

- (2) **Decorative properties**

- *Color*
- ***color dynamics.***
- For example, the application of cold colors in hot industrial production rooms and warm colors in cold rooms affects the sensing of temperature by the organism.
- **Red color** surrounding man from every side produces excitation and nervousness, **yellow** - brings on a happy mood, **green** may act depressively on neurotics, some shades of **brown** may cause a feeling of sadness; **white** retards the functions of the brain while **black** has an unfavorable effect on people who easily succumb to psychological depression

3.7 Service properties of coatings

- (2) **Decorative properties**
- ***Luster***
- The degree of luster is described by the ratio of the coefficient of oriented reflection of the observed surface to the coefficient of total reflection. The **numerical value of this degree of luster** varies from zero (ideally dispersive surface, practically non-existent with approximate properties exhibited by coarse, rough and matte surfaces, e.g., those obtained by thermal spraying) and unity (ideally reflecting surface, practically non-existent, with approximate properties exhibited by very smooth, polished surfaces, i.e., mirrorlike).
- An example of the latter is the surface of an electroplated coating with addition of brighteners, deposited on an ideally smooth surface

3.7 Service properties of coatings

- (2) **Decorative properties**
- ***Luster***
- The degree of luster of coatings decreases with time of service, as the result of aging and absorption of particles from the environment.
- Moreover, in subjective observation it depends on lighting conditions, angle of viewing, acuity of contrast of a visible object, seen as a reflection by the surface.