第三章 表面层结构与性质

Contents

3.1 The surface and the surface layer

3.1.2 The surface layer

Spontaneously -natural surface
Artificially
---surface layers are formed before the beginning of their service, by subjecting the object to technological treatment process - these are ***technological surface layers***.

---surface layers are produced on objects during service, e.g. layers formed during low wear friction - these are ***service generated surface layers***.

3.1 The surface and the surface layer

3.1.2 The surface layer

Superficial layer
The layer of deformed (by the production process) SOLID -physically (by heat, force, diffusion of foreign atoms), chemically (e.g., by oxidation) and structurally situated **below the physically pure surface** may be called the **subsurface layer** (or **layers**).

Since the situation of this layer (or layers), relative to the core of the object, is on the side of the real surface, the term applied is **superficial layer**

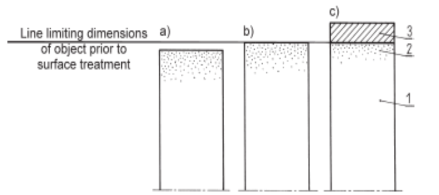
3.1 The surface and the surface layer

3.1.2 The surface layer

Coating
Layers of adsorbed gas, water vapour, sweat, lubricant, and solid particles (dust, material debris), **situated above the physically pure surface**, may be termed **supersurface layers**.
During technological processes of manufacturing and during service, these layers form the source of nucleation of a new phase, **leading to a new layer**, or are removed (to activate the real surface) before being deposited on the almost physically pure surface **of a layer of new material, different from that of the core**.
Since some 40–50 years ago this layer has been referred to as **coating**

3.1 The surface and the surface layer

3.1.2 The surface layer



Surface layers= superficial layer (a,b)
=superficial layer +coating(c)

3.2 Superficial layer and structure models

3.2.1 Superficial layer

surface
machining → abrasive and erosion
obtain a smoother or a rougher surface (only property)
→ **Beilby's layer**

1. Definition of Superficial layer

- a layer of material, limited by the real surface of an object,

which **includes** this surface and that portion of the material inward from the real surface which exhibits changed physical, and sometimes chemical properties in comparison with properties of the material core.

2. Three aspects for the superficial layer

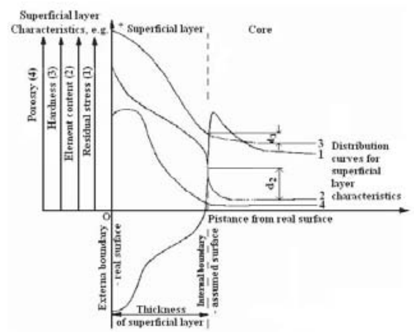
1) The **properties** of the superficial layer **depend** predominantly **on the type of this treatment**， are usually not constant with time.
– they may change **spontaneously**, in a natural manner, without the participation of extraneous technical factors, e.g., as a result of natural aging, stress-relieving;
– they may change **non-spontaneously**, under the influence of extraneous technical factors (forces) occurring during the service of the object, e.g. as a result of loading, wear, chemical action of the environment

3.2.1 Superficial layer

2) The superficial layer zone is the portion of the superficial layer, the volume of which is determined by the existence of a given property性质. The individual layers may permeate one another, with a transition from one to the other, or they may occupy together the same part of space.

3) The internal limit of the superficial layer is the theoretical surface determined by points corresponding to boundary values of that property of the superficial layer.
The determination of the internal limit of the superficial layer is very difficult and in most cases is only an approximation, an assumed value

3. Determination of internal boundary of superficial layer.



4. Structure models of the superficial layer

- **Specific characters of the solid surface**:

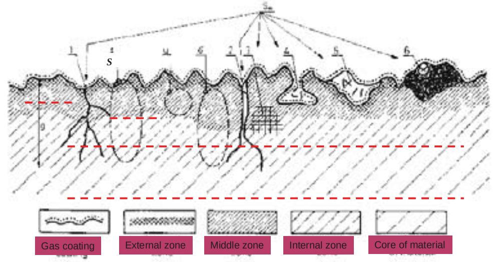
  Each surface, regardless of the method of formation, is characterized by **a certain state of unevenness**

  Regardless of the type of treatment operation or treated material, the **nascent atoms of the solid surface** are characterized by **high chemical activity** which influences the interaction between the surface and the environment.

  Anyway, **the formed superficial layer always has a structure** and properties which depend on **not only** the core material (chemical composition and physicochemical properties) **but also** on the **type** and **conditions** of the treatment operation.

The only models discussed here will be those of the superficial layer formed as **the result of machining**

The 3-zone model

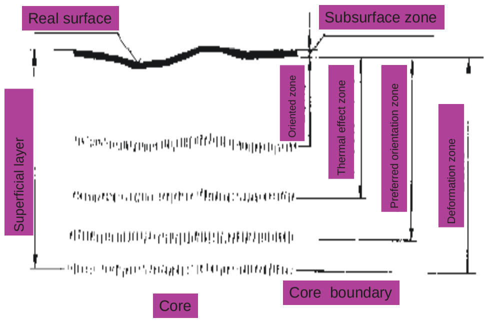


g-thickness of superficial layer; *S*-structure of superficial layer;
u- strengthening of the middle zone;
σ - residual stresses in the superficial layer;
Sw-flaws of the superficial layer; *1*–micro fracture; *2*- fissure; *3*-microshrinkage; *4*-porosity; *5*–gap; *6*-inclusion

The 3-zone model

- The **external** zone is made up by a layer of foreign particles, mixed with spalled particles of the core material. From the side of the environment, the external zone is covered by a layer of adsorbed gas. The thickness of the external zone is **0.001 to 0.02 µm** while that of the gas layer approximately (2 to 3)$\times10^{-4}$ µm.
- The **middle** zone consists of strongly **deformed grains** of the core material and in many cases may be significantly textured. Its thickness ranges from **0.5 to 500 µm**. Main usable properties of the physical surface depend on the structure of this zone.
- The **internal** zone consists of grains which are **not permanently deformed** but has a different structure than that of the core, e.g., as a result of transformations induced by heat. Residual stresses reach this zone. The thickness of this zone may reach **several thousand micrometers**.

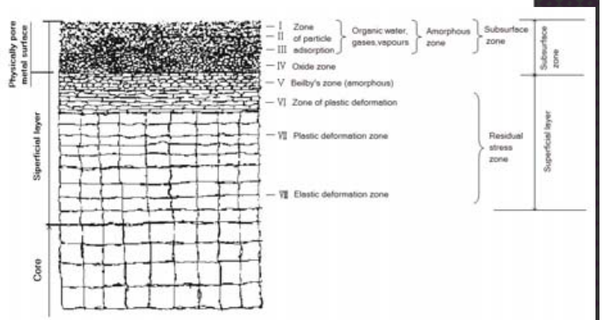
The 5-zone model



The 5-zone model

- The **subsurface** zone consists of the part of the superficial layer adhering directly to the real surface. It is built up of ions, adsorbed or chemically bonded to the core, and originating from the environment or from elements in contact with the object.
- The **directional** zone, lying under the subsurface zone, **constitutes a portion of the zone of deformation**, with a clearly defined orientation of material grains.
- The **heat affected** zone constitutes **a portion of the zone of deformation** in which significant changes took place as the result of heat processes.
- The **preferred orientation** zone **constitutes a portion of the zone of deformation with a preferred crystal or grain orientation.**
- The **zone of deformation** makes up the overwhelming majority of the superficial layer where **permanent deformation took place**, and consists of the three above described zones.

The 8-zone model



The 8-zone model

Zone I is created as the result of adsorption by the metal surface of polarized particles of organic origin (grease. lubricants, perspiration, etc.).
Zone II is created as the result of adsorption of water particles (usually from vapors).
Zone III is created as the result of adsorption of gases (nitrogen, sulfur and phosphorus vapors).
Zones I to III blend one into another and are created by the adsorption of particles of a dipole structure.

Zone IV constitutes a layer of oxides of the core metal. The thickness of this layer depends on the chemical properties of the core metal and the rate of diffusion of oxygen through the oxide layer. This zone forms a layer protecting the core from corrosion. It secures the core against further diffusion of oxygen and other aggressive substances.

The 8-zone model

Zone V is formed as the result of damage inflicted (造成)on the grains (crystallites) of the core metal by the machining tool. This introduces defects to the crystal lattice and causes the structure of that zone to be virtually amorphous, containing fragments of grains. This is Beilby layer or amorphous layer. The thickness of this layer varies from **0.1 to 1 µm**.

Zone VI comprises the zone of permanently deformed metal, characterized by its significant fibrous structure. The thickness of this zone usually does **not exceed several tenths of a millimeter**.

The 8-zone model

Zone VII comprises the zone of material which is only permanently deformed but with preferred orientation. The thickness of this zone depends on the time of deformation and does **not exceed several tenths of a millimeter** .
Zone VIII comprises the zone of elastic deformations and tensile stresses.

Residual stresses are present in zones VI to VIII. Their origin, sign and value depend on permanent deformation caused by the forces of machining, friction and temperature.
In zone VIII and partially in VII tensile stresses are formed, while compressive stresses occur in zone VI.

During service, zones I to III exert a significant influence on the friction process, and zones V to VIII - on the course of wear.

3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

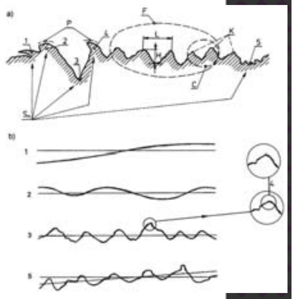
The three-dimensional structure of the surface is made up of surface **asperities(粗糙，不平)**, or **peaks** and **valleys** *which are usually traces of treatment or wear*.

These **asperities** are described by parameters of **roughness** and **waviness (波度)**, as well as **flaws(缺陷)** in the geometrical structure of the surface.

3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

a) The profile of asperities on surface of a solid: H - peak to valley height; L - peak to peak distance; F - waviness; C - roughness; P - adhesion; K - orientation of asperities; S_n-asperity flaws; *1* - flaking; *2* - folding; *3* - scratch; *4* –burr毛边; *5* - pit;
b) elements and resultant unevenness of surface: *1* - shape flaw; *2* - waviness; *3* - roughness; *4* – submicro roughness;*5* - resultant structure of real surface.



3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

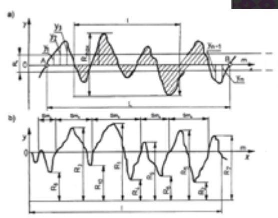
Surface roughness

– mean arithmetical deviation $\mathbf{R_a}$

$$R_a = \frac{1}{n}\sum_{i=1}^{i=n}|y_i|$$

– 10 point roughness height R_z

the mean distance of five highest peaks to five lowest valleys



3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

- **Structural flaws**
- Over 30 different types of surface flaws are distinguished

They are formed by:
– interaction with other bodies;
– stresses and flaws of the material machined or modified
– corrosion: pitting, corrosion spots;
– erosion（腐蚀，侵蚀；磨损）: pits, craters弹坑

3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

- **Structural flaws**
- **Defects** - flaws formed during the treatment operation or during service, as the result of **mechanical damage**, **chemical or erosive damage**, or **hidden material flaws**(暗伤;暗疵)revealed during machining by exposing them to the surface(材料本身具有的,由于加工而暴露出来)
- **Grooves**(凹槽) - surface damage formed by the movement of an element of the **mating surface**(配合表面) or an element of the cutting tool, forced into the material surface.
  A characteristic of the groove is the **plastic stacking**堆垛of material along its side faces (raising of sides above the surface) and ahead of the grooving tool, as well as rounding 倒角of the groove bottom.

3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

- **Structural flaws**
- **Scratches**(刮痕) - surface damage caused by the same mechanism as grooves, but without rounding of the bottom
- **Cracks** - surface flaws caused by exceeding the material's strength, as the result of a point concentration of surface stresses.
- **Pores** - surface flaws, exposed by surface treatment and constituted by empty spaces inside the material *in the form of* crevices裂缝 , canals导管, 槽or blisters泡.
  Pores formed by design (e.g., in order to enhance lubricity after filling with other material) are not considered surface flaws.

3.3 Potential properties of the superficial layer

3.3.1 Geometrical parameters :

- When selecting the right three-dimensional surface structure to meet service requirements, a general rule prevails that
  with the rise of loading level, relative movement velocity and accuracy - the allowable roughness and waviness, as well as the size and amount of surface flaws must be reduced.
- A **deviation** from the above rule occurs in the case of boundary friction conditions, where friction resistance and wear depend on roughness height.

3.3 Potential properties of the superficial layer

3.3.2 Stereometric-physico-chemical parameters

1)Emissivity - constitutes the main parameter, characterizing the quality of the superficial layer as a thermal radiator

Total emissivity ε_T describes what portion of radiant energy M is emitted by a unit surface, relative to a unit surface M_{bb} of a **hypothetical blackbody** in same temperature conditions.

Monochromatic emissivity ε_λ describes the appropriate ratios of monochromatic radiant power densities of the tested body and blackbody at the same temperature for any chosen radiation wavelength

$$\varepsilon_T = \frac{M}{M_{bb}} = \frac{\int m_\lambda d\lambda}{\int m_{\lambda bb} d\lambda} \qquad \varepsilon_{\lambda 1} = \frac{m_{\lambda 1}}{m_{\lambda 1,bb}}; \qquad \varepsilon_{\lambda 2} = \frac{m_{\lambda 2}}{m_{\lambda 2,bb}}; \qquad \varepsilon_{\lambda n} = \frac{m_{\lambda n}}{m_{\lambda n,bb}}$$

$$\varepsilon = F\{\varphi(m), f[t_o, \tau_o, t_m, \upsilon_t, \xi(u, p, h)], \psi(n)\}$$

where:
m - parameter dependent on the type of material,;
t_o- oxidation temperature,
τ_o - oxidation time,
t_m - temperature at which emissivity is measured,
υ_t - rate of temperature change,
u - environment in which the temperature corrosion process (scaling) takes place;
p - pressure of corrosive environment,
h - humidity of corrosive environment at service or ambient temperature,
n - parameter taking into account unevenness(roughness) of the radiating surface.

(t_o … h: f; u, p, h: ξ)

3.3 Potential properties of the superficial layer

From among the nine variables, the biggest effect on emissivity is exhibited by:

– **surface roughness**, to a lesser degree surface flaws and to a minute degree waviness,

– **physico-chemical condition of the emitting material** (non-oxidized material, material covered by a film of oxides or other chemical compounds)

Example:

The relation of the emissivity of the metal to the roughness

The total emissivity of the **metallic material**, working in an atmosphere composed of air, is expressed by

$\varepsilon_T = \varepsilon_{T(init)} + \Delta\varepsilon_T$

where: $\varepsilon_{T(init)}$ is the initial emissivity of the non-oxidized material, dependent only on the type of emitting material and its smoothness; $\Delta\varepsilon_T$ - is the increment of emissivity, resultant from **surface oxidation and surface unevenness**.

$\Delta\varepsilon_T = \varepsilon_{T(n)} + \varepsilon_{T(m)}$

where: $\varepsilon_{T(n)}$ is the rise in emissivity, stemming from the rise in surface unevenness, being the result of oxidation;

$\varepsilon_{T(m)}$ is the rise in emissivity stemming from the change in chemical and phase composition of the emitting material (metal - metal oxides)

- For the case where the character of the unevenness profile can be simplified to a series of wedge-shaped楔形的, V形的cavities, the **cavities** as shown on the profile plot are represented by **triangular-shaped teeth**, regardless of the direction in which the profile is measured. The value determined is the mean emissivity of the cavity material , can be expressed by the formula:

$$\varepsilon_{T(n)} = \varepsilon_{T(init)} \frac{W}{1+(W-1)\varepsilon_{T(init)}}; \qquad W = \frac{n_{w(t)}}{n_{w(init)}};$$

- where W - relative cavitivity, expressed by the formula
- where: $n_{w(t)}$ - cavitivity at temperature t; $n_{w(init)}$ - initial cavitivity
- also

$$n_w = \sqrt{1 + 4\left(\frac{R_z}{S}\right)^2}$$

- where: R_z - height of unevenness; S - surface roughness spacing.

3.3 Potential properties of the superficial layer

- Generally, the emissivity of the surperficial layer of every material increases

  with a rise of the unevenness of the surface,

  the degree of corrosiveness of the environment (e.g., a rise of its humidity)

  and the degree of corrosion (most often the degree of oxidation).

  All of these factors intensify with a rise of temperature.

- **Greatest emissivity is exhibited by surfaces which are rough, matte(不光滑的), dark, oxidized and corroded**.

3.3 Potential properties of the superficial layer

3.3.2 Stereometric-physico-chemical parameters

- **2) Reflectivity** (R) **-** depends on the same parameters as emissivity.
- Since for non-transparent bodies, $\varepsilon_T + R = 1$

- **Highest reflectivity for heat radiation is exhibited by surfaces which are smooth (polished), shiny and bright**.