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ANALYSIS OF THE COATINGS SELECTION FOR MACHINE-BUILDING PARTS

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Abstract
Set parameters of materials realised not in the entire volume, but only in the surface layer of parts are enough to provide working ability of many joints used in mechanical engineering. First of all, it relates to such important characteristics of materials as wear resistance and resistance to electrochemical corrosion and oxidation. Modifying of surface layer of machine parts with the aim of providing it with special properties not typical of materials within the volume of parts is the subject of a scientific and

technical discipline called surface engineering. It utilises a vast multiplicity of special technologies. Apart from the methods of surface thermal and chemothermal processing described above, targeted alteration of properties of surface of articles may be arrived through application of coatings on them – relatively thin layers of a material with required properties which are adhesively bound to the article surface.

Keywords: Layered coatings; diffusion coatings; metal coatings; coatings of polymers and rubber; coatings of metals and alloys; inorganic non-metal coatings; corrosion resistant coatings; electrical insulating films.

1. Introduction

It includeincludees metals and alloys, polymers, oxides, and other chemical compositions. Metal coatings applied, mostly, using the methods of chemical and electrochemical deposition play an important role in increasing of corrosion and wear resistance of metal articles. Polymer coatings which provide the optimal combination of protective action, electrical insulating, decorative, and other properties are widely spread nowadays. Coatings of oxides, nitrides, and other chemical compositions of inorganic nature are used for articles of mechanical engineering operated at high temperatures and in aggressive media.

The technology of application of composite coatings which includes such highly effective technological methods as gas flame and plasma spraying, and electrical contact bake-on etc. is being developed.

According to the mechanism of fixing of a thin modifying layer on the surface of articles, diffusion and layered coatings are distinguished. Diffusion coatings are embedded into the surface layer of an article and practically do not change its dimensions, that is formation of coatings of this type occurs according to the mechanism of coating material atom diffusion into the article surface layer. Diffusion layer depth normally does not exceed 200 μm, but sometimes is up to 2-3 mm. Layered coatings are a thin layer of a coating material which is adhesively fixed on the article surface. Thickness of layered coatings differs within a wide range: from fractions of a micrometre to tens of millimetres. Diffusion coatings are formed under a long-time contact of volatile compositions of metals and non-metals in active gas media and also of pastes, liquid melts, and solid powders with heated articles the surface layer of which absorbs substances in contact with it intensively. If such conditions fail to be realised, layered coatings are formed, and if intermediate modes occur, diffusion-layered coatings are formed.

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According to the application, corrosion, heat, wear resistant, anti-friction, and decorative coatings are most widely spread in mechanical engineering.

2. Methods

Coatings of polymers and rubber

Films are laminated polymer materials of no more than 0.25 mm thickness; flat articles of bigger thickness are classified as sheets. The lower thickness limit of films is determined by technological factors of their formation and by cohesion strength of a polymer in a plastic state.

Polymer films are considered as a distinct material type for their properties differ radically from the properties of solid film-forming polymers.

Properties of a polymer film depend to a great extent on the properties of its surface layers which have a substantial area and to a lesser extent on bulk properties of a material which makes up the base of a film. The less is thickness of film materials, the more their specific features appear.

Specific features of polymer films are determined by asymmetry of polymer molecules which form highly directed supramolecular structures possessing anisotropy of properties in the process of film formation.

Anisotropy of film polymers is different when they are formed using methods of uniaxial and biaxial drawing. Films are modified using chemical reagents which cross-link the structure of polymers or change properties of film surface layers.

The basic method of obtainment of polymer films is extrusion of thermoplastic polymers (polystyrene, polyethylene, polypropylene, chlorated polyolefins, and other polymers) and their pressing out through a flat or annular slit in a plastic state.

After that flat film workpieces are rolled and tubular ones are subject to break and drawing off using compressed air.

The second large group of film formation methods includes drying of a thin layer of polymer solutions on solid sub-layers (cellulose ethers, acetates etc.)

Polymer films are widely applied in chemical, consumer goods, and food industry and agriculture. Polymer films are used as package materials for food products, consumer goods, liquid and bulk chemical and petrochemical products, and for household purposes.

Polyethylene, polypropylene, cellulose and its ethers, polystyrene, polyamides, and vinyl-chloride polymers and copolymers etc. are used to manufacture package films.

Electrical insulating films serve to manufacture winding and equipment wires, capacitors and for slot insulation of electric machines (polystyrene, polytetrafluoroethylene, polycarbonate, polyethylene-terephthalate, polyamide, and polyolefin films).

Electret (Electret (an electric analogue of a magnet) is a dielectric which durably retains an electrostatic field in the surrounding space as a result of prior electrisation or polarisation) and piezoelectric (Piezoelectric effect is appearance of opposite electric charges on the opposite faces of some crystals (piezoelectrics) under mechanical deformation of them (compression, extension and so on)) films based on polyvinylidene fluoride, polyvinyl fluoride, and polyvinyl chloride are used in microphones, thermoelectric and electromechanical transformers.

Films are means of protection of metal parts from corrosion in mechanical engineering. The parts are packed in film covers and bags which slow down the access of atmospheric moisture and aggressive gases to the surface of protected articles. As a rule, corrosion inhibitors are placed inside the package with an article (on the article surface, in special porous bags etc.). Inclusion of a corrosion inhibitor into the composition of a polymer film during its manufacturing (inhibited polymer films) is a progressive method.

The most important requirements to polymer films for article packaging in mechanical engineering include: high failure stress and elasticity modulus; resistance to tearing, multiple bending, impact of oils and other lubricating materials, biological and other factors; elasticity; low permittivity for oxygen, water vapours, aggressive gases, and inhibitors; and resistance to ageing. Films of low-density polyethylene and polyvinyl chloride are the most widely used one-layer films. The first ones are characterised by high vapour resistance and elasticity, are easily welded, but are not enough resistant to oils and are subject to ageing under the influence of sun rays. Polyvinyl-chloride films are stronger and more resistant to oils, but are less plastic and frost resistant. Films of high-density polyethylene, polystyrene, polypropylene, polyamide, polyethylene terephthalate, and some other polymers have a limited application.

Coatings of metals and alloys

Metal coatings applied to articles of metals and to non-metals, in most cases, are characterised by high adhesion and sustain mechanical and heat shocks good. They may be applied using almost all the methods existing in technology, besides the application method determines coating effectiveness to a great extent.

Coatings of metals and alloys are widely used in mechanical engineering mostly to increase corrosion and wear resistance of metal articles. Coatings of aluminium, cadmium, nickel, tin, lead, chromium, zinc, and their alloys are most often used for this purpose. Slide and interrupting electrical contacts are covered with noble metals and their alloys to increase reliability. Types of metal coatings and methods of their application are classified in GOST 9.301-86.

Technologies of galvanic deposition, metallisation through sputtering, dipping into liquid melts, and other methods are used to apply corrosion resistant coatings. Metal corrosion resistant coatings are divided into anode and cathode ones depending on the relation of electrode potentials of metals of a coating and a sub-layer. Electrode potential of anode coatings is lower than that of a metal part which they are applied to (a sub-layer), therefore when integrity of a coating breaks down, the last one dissolves electrochemically. Such coatings include, for example, ones of zinc and cadmium on steel parts. Cathode coatings protect metal of an article only till their integrity is observed; otherwise article corrosion takes place more actively. Cathode coatings on steel articles are formed of tin and nickel, for example.

Covering of steel parts with zinc (zinc plating), nickel (nickel plating), cadmium (cadmium plating), and chromium (chromium plating) are most widespread in mechanical engineering.

Zinc coatings of 20-50 μm thickness are obtained through hot metallisation and electrolytic deposition. They are designed to protect steel and cast iron parts from corrosion mostly in atmospheric conditions. Coating application has to be the final operation of article manufacturing since a zinc coating turns into an iron-zinc alloy after thermal processing of an article at 500-550°C during 10-20 min and further diffusion annealing. Tubes protected with such coatings are used during compressor extraction of petroleum.

The closest zinc analogue – cadmium – forms coatings resistant to sea water and alkali solutions. Thickness of cadmium coatings makes up 3-15 μm.

The practical importance of nickel corrosion resistant coatings which increase chemical resistance of steel parts and provide them with decorative appearance is universally known. Nickel plating is carried out using various methods: galvanic, chemical, and diffusion ones etc. Thickness of a nickel coating normally makes up 10-15 μm; it is applied to a copper sub-layer during processing of steel parts to prevent from formation of a porous layer.

Chromium plating of steel parts is carried out to protect them from corrosion in a gas atmosphere, a humid medium, alkali, and nitric and organic acids. Thickness of a chromium coating is less than that of a nickel one and makes up 0.5-10 μm. Thicker coatings (5-100 μm) are used to provide parts operated in corrosion media with wear resistance. Chromium plating is normally carried out on a copper or nickel sub-layer. Chromium diffusion coatings, which are solid solutions in iron, possess significant heat resistance in an oxidation atmosphere, wear resistance, and resistance in many liquid aggressive media. Such coatings are operable in combustion products of natural gas and mazut up to temperatures about 800°C.

Tin, lead, titanium, and zirconium coatings are widely used for corrosion protection. Copper coatings are used mostly as a sub-layer before galvanic plating of nickel, chromium, silver, and platinum.

Temperature resistant metal coatings make up a distinct and very important class. Application of aluminium is one of the most effective ways to protect metals from oxidation in gas media at high temperatures. An aluminium diffusion coating protects steel from oxidation in the air up to 1000°C. A pure aluminium coating on sheet steel obtained through hot dipping is stable up to 700°C. Aluminium coatings have proven to be an excellent high temperature protection medium for alloyed steels, alloys based on nickel, titanium, and refractory metals.

Beryllides (for example, $MaBe_2$, Wbe_2, $CrBe_2$, and $TaBe_2$ etc.) possess high heat-resistance among materials for intermetallic compositions. Beryllium is a perspective component of coatings designed to protect the four refractory metals (Mo, W, Nb, Ta). In its turn, coatings of refractory metals are effective in cases when working surfaces of parts have to be provided with erosion resistance during operation in high temperature gas oxygen-free media.

The same metals are resistant to concentrated sulphuric and hydrochloric acid.

Great attention has been paid to combined heat resistant coatings recently. Among double metal systems which are the basis for them Al–Ni, Al–Co, Al–Cr, Cr–Ni, Cr–Ti, and Cr–Pd etc. are of biggest interest. Thus, diffusion vacuum metallisation with aluminium and chromium has proven to be an effective means to increase reliability and long life of turbine blades operated at temperatures up to 750°C [1].

Wear resistant metal coatings operable both at normal and relatively high temperatures make up a vast class. They consist of carbon alloys of iron, nickel, or cobalt with metals (W, Cr, Mo, Ti, and Mn) which, forming carbides, provide coatings with high hardness and resistance to abrasion wear.

Wear resistant metal coatings are applied to articles through surfacing, thermal diffusion, and electrical contact bake-on.

Inorganic non-metal coatings

Inorganic coatings are formed, as a rule, on the surface of metal articles to protect them from corrosion, to decrease a friction coefficient, to increase heat and wear resistance. Oxides, carbides, nitrides, and phosphates of metals, enamels and solid lubricants are the primary materials for such coatings. Thickness of an applied layer

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varies depending on the coating purpose. The thinnest ones (2-3 μm) are used to protect from atmospheric corrosion, relatively thick ones (up to 2 mm) – to increase resistance to wear or to acids and alkali. Inorganic coatings on steel articles are formed through thermal and chemical article processing, surfacing out of powders, chemical deposition out of a gas phase, and cathode sputtering in vacuum etc.

Protective oxide coatings are formed as a result of oxidation of an article surface layer. They may be considered coatings by convention as practically they result from modifying of a part surface layer using chemical and thermal methods. Thermal oxidation (bluing), chemical oxidation in boiling sodium hydroxide, and phosphatising (formation of a phosphate film) are widespread methods of steel article protection. A protective oxide film on aluminium article surface is formed using chemical and electrochemical (anodising) methods.

High-strength and wear resistant coatings based on aluminium oxide are applied to articles of metals, hard alloys, and ceramics using plasma spraying methods. Zirconium and hafnium oxides are used to obtain heat resistant coatings on special steels used in rocket engineering.

Carbide, nitride, and carbonitride coatings are applied to articles of steel and hard alloys to increase their wear and corrosion resistance basically using ion-plasma methods and chemical deposition out of a gas phase (gas-phase deposition). Multi-layer and composite coatings of this type are often used. Titanium carbide, nitride, and carbonitride and chromium and molybdenum carbides are often used as materials for coatings. The principal difference in technology of application of the named coatings using ion-plasma and gas-phase methods lies in that, the first be the case, article heating to high temperatures is not required, and the second be the case, heating temperature reaches 900-1100°C, which limits the application of the method. Thickness of coatings of nitrides and carbides normally makes up 4-8 μm. Wear resistance of steels to which a coating, for example, of titanium nitride is applied is several times as high as the one of high-strength alloyed steels and even of steel articles surfaced with hard alloys.

Silicate coatings (enamels) combine strength properties of metals with corrosion, thermal, and abrasion resistance of silicates. Therefore these coatings are widely used in mechanical engineering. Powders and enamels are applied to articles of steels and cast irons and are further subject to burning at the temperature of 1000°C. Coatings of low-temperature enamels with high lead content and melting temperature about 500°C are used for articles of aluminium.

Extra possibilities in the area of enamelling appeared in connection with designing of new glass crystalline silicate materials – glass ceramics. Glass-ceramic coatings are silicate enamels crystallised in a special way which contain a significant amount (30% and more) of a uniformly spread finely dispersed crystal phase. Basic compositions of glass-ceramic surfacing enamels typically include a significant amount of an oxidant Li_2O (3-12%) which initiates finely dispersed and bulk crystallisation of glass ceramics. Glass-ceramic coatings, unlike conventional vitreous enamels, possess significantly higher impact strength, increased microhardness and abrasion resistance, and higher resistance to rapid temperature changes.

Inorganic solid lubricating coatings are used to decrease a friction coefficient in friction joints of machines where it is impossible to use liquid and plastic lubricants (for example in vacuum, at elevated temperatures and ultra-high operating rates etc.). Graphite, molybdenum disulphite, tungsten disulphite, other dichalcogenides of transitive metals, and also halogen compositions of metals, both pure and in the form of compositions with polymer, metal, and silicate binders, serve as materials for such coatings. Operating temperatures of solid lubricating coatings are 400-500°C in the air, up to 1320°C in vacuum (pure molybdenum and tungsten disulphides). Unlike graphite-based coatings which provide a low and stable friction coefficient (about 0.1) in a normal atmosphere, molybdenum disulphide and other dichalcogenides are characterised by low friction coefficients (0.05) in vacuum. Methods if application of inorganic solids lubricating coatings are selected depending on composition, shape, and dimensions of a sub-layer.

3. Results and Discussion

The application of composite film materials becomes more and more wide: reinforced films (for example, with meshes of polyamide and glass fibres), multi-layer ones (polyamide-polyethylene, polyethylene terephthalate-polyethylene), and also combined multi-layer ones such as film-paper, film-cardboard, and film-foil.

The technological process of packaging of articles of mechanical engineering normally includes preparation of the last ones, cutting and manufacturing of cover bags of polymer films, laying of auxiliary materials (desiccants, corrosion inhibitors etc.), and hermetic sealing of an article in the cover through welding or gluing. Packaging of metal articles is carried out using other methods: thermal vacuum moulding, in the process of tubular film extrusion, and through film heat shrinkage.

A large group of metal alloys is used to obtain anti-friction coatings. Alloys based on tin and lead, ones containing antimony, copper, cadmium, and other metals (tin and lead babbit metals) are most widely known. Coatings of alloys based on copper (bronze), aluminium, magnesium, zinc, and forgeable anti-friction cast irons with graphite inclusions are also used. Anti-friction coatings of the named alloys are applied using wire electric metallisation equipment and through plasma technology methods.

Electric vacuum and radio-electronic industry utilises metal connection coatings to metallise non-metals and weld ceramics. Magnetic alloys based on Fe, Co, and Ni are used to obtain magnetic films on parts of data storage media. Magnetic coatings of about 100 μm thickness are used as magnetic shields.

One-component solid lubricants are often applied to the surface of parts through brushing or touching with cloth. When a silicate binder (liquid glass) is used, the composition layer applied to the article surface is heated to remove water and for solidification. If a binder consists of thermoset organic or silicon polymers, a powder mixture of a solid lubricant and a binder is sprayed on the article surface and then heated. Application of such solid lubricants as molybdenum disulphide is carried out through plasma spraying. The thickness of lubricating layers sprayed in plasma is much less (about 0.2 μm) than that when powder suspensions are applied in a binder (up to 15 μm) and operating life of thin coatings is much longer.

Great attention has been paid to coating reinforcement in recent years. Reinforcement is one of the most effective ways to increase operating life of brittle coatings, first of all, based on ceramic and binding materials. Welding of a metal mesh which a coating material is rubbed into or sprayed on to the part surface is the most effective reinforcement method. Thus, for example, resistance of Al_2O_3 coatings on steel to multiple rapid changes of temperature from room one to 1000°C is able to be increased by several times.

4. Conclusion

Inhibited polymer films (one-layer and multi-layer ones) are perspective for long-term protection of articles of mechanical engineering. Such films allow to combine conservation and barrier packaging in one process cycle and may be used both for interoperation protection and for long-term storage of articles (from 3 to 7 years).

Further progress in the area of corrosion protection of metal articles, devices, and equipment is connected with development of new polymer films, of high-performance packaging equipment and with improvement of conservation-packaging processes for articles of mechanical engineering.

Apart from the considered coatings which are mostly used in general mechanical engineering, a number of special purpose coatings widely used in electronic and radio engineering exist. Thin film metal coatings on dielectrics (resistive and conductive films in microelectronics), thin films of metals with low work function (coatings of Cs and Ba on tungsten cathodes, which increase electron emission by millions of times), ultra-thin (0.05 μm) metal films (Al, Ag, and Au etc.) on glass, mica, and glass ceramics which are characterised by high transparency or reflective power take up a special place among them.

Another reinforcement principle lies in impregnation of a porous coating base, first of all, metal one, with suspensions containing an anti-friction coating component. For example, a plasma porous coating of refractory steel is impregnated with a suspension based on an enamel or other oxides. After burning of a suspension layer a coating which consists of a metal carcass filled with an enamel and oxides is obtained on an article [1].

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