Crossref
**DOI**: 10.31643/2024/6445.03
Engineering and Technology



# An Overview of Epoxy Resins as coating to protect metals from corrosion

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Received: *February 21, 2023*
Peer-reviewed: *March 24, 2023*
Accepted: *April 4, 2023*

**ABSTRACT**
Any structures of metal, which are used in construction work, must be qualitatively protected from the external environment, more precisely, from the development of corrosion. Under the influence of the environment as a result of corrosive processes, the metal loses its properties. The presence of corrosion reduces the service life of any equipment in production, it worsens the quality of products. To solve the problems of increasing service life and providing chemical protection of metal, which is made of equipment, constructions, and structures, use highly effective anti-corrosion coatings based on epoxy resins. These materials are chemically resistant and provide a barrier that limits the access of corrosive media to the coated surface. Epoxy resins are stable to the action of halogens, acids, and alkalis, and have high adhesion to metals. However, having a complex of positive properties, epoxy resins have significant disadvantages - high combustibility, stiffness, and relatively low physical and mechanical properties, including resistance to impact, due to the limited mobility of inter-nodal sites of the spatial network of polymer macromolecules. Therefore, epoxy is cured with various hardeners and mixed with a variety of fillers (metallic, mineral, and organic), and many other components to reduce the cost of materials and to allow the properties of the resins themselves to be improved in the desired direction. This overview article discusses the basic properties of epoxy resins and the effects of various hardeners, and modifiers on the anti-corrosive properties of epoxy coatings, as well as general applications of epoxy resins and the health risks of their use.

***Keywords:*** anticorrosive coating; epoxy resin; hardeners; modification; composite materials; applications.

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## Introduction

Ensuring reliable protection of metal products against corrosion remains one of the most important tasks in the metalworking industry. Rust is considered one of the main problems of all metal structures. Its ruthless action reduces the performance characteristics of metal products, spoils the appearance, and reduces the service life by several times. The most common way to protect construction is to apply coatings on the surface of the metal, preventing its destruction under the influence of various corrosive environmental factors. The protective coatings that modern technology has at its disposal are very diverse both in their properties and in the way they are obtained. The use of protective, protective-decorative, and special coatings can solve many problems [1]. By choosing the coating material, conditions of their application, and combining metallic and non-metallic coatings, it is possible to give the surface of products a different color and texture, the necessary physical, mechanical, and chemical properties: increased hardness and wear resistance, corrosion resistance, high reflectivity, improved anti-friction properties, surface electrical conductivity, etc.

However, the optimal choice of coatings or methods of finishing is not possible without a comprehensive consideration of their properties and the peculiarities of obtaining [[2], [3]].

Nowadays, epoxy resins are widely and effectively used as a protective coating in the construction industry. Epoxy resins are a versatile class of resins that are used to produce composite materials and structures, as well as for casting, sealing, protection and bonding of various materials, and can also act as fire and corrosion-resistant coatings. Epoxy resins are widely used in industry and households because they have an excellent combination of various characteristics [4]:

– excellent resistance to many chemicals;
– moisture resistance;
– very high bonding strength;
– excellent heat resistance;
– ease of use;
– low shrinkage

The use of epoxy resins in various branches of technology as adhesives, fire- and corrosion-resistant coatings, compounds, and binders in the production of composite materials predetermines the search for new modifying additives to provide epoxy composites with reduced flammability and high deformation and strength properties that meet the requirements of most industries. Reducing the flammability, heat resistance, and combustibility of polymers, high corrosion properties, and the creation of fire-safe materials for various types of building structures, metal structures is an urgent problem that requires urgent solutions [[4], [5]].

The purpose of this review article is to determine the level of physical-mechanical and barrier properties of epoxy coatings cured with different hardeners and to select the most suitable combination of resin and hardener to create on its basis a highly effective anti-corrosion barrier-type material.

**Epoxy resin: its structure, properties, and types**

Epoxy resins are oligomers that contain epoxy groups and can form cross-linked polymers under the action of hardeners (polyamines, etc.).

Epoxy resins are produced in both liquid and solid states. They are thermoplastic, but under the influence of various hardeners, they turn into non-melting polymers. The use of various additives (hardeners, fillers, plasticizers, thinners, curing gas pedals) makes it possible to obtain materials with a wide variety of properties based on epoxy resins. Epoxy resins are resistant to halogens, acids, and alkalis and are characterized by high mechanical strength, water resistance, high electrical strength, and good adhesion to polar compounds, metals, porcelain, mica, etc. A significant advantage of epoxy resins is their low shrinkage during the solid-state transition [[6], [7]].

The main characteristic feature of epoxy resins is their ability, under certain conditions, to transform into polymers of a mesh structure, which makes such resins suitable for the manufacture of various plastic materials (compounds, adhesives, enamels, binders for laminated plastics, sealants, etc.). The mentioned polymer meshes are formed either because of chemical reactions of epoxy groups of resin with a polyfunctional substance or due to the polymerization of epoxy groups under the influence of catalytically active compounds. In such cases, polyfunctional substances are called hardeners (or crosslinking agents), and catalytically active substances are called catalysts of curing (or catalytically active hardeners).

The following types of epoxy resins are the most used and, as a consequence, the most important:

– epoxy resins based on bisphenol A;
– epoxy resins based on other di- and polyphenols;
– amino-epoxy resins;
– cycloaliphatic epoxy resins;
– aliphatic epoxy resins and monoglycid compounds;
– oligo urethane epoxides;
– halogen-containing epoxy resins [[7], [8]].

**Effect of hardeners on the anti-corrosion properties of epoxy coatings**

At present application of insulating coatings based on polymeric materials is a widespread method of surface protection of various products and structures from the effects of various environments, as well as to increase their operational life during repair and restoration work. Among polymers, epoxy resins are widely used. The use of epoxy resins as the main components of the coatings under consideration is explained by a complex of physical and mechanical characteristics, including high adhesion to most known materials, low shrinkage deformation, and the ability to cure in a wide temperature range [7]. Epoxide groups have a high chemical activity, which makes it possible to use a wide range of organic and inorganic compounds as hardeners of epoxy resins. The hardeners of epoxy resins, as a rule, are their co-monomers that allow actively influence both the processing of epoxy compositions and the properties of the resulting polymers. Increasing industrial requirements for the quality of epoxy materials, and their performance under conditions of elevated temperatures, adverse climatic effects, strong vibrations and other adverse effects require the development and industrial development of a wide range of hardeners [9].

The nature of the curing process of epoxy composites depends on several factors: reactivity, quantitative ratio, the thermal conductivity of the components to be mixed, initial temperature, etc. [[10], [11]].

Epoxy oligomers can be cured with almost any carboxylic compound, acid or Lewis's base.

**Table 1** - Types of epoxy hardeners and their descriptions

| Hardener types | General Description |
|---|---|
| 1. Amine hardeners | The group of amine hardeners includes aliphatic, alicyclic, aryl aliphatic, aromatic, hetero-chain (dicyandiamide), and heterocyclic di- and polyamines as well as their modifications.<br>The subgroup of aliphatic polyamines includes hardeners that cure epoxy oligomers at room temperature or under moderate heat. The most characteristic representatives of this subgroup are the condensation products of ammonia with dichloroethane, ethylene polyamines DETA (diethylenetriamine), TETA (triethylenetetramine), and the total technical product - (polyethylene polyamine), GMDA (hexamethylenediamine), DPTA (dipropylenetriamine), etc.<br>Such compounds are very uncomfortable to handle, have a bad odor, significant vapor elasticity, and are volatile and quite toxic [[14], [15]]. |
| 2. di- and polycarboxylic acid anhydrides | Anhydride hardeners are used in the construction of electrical insulating materials as well as products with increased heat resistance. This group of hardeners includes a very wide range of anhydrides of di- and polycarboxylic acids of the aliphatic, aromatic and hydroaromatic series as well as polyanhydrides of linear aliphatic dicarboxylic acids, ester acids and other similar compounds. Adducts of maleic anhydride with various dienes (tetrahydro phthalic and endic anhydrides), products of their hydrogenation (hexahydro phthalic anhydride) and catalytic isomerization are widely used [16].<br>The curing ability of anhydride hardeners provides a variety of polymer materials with good thermal stability and high dielectric properties.<br>Triazintetracarboxylic acids and 2, 4-di (alkylenoxy-6-aminoalkylene) - sim-triazines can be effective hardeners of epoxy resins. They have found applications in heat-resistant adhesives for metals. |
| 3. oligomeric hardeners with phenolic hydroxyls, carbonyl, isocyanate, amino groups, etc. | Polyfunctional oligomers (phenol-, aminophenol-, amino aldehyde condensates, oligo ethers, oligoimides) belong to oligomeric hardeners. They are used to create materials with a specific combination of properties, such as high chemical resistance and thermal stability, the ability to maintain long-term technological properties at room temperature, to harden quickly when heated, etc.<br>Oligomers obtained by the reaction of unsaturated nitriles with olefins with subsequent hydrogenation of the reaction products are used as hardeners of epoxy resins used to make materials with reduced ability to sorb water [17].<br>The water absorption of epoxy polymers produced using such hardeners is 30% lower than that of triethylenetetramine curing.<br>It is also proposed to use diaminomaleonitrile and its derivatives as a hardener.<br>Moist, high coke number epoxy polymers are obtained by using imidamine hardeners which are synthesized by the reaction of diamines with tetracarboxylic acids dianhydrides. This produces epoxy polymers with a softening point above 300°C. Many publications are devoted to the curing of epoxy oligomers by isocyanates and their derivatives. Polyetherurea, reaction products of urea with polyalkylene polyamine, and imidazole adducts with isocyanates are patented as hardeners. At the same time compositions providing high protective properties and dielectric properties are obtained. Such systems are used for enameling wires, as protective coatings, in the manufacture of printing plates, as anti-corrosive coatings for ship protection, etc [18]. |
| 4. catalysts and curing gas pedals for epoxy oligomers | Catalytic hardeners such as boron trifluoride complexes with amines are the most common. A characteristic feature of these hardeners is the high curing rate of epoxy resins. Depending on the activity of the curing agent and the temperature, complete curing can be achieved within a few seconds to 2-3 hours [7]. |

However, only a small fraction of potential hardeners is suitable for industrial use. These practically useful hardeners can be roughly divided into four types:

− amine hardeners;

− anhydrides of di- and polycarboxylic acids;

− oligomeric hardeners with phenolic hydroxyls, carboxyl, isocyanate, amino groups, etc.

− catalysts and curing gas pedals for epoxy oligomers [[12], [13]].

Each type of hardener has a characteristic eventual topology that determines the structure of the corresponding epoxy polymers Table 1.

The most important property of the assortment of hardeners is that it allows regulating within a wide range of the curing conditions and properties of polymer materials, and provides rational use of epoxy oligomers, as well as the implementation of technical services during their processing.

**Epoxy based composites**

One of the ways to increase the durability of buildings and constructions is the use of polymeric composite materials (PCM) in their construction, the scope of their application in construction is steadily expanding. In connection with the appearance of new chemically resistant materials, it is offered to use them for protection against harmful natural and technogenic influences.

Epoxy resins are widely used as binders in PC due to their high physical and mechanical characteristics. Epoxy resins are among the best types of binders for a large number of fiber composites, which can be explained by the following reasons [[10], [19]]:

– good adhesion to a large number of fillers, reinforcing components, and substrates;

– variety of available epoxy resins and curing agents, allowing to obtain after-curing materials with a wide combination of properties, satisfying various technology requirements;

– absence of water release or any volatile substances during chemical and small shrinkage phenomena during curing;

– chemical resistance and good electrical insulating properties [20].

Polymeric composite materials based on epoxy resins have several valuable properties: high dielectric properties, increased mechanical strength, water resistance, low shrinkage during cross-linking, and good adhesion to metals, porcelain, and glass. It allows using of them as binders in the production of polymer composites, varnishes, glues, and impregnating and pouring compounds [21].

To impart valuable technical properties to epoxy oligomers, they create a cross-linked structure, i.e., they are cured. The introduction of special hardeners ensures that under certain conditions transverse chemical bonds are formed. As a result of curing, epoxy resins are easily converted into a thermosetting state.

Choosing the type of hardener, it is possible to change the physical-mechanical and chemical properties of the resulting composites in a wide range - from rubber-like too rigid, high-strength and high-modulus composites that retain their strength indicators under prolonged exposure to temperatures up to 200°C and higher. But it is worth noting that the properties of epoxy composites are largely influenced not only by the type but also by the amount of hardener injected. The amount of hardener is adjusted depending on the epoxy number of the resin (epoxy group content), taking into account the correction factor. The value of the factor in turn depends on the number of active hydrogen atoms in the hardener which react with the epoxy group. Also, the nature of the hardener determines the density of the spatial mesh in epoxy compositions, which in turn significantly affects the value of internal stresses [22].

To improve the properties of composites (complex damping and deformation strength properties, increase of heat resistance, chemical, and atmospheric stability, adhesion, manufacturability, etc.) polymers are subjected to modification [23].

**Modification of epoxy resins to improve mechanical and physical properties**

Obtaining epoxy polymer composites for construction purposes with predetermined properties is usually associated with the application of physical and chemical methods of modification: the introduction of solid insoluble fillers and aggregates, surfactants, inert plasticizers, and diluents. The choice of this or that modifier or their combination makes it necessary to carry out a complex of experimental studies to determine and regulate the properties of a developed material and optimize its structure. To improve the technological, physical-mechanical, operational, and other properties of epoxy oligomers their modification is made. The modification consists of the purposeful change of the polymer's structure at different levels and related properties. There are 3 methods of modification: physical modification, chemical modification, and physical-chemical modification [24].

Physical modification is achieved by adding substances to the resin that do not enter into chemical bonding with the binder. For example, the introduction of fillers (silica sand, marshalite, asbestos) increases the hardness, heat resistance, and thermal conductivity of the composition, reduces shrinkage during curing, and thermal expansion coefficient, as well as reduces the cost of the composition.

Chemical modification is carried out by adding thinners and solvents of epoxy compositions (these include unsaturated monomer compounds such as styrene, liquid polyester acrylate TGM-3, and aliphatic epoxy resins DEG-1, MEG-1, which are self-polymerizing substances and, polymerizing under the same conditions, come into interaction with the main composition, forming a solid solution of one polymer in another). The presence of such "active diluents" makes it possible to obtain low-viscosity flowing compositions [[25], [26]].

Physical and chemical modification. Various plasticizers and modifiers (dibutyl phthalate, Thiokol, polyesters) are used. They increase the elasticity, impact strength, and frost resistance of epoxy compositions, but reduce viscosity, heat resistance, adhesion properties, moisture resistance, and electrical insulation properties [24].

The properties of epoxy resins depend on the ratio of the quantities of the reacting ingredients. Depending on the length of the molecule formed, epoxy resins can be either viscous liquids or brittle solids.

Epoxy resin compositions containing hardeners, plasticizers, solvents and other components have sufficient fluidity to fill molds, strips, gaps, gaps, pores and capillaries. Resins can be mixed with a variety of fillers (metal, mineral and organic), as well as many other components, which reduces the cost of materials and makes it possible to improve the properties of the resins themselves in the desired direction. Compositions based on epoxy resins have high adhesion to a variety of materials, have a high chemical and thermal resistance, do not cause corrosion of materials in contact with them, and are very good dielectrics [27].

Table 2 lists some of the most common Epoxy resin components and their main functions.

**Table 2 -** Components of Epoxy resin and their main functions

| Modified components | Basic functions |
|---|---|
| 1. Interaction of epoxy resins with various hardeners | The ideal diluent for viscous epoxy resin is the hardener. Initially, epoxy resin is in a semi-liquid state. But when compounds with a mobile hydrogen atom are added, they can harden to form a three-dimensional network of chemical non-melting and insoluble products. Thus, it is not the epoxy resin themselves that are thermosetting, but their mixtures with hardeners and catalysts. The high chemical activity of epoxy groups allows using a lot of classes of organic and inorganic compounds as hardeners. Diamines (hexamethylenediamine, meta phenylenediamine, polyethylene polyamine), carboxylic acids or their anhydrides (maleic, phthalic) are used as hardeners for epoxy resin.<br>Epoxy resin mixed with hardeners form thermosetting compositions with a number of useful and valuable properties: high strength; high adhesion ability with different types of surfaces (ceramics, metal, glass, concrete, wood); high resistance to external mechanical and chemical influences; during curing they do not emit volatile products and have low shrinkage (2-2.5%); high moisture and water resistance; high dielectric properties (has low thermal conductivity); environmental friendliness (after complete curing the material is non-toxic) [[13], [15]]. |

**Continuation of table - 2**

| | |
|---|---|
| 2. Plasticizers and modifiers | Plasticizers modify the system viscosity, flexibility, and mobility of molecular structures. Many plasticizers can increase the impact toughness of the polymer without loss of strength and modulus of elasticity, and can also improve fire, light and heat resistance. Among plasticizers of interest are tricresyl phosphate (TCP) and oleic acid (OA) due to their compatibility with ER.<br>1. Tricresyl phosphate is an ester of tricresol or dicresol orthophosphoric acid. TCP is readily soluble in fats, oils and many organic solvents; it is insoluble in water.<br>2. Oleic acid is a monounsaturated fatty acid with only one unsaturated bond in its molecule; it belongs to the group of Omega-9 unsaturated fatty acids. OA is soluble in organic solvents and insoluble in water. OA is common as unsaturated fatty acids and is found in vegetable and animal fats. OA are used as components of detergents, varnishes, olives, emulsifiers and plasticizers. Plasticizers also include dibutyl phthalate, thiokol, and polyesters, which increase elasticity and impact strength, reduce viscosity, improve frost resistance of epoxy compositions, but at the same time reduce heat resistance, adhesion properties, moisture resistance, and most importantly, dielectric properties [[27], [28]].<br>ER is modified by introducing various chemical compounds (thermoplastics, plasticizers). We can distinguish three main groups of modifications: chemical, chemical-physical and physical, which, in turn, are divided into - chemical: changing the chemical composition of the resin, adjusting the type of hardener and adding reactive additives; - chemical-physical: alloying, adding surfactants, combining with inert plasticizers and diluents soluble in the resin, modifying solid insoluble large additives (mineral or organic); - physical: ultrasound pretreatment of resin, vibration, high-frequency currents, treatment during curing. For the plasticizer to be effective, it must be thoroughly mixed and incorporated into the polymer matrix. This is usually accomplished by heating and mixing until either the polymer dissolves into the plasticizer or the plasticizer dissolves into the polymer [29].<br>Epoxy derivatives of 2-hydroxybenzoic acid, 3-diethylamino-2-hydroxypropyl ether of 2-hydroxybenzoic acid, 3-diethylamino-2-hydroxypropyl ether of 2-chlorobenzoic acid and 3-diethylamino-2-hydroxypropyl ether of 2-methoxybenzoic acid are used as modifying additives for ED-20. The introduction of these modifiers into epoxy composites significantly increases the physical-mechanical and thermal characteristics of the epoxy compound to unmodified ER. The obtained epoxydian compositions can be used as coatings. |
| 3. Fillers | Fillers are various solid particles (inorganic, organic) that can be irregular, pointed, fibrous or lamellar in shape and are used in fairly large quantities in plastics. Fillers include quartz sand, marshalite, and asbestos [30]. They increase the hardness and heat resistance of the composition, reduce shrinkage during curing, increase thermal conductivity, reduce the thermal expansion coefficient, as well as reduce the cost of the composition [31].<br>In [31] the effect of fillers on the resistance to aggressive environments, such as sulfuric acid (30%, d = 1.84 g/cm3) was noted. The tested ER (binder + kaolin) and (binder + lignin) retain their protective properties unchanged for 100-120 days. At the same time on unfilled samples, signs of the destruction of coatings are noted already after 60-65 days of tests. The results of the studies show that the filler gives a good effect.<br>In this case, there is a stabilizing effect of fillers due to their compositions, since they include metal oxides, which are resistant to the action of mineral acids, and the Nelson effect is realized - the path of the passage of an aggressive liquid deep into the matrix is increased. It was found that if the concentration of the filler in the polymer system exceeds some critical value, the permeability increases sharply, and liquid transfer occurs [32]. |
| 4. Diluents and solvents | Unsaturated monomer compounds (styrene, liquid polyester acrylate TGM-3 and aliphatic epoxy resins DEG-1, MEG-1) can be referred to as thinners and solvents. They are polymerizing substances themselves and, polymerizing under the same conditions, come into interaction with the main composition, forming a solid solution of one polymer in another. In most cases, the presence of such diluents ("active diluents") in the composition of ER is caused by a certain need. For example, without them, it is impossible to obtain low viscous flowing compositions with the necessary technological properties [33]. In some cases, when making electric insulating varnishes from ER, conventional solvents (toluene, xylene, and acetone) are introduced into ER. |

**Modification of epoxy resins by nanoparticles**

Today, a promising application of nanoparticles is the modification of polymers to improve their characteristics. Thus, a new class of materials appears - polymer nanocomposites (PNC). The simplest and most economical way to produce such materials is to mix a polymer in a liquid state with a nanoscale phase and then polymerize the resulting composite [34].

An important parameter of nanoparticles is their specific surface area, through which particles interact with the functional groups of polymers. In this case, the molecules of the polymer matrix are adsorbed onto the particles, and the adhesion forces provide a strong bond. The factors determining the efficiency of modification of polymeric materials by nanoparticles are being actively studied all over the world. Such factors as the size, shape and number of particles, their distribution in the matrix material, the surface area of "polymer-particle" interaction, as well as the improvement of system interaction through the use of surface-active agents have the greatest influence [35]. A large number of studies show that the modification of epoxy compositions with nanoparticles affects their mechanical properties. Epoxy coatings containing nanoparticles have significant barrier properties for corrosion protection and reduce the tendency for bubble formation or delamination of the coating.

In the work [36] the authors showed the influence of nanoparticles on the anticorrosive and mechanical properties of epoxy coating. In this work, the influence of nanoparticles such as $SiO_2$, Zn, $Fe_2O_3$ and halloysite clay on the surface morphology, anticorrosion behavior and Young's modulus of epoxy coatings was investigated. After analyzing the experimental data, the authors reported that the nanoparticles improved the quality of the cured epoxy coating, reduced the porosity of the coating matrix, and zigzagged the diffusion path available to harmful species, resulting in improved barrier characteristics of the epoxy coating. And the nanoparticles also improved the adhesion of the cured epoxy coating to the substrate and changed the physicochemical properties of the coating-steel interface, the specific path of which depends on the type of nanoparticles.

It was found that dispersion of Zn, $SiO_2$, $Fe_2O_3$ and halloysite clay nanoparticles in the epoxy resin matrix with a concentration of 1% of the total weight of the epoxy resin and its hardener provides a positive role of nanoparticles on the high corrosion resistance of coated steel, which was immersed in NaCl solutions with a concentration of 0.3 wt. % and 3 wt. % for 28 days.

In the work [36] the authors studied the modification of epoxy binders with silica nanoparticles and the technology of obtaining composite materials based on them with improved performance characteristics. Based on the results of the study, the authors found that it is most advantageous to introduce nanoparticles in the least viscous medium (hardener) because in such a medium the obstacles to the breakdown of agglomerates and uniform distribution of particles should be minimal. The authors of work [36] determined the optimal degrees of epoxy matrix filling with nanoparticles: from 0.20 to 0.30 wt. %. The introduction of nanoparticles in optimal proportions increases the following characteristics of the epoxy binder: tensile strength increases by 32%.

**Modification of epoxy resins with sic**

To impart the required properties to epoxy composites, abrasive fillers are introduced into their composition. Filling is the most widely used and highly effective way of directional regulation of the properties of epoxy polymers to improve mechanical strength and stiffness, chemical resistance and heat resistance [30].

Epoxy polymers have such a complex of properties (adhesion, mechanical, electrical, etc.) that in many cases make them indispensable as a base for adhesives, paints, compounds and reinforced plastics. But these polymers also have a number of drawbacks. One of them is increased flammability. Epoxy resin materials ignite and burn when ignited. The main volatile combustion products are $CO_2$ and CO, and formic acid and other substances are also found in the combustion products [11].

One of the promising directions for solving the problem of increasing the fire resistance of epoxy compositions is the use of highly dispersed silicon carbide in their composition. Silicon carbide is used in many industries due to its structure, high hardness, and inertness in many aggressive environments. It is also used as an additive that increases the fire resistance of rubbers.

Silicon carbide has increased hardness and strength at high temperatures, as well as wear resistance, chemical resistance, fire resistance and thermal shock resistance. This provides great interest in its use in many industries [37].

In the work [38] the authors studied the possibility of using highly dispersed silicon carbide in epoxy compositions to improve fire resistance. The results of the study showed that the introduction of silicon carbide in the epoxy composition allows holding the temperature of the unheated surface of the sample up to 240°C much longer. The introduction of silicon carbide in the epoxy increases the fire-retardant properties of the coatings.

Currently, to increase the activity of silicon carbide surface it is modified: by oxidation - thermal or chemical, grafting monomers, oligomers and polymers.

**Application of er-based materials**

Due to its properties epoxy resin has found wide application in many areas of human activity: environmental design, construction, electrical engineering, mechanical engineering, aircraft construction, and rocket and shipbuilding. In construction, ER is used for marking strips on tracks.

Resin is used to glue bridge structures, and in shipbuilding, ER is used to make ship propellers and compressor blades. Resin is the basic material to produce gas and liquid vessels. In mechanical engineering, resin corrects casting defects and is used for dies and molds. Even some tools, such as springs and springs, are made from resin. Resin-based fiberglass plastic is used to make antifriction pads. In aircraft construction, ER is used for wing cladding, fuselage, nozzle cone, and jet engine parts. It is also used to make helicopter blades, rocket engine casings, and fuel tanks [39].

**Table 3 -** Main applications of epoxy materials

| Epoxy materials | Description |
|---|---|
| Epoxy varnishes and enamels | Epoxy varnishes and enamels have high protective properties, so they are widely used for corrosion protection of metal products and structures, concrete, and wood products, operated in different atmospheric conditions, fresh and seawater, soil, etc. The coatings are characterized by high chemical resistance, hardness, and mechanical and adhesive strength, due to which a long-term protective effect is provided. The greatest use in the production of epoxy varnishes and enamels is found in diane epoxy resins.<br>Varnishes and enamels are produced by dissolving the film-forming agent (epoxy resin) in organic solvents (glycol ethers, aromatic hydrocarbons, ketones, alcohols). Varnishes include additives that improve pouring (urea-formaldehyde resins, silicone-organic liquids), hardeners, and hardening gas pedals (phenols, phosphoric acid). Enamels may also contain fillers, pigments, plasticizers, and thixotropic additives (bentonite, aerosol). As dyes are usually used chemically stable inorganic pigments - titanium dioxide, carbon black, chrome oxide, etc., fillers are talcum, asbestos, barite, and mica [40, 41]. |
| Epoxy Adhesives | Epoxy adhesive is one of the most popular types of adhesives, as it can join almost all types of materials, level the surface, and fill cracks and cavities. The epoxy-based adhesive creates a strong bond and, once cured, is resistant to chemicals, grease, and oil, and has electrical insulating properties. Because of their unique characteristics, epoxy adhesives have gained well-deserved popularity in various fields. They are used in construction, engineering, aerospace, shipbuilding, and automotive industries, as well as in everyday life to repair shoes, furniture, sanitary ware, and household appliances [42].<br>Epoxy adhesive can reliably bond a variety of materials such as different metal alloys, plastics, ceramics, porcelain, earthenware, glass, wood, and different types of building materials, and you can bond these materials in any combination [43]. |
| Epoxy compounds | The epoxy compound is a two-component polymer that includes epoxy resin, hardener, catalyst, thinner, filler, curing gas pedal, and plasticizer. Epoxy compounds are suitable for the production of tabletops, for the production of 3D tables, for the production of poured floors, and for the production of decorative products. |
| Epoxy primers | Epoxy primer is an anti-corrosive paint material. Epoxy primer protects metal surfaces from rust. This material consists of a special resin of the same name, which gives the primer its unique properties. Thus, the treated objects become resistant to corrosion and external influences. The primer improves adhesion to other substrates and prepares the surface for painting.<br>Epoxy primer is hydrophobic. The coating acts as a quality protection for the substrate from the effects of the wet environment. It also tolerates temperature fluctuations well [44]. |

**Continuation of table - 3**

| | |
|---|---|
| Epoxy fillers | Epoxy putty is used for surfaces of different types: concrete, ceramic, wood and even metal. Epoxy putty consists of several components: hardener, filler, and epoxy resins [45]. Epoxy putties are used for minor repairs as well as in large-scale construction for the following purposes:<br>− Waterproofing.<br>− Joining different materials - metal, ceramics, plastic, wood, concrete.<br>− Alignment of various substrates, including stone, concrete, and wood.<br>− Restoration of surfaces and masking of irregularities, and joints, elimination of various damages - potholes, cracks, and chips [30].<br>Epoxy fillers can be applied to a variety of substrate materials:<br>− stone and brick;<br>− concrete and foam concrete; glass and plexiglass; metal; plastic; ceramics [46]. |
| Epoxy mastics | Epoxy mastic is a special material that is thick and has plastic mass. This product is made based on epoxy resins and has a mixture of dry pigment and filler.<br>The epoxy resin is dissolved by an organic solvent with the addition of a plasticizer, which gives the material properties of increased strength and durability. Epoxy mastics are used for flooring of high strength and resistance. |
| Epoxy polymer concretes | Polymer concrete is an artificial stone, a modern type of concrete mortar, which uses different polymer compounds instead of the usual cement. Most often used for polymer concretes are furan, epoxy, and unsaturated polyester resins. The fillers may be basalt or granite rubble, crushed sandstone, or quartz sand. Concrete polymer is actively used in construction, production of ritual elements, furniture, pouring floors, creating tabletops, and a variety of items [47].<br>The main advantages of polymer concrete are: high level of water resistance, resistance to high/low temperatures, and fluctuations, and excellent resistance to aggressive chemical components - polymer concrete can be used in different conditions without the need for additional coatings, primers, impregnations, a large selection of options for appearance - polymer concrete can be different colors and textures, imitate those or other materials (malachite, granite, marble, etc.) [48]. |

Epoxy resin is used as a finishing coat for various surfaces in the interior, such as concrete, wood, metal, and even glass. It protects coatings from water, high temperatures, and various mechanical and chemical damage. To increase the aesthetic properties of the resin used to make objects and objects of environmental design, dyes, and glitters are added to it. In addition, non-standard solutions are often used in the addition of various fillers, including:

– cement (gives strength to the material and creates an unusual decorative effect);

– rocks and mineral stones, in crushed and natural size (the most popular are marble and garnet);

– quartz sand (used both in the manufacture of floors and countertops and when creating small decorative items);

– wood flour or bark (gives density and strength, small fractions are used in the manufacture of furniture in the manufacture of a special composite);

– aluminum powder, liquid gold (create unusual effects); natural dyes (graphite gives black color, titanium dioxide – white) [[25], [49]].

**Assessment of the toxic hazard of epoxy resin**

Epoxy resins have been used in manufacturing and the paint industry since the 1950s, so the risks associated with working with them are well understood. It is important to understand that epoxy is non-toxic and non-volatile, but the compounds used to cure it are hazardous to health. The type of hardener can be anything:

*Amine hardeners.* These hardeners have a slightly unpleasant odor, are used in the home, and are of the cold-curing type. They cure at room temperature of 23°C. An increase in odor, and therefore an increase in toxicity of the material usually occurs during the polymerization reaction, which by its nature is exothermic, that is proceeding with the release of significant heat, and from the heated epoxy mixture volatile substances are released much more actively than from the cold [14].

*Acid hardeners.* Carboxylic acids and their anhydrides are used - maleic, phthalic, hexahydrophthalic, and others. Acid hardeners give more reliable results but are difficult to use. This type of curing is called hot curing, and during temperature exposure (100-200°C), the epoxy improves its physical and chemical properties.

The main danger of using epoxy resin is the high allergenicity of the resin itself and the hardener. The greatest danger posed by the resin substance is severe skin lesions. The strongest skin irritations and allergic manifestations occur upon direct contact with the liquid mass with unprotected skin. Dermatitis is also accompanied by severe irritation of the respiratory tract membranes, and lesions of the mucous membranes. To avoid such effects, use gloves and a respirator with charcoal filters [50].

**Safety precautions.**

*Protect breathing:* When working with epoxy you must protect your breath with a respirator or half mask with organic vapor filters! They are also suitable for working with alcoholic inks.

The greatest amount of vapor is released when the two components are mixed and when working with the burner. The solid resin (approximately 24-48 hours after pouring) becomes harmless. A very important point is to work in a well-ventilated room. During mixing with the hardener, as well as directly during polymerization, a certain number of harmful substances are emitted.

*Protect your eyes:* If you work with large quantities of resin, wear special safety glasses, or do not touch your face while working. The slightest contact of the resin with your mucosa can cause severe irritation and inflammation.

*Protect your skin:* From the time you open the resin packs until you finish cleaning the work area, wear gloves and, preferably, sleeves or long-sleeved clothing to protect your hands from the resin [51].

## Conclusions

In this article, we reviewed the types of epoxy resins and hardeners. The properties of cured epoxies depend on the type of epoxy, the hardener, and the curing process used. The strength of epoxy resins can be improved by incorporating thermoplastic components, inorganic substances, carbon fibers, clay, and carbon nanotubes. Epoxy resin is a very resistant and durable material. The resin will reliably protect the coated surface from all kinds of mechanical stresses and guarantee water resistance and act as a barrier to aggressive acid and alkaline nature. Epoxy resins have a wide range of applications, and the possibilities of its use are extremely diverse: from epoxy adhesive to transparent jewelry resin.

**Conflict of interest.** On behalf of all authors, the correspondent author declares that there is no conflict of interest.

***Cite this article as:*** Makhmetova AR, Negim El-Sayed, Ainakulova DT, Yeligbayeva G, Khatib JM. An Overview of Epoxy Resin as coating to protect metals from corrosion. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2024; 328(1):20-32. https://doi.org/10.31643/2024/6445.03

# Металдарды коррозиядан қорғау үшін жабын ретінде қолданылатын эпоксидті шайырға шолу

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Мақала келді: *21 ақпан 2023*
Сараптамадан өтті: *24 наурыз 2023*
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**ТҮЙІНДЕМЕ**
Құрылыс жұмыстарында қолданылатын кез-келген металл конструкциялар сыртқы ортаның әсерінен, дәлірек айтсақ, коррозиядан сапалы қорғалуы керек. Коррозиялық процестер нәтижесінде қоршаған ортаның әсерінен металл өзінің қасиеттерін жоғалтады. Коррозияның болуы өндірістегі кез-келген жабдықтың, металл конструкцияларының қызмет ету мерзімінің қысқаруына әкеледі, бұл өнімнің сапасын нашарлатады. Жабдықтардың және құрылымдардан жасалған металдардың қызмет ету мерзімін ұзарту және химиялық қорғауды қамтамасыз ету мәселелерін шешу үшін эпоксидті шайыр негізіндегі жоғары тиімді коррозияға қарсы жабындар қолданылады. Бұл материалдар химиялық төзімділікке ие және агрессивті ортаның жабылған бетке кіруін шектейтін тосқауыл болады. Эпоксидті

шайырлар галогендердің, қышқылдардың, сілтілердің әсеріне төзімді, металдармен жоғары жабысқыштыққа ие. Алайда, осындай жақсы қасиеттерге ие бола тұра, эпоксидті шайырлардың айтарлықтай кемшіліктері де бар. Олар жоғары жанғыш, қатты және салыстырмалы түрде физикалық-механикалық қасиеттері төмен болады. Мысалы полимер макромолекулаларының кеңістіктік торының түйінаралық учаскелерінің шектеулі қозғалғыштығына байланысты соққыға төзімділігін жатқызуға болады. Сондықтан эпоксидті әртүрлі қатайтқыштармен қатайтады, сонымен қатар материалдардың құнын төмендету және шайырлардың қасиеттерін қажетті бағытта жақсартуға мүмкіндік беру үшін әртүрлі толтырғыштармен (металл, минералды және органикалық толтырғыштар) және басқа да көптеген компоненттермен араластырады. Бұл мақалада эпоксидті шайырлардың негізгі қасиеттері мен әртүрлі қатайтқыштардың, модификаторлардың эпоксидті жабындардың коррозияға қарсы қасиеттеріне әсері талқыланады. Оған қоса эпоксидті шайырларды қолданудың жалпы бағыттары мен оларды қолдану кезіндегі денсаулыққа қаупі қарастырылады.

***Түйін сөздер:*** коррозияға қарсы жабын; эпоксидті шайыр; қатайтқыш; модификация; композициялық материалдар; қолдану.

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# Обзор эпоксидной смолы как покрытие для защиты металлов от коррозии

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Поступила: *21 февраля 2023*
Рецензирование: *24 марта 2023*
Принята в печать: *4 апреля 2023*

**АННОТАЦИЯ**

Любые сооружения из металла, которые используются в строительных работах, должны быть качественно защищены от воздействия внешней среды, а точнее, от развития коррозии. Под влиянием окружающей среды в результате коррозионных процессов металл теряет свои свойства. Наличие коррозии сокращает срок службы любого оборудования на производстве, ухудшает качество выпускаемой продукции. Для решения проблем с увеличением срока службы и обеспечения химической защиты металла, из которого изготовлено оборудование, конструкции, сооружения, используют высокоэффективные антикоррозионные покрытия на основе эпоксидных смол. Эти материалы являются химически стойкими и обеспечивают барьер, ограничивающий доступ агрессивных сред к покрытой поверхности. Эпоксидные смолы устойчивы к действию галогенов, кислот и щелочей, обладают высокой адгезией к металлам. Однако, обладая комплексом положительных свойств, эпоксидные смолы имеют существенные недостатки - высокую горючесть, жесткость и относительно низкие физико-механические свойства, в том числе стойкость к ударам, обусловленные ограниченной подвижностью межузловых участков пространственной сети макромолекул полимера. Поэтому эпоксидную смолу отверждают различными отвердителями, смешивают с разнообразными наполнителями (металлическими, минеральными и органическими) и многими другими компонентами, чтобы снизить стоимость материалов и позволить улучшить свойства самих смол в желаемом направлении. В данной обзорной статье рассматриваются основные свойства эпоксидных смол и влияние различных отвердителей и модификаторов на антикоррозионные свойства эпоксидных покрытий, а также общие области применения эпоксидных смол и риски для здоровья при их использовании.

***Ключевые слова:*** антикоррозионное покрытие; эпоксидная смола; отвердитель; модификация; композиционные материалы; применение.

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