DOI: 10.31471/2311-1399-2022-2(18)-53-61

Technology of forming modified epoxy composite coatings for the protection of oil and gas complex structures

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Received: 18.09.2022   Accepted: 25.10.2022

Abstract

The work defines the adhesive strength of epoxy composite coatings formed by different technological modes, which contain finely dispersed powder of titanium oxide (TiO_2) and polyvinyl chloride dissolved in cyclohexanone. The highest values of adhesive strength were obtained for two-layer coatings, in which the lower (adhesive) layer contains chromium (III) oxide powder, and the upper (operational) layer consists of a modified epoxy polymer binder filled with treated titanium (IV) oxide powder. The formation modes of epoxy composite coatings were optimized, for which higher values of adhesive strength were obtained. Higher values of toughness by 40–45 % were obtained for epoxy composites, for which the forming technology included exposure of polyvinyl chloride powder in cyclohexanone with the subsequent introduction of TiO_2 powder. This ensures saturation of the filler particles surface with polyvinyl chloride macromolecules, which form additional chemical bonds and perceive dynamic loads. The practical purpose of the developed epoxy composite coating is to protect the constructions, equipment and the oil and gas hardware complex from the influence of hydroabrasive flows during the transportation of oil and petroleum products, which is a complex effect of aggressive substances, water and temperature, which cause the appearance of areas of destruction on the internal surfaces of pipelines and equipment. The difficulty of applying epoxy composite coatings containing prepared finely dispersed titanium (IV) oxide powder is that the powder particles coagulation occurs. The use of cyclohexanone increases the manufacturability of the composition by reducing the ability of powder particles to coagulate.

Keywords: adhesive strength, cyclohexanone, polyvinyl chloride, titanium (IV) oxide powder.

Introduction

Despite the fact that alloy steels and aluminum alloys are widely used in the aerospace and automotive industries, they are sensitive to atmospheric corrosion and wear during long-term service under severe operating conditions [1]. Coatings are mainly used to protect parts subject to corrosion, various forms of wear, and in some cases to provide a decorative appearance. They are used in the oil and gas, petrochemical, marine, medical, defense, paper, energy, metalworking and cement industries [2].

Due to the combination of exceptional mechanical properties (strength and stiffness, insulating ability, low shrinkage at hardening, chemical resistance, adhesive and cohesive strength), epoxy resin is still widely used in industry, its application areas are constantly expanding to form coatings in the aerospace, automotive and electronic industries. Epoxy coatings are used to protect metal surfaces from corrosion, oil and chemical reactions that can lead to dangerous consequences. The effectiveness of coatings based on epoxy resin can be significantly increased through the use of functional fillers, which will improve the resistance of epoxy composite coatings to corrosion and the effects of abrasive or hydroabrasive wear [3]. However, the microstructure of an epoxy polymer with a high degree of structuring leads to undesirable brittleness, low tribotechnical characteristics and anti-corrosion resistance due to the formation of a highly stressed state and insufficient resistance to the formation of cracks. Therefore, an effective way to improve properties, especially tribotechnical and anti-corrosion properties, is the addition of highly effective nanofillers to matrices based on epoxy polymers [4].

In the work [4], the influence of two different forms of fullerene C_{60} (FC_{60}) and functionalization graphene (FG) in the polymer matrix on the tribotechnical and anti-corrosion characteristics of the epoxy coating was investigated. To improve the dispersion and compatibility of C_{60} and graphene with the epoxy polymer matrix, silane coupling agent 3-aminopropyltriethoxysine (KH550) was grafted onto the surface of C_{60} and graphene by chemical modification. The results of tribotechnical and anti-corrosion studies showed that the composite coatings have a lower coefficient of friction, area of wear traces and higher anti-corrosion resistance compared to unfilled epoxy polymers due to the balance of reinforcing, lubricating and barrier properties of nanofillers and cracks in the case of introducing the optimal concentration of FC_{60} additive and graphene in the range of 0.45–0.55 % by weight. "FC_{60} – epoxy resin"

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coatings showed better tribotechnical properties, but worse corrosion resistance compared to "FG – epoxy resin" coatings due to the use of different forms of nanofillers.

Epoxy resins represent a special class of organic macromolecules that are widely used in technology and industry. Due to their macromolecular nature, epoxy resins provide better surface coverage and anti-corrosion action than simple organic corrosion inhibitors. The peripheral polar functional groups of the epoxy resin act as adsorption centers during the interaction of the metal with the inhibitor. Pure and hardened epoxies have been used as anti-corrosion coating materials, especially for carbon steel in acid solutions and sodium chloride solutions (3.0 and 3.5 %), because most epoxy resins act as corrosion inhibitors on the metal surface. Numerous theoretical calculations and practical applications confirm the effectiveness of the adsorption behavior of epoxy resins on metal surfaces due to the appearance of anti-corrosion effects. However, most epoxy resins have limited solubility, so they are best used as the coatings for anti-corrosion purposes. A review of the literature revealed that numerous coatings based on epoxy resins have been developed and successfully applied to carbon steel and aluminum in salt solutions. The anti-corrosion effect of epoxy polymer coatings can be further enhanced by adding organic and inorganic additives. Additives block the surface micropores, that are present in epoxy coatings, through which corrosive substances can penetrate or diffuse and destroy the structure of the coating [5].

Silicon nitride was first used as an anti-corrosion pigment in organic coatings. An effective strategy was the combination of inorganic fillers and organosilanes and was used to increase the dispersibility of silicon nitride in epoxy resin. The formed nanocomposites were used to protect carbon steel Q235 from the corrosion. As the immersion time increased, the corrosion resistance as well as the adhesion strength of the epoxy resin and unmodified silicon nitride coatings decreased significantly. However, for the modified silicon nitride coating, the corrosion resistance and adhesion strength remain at a high level after 2400 hours of immersion. The high corrosion resistance indicators can be explained by the chemical interaction between the functional groups of silane KH-570 and the silicon nitride powder as a result of the easy formation of Si-O-Si bonds. In addition, modified silicon nitride coatings form a strong barrier to the corrosive electrolyte due to the hydrophobicity of the modified silicon nitride powder and the strengthening of chemical bonds [6].

Epoxy resin is most often used to form protective coatings in engineering and industry due to its numerous advantages, including temperature stability, adhesiveness and resistance to solvents. However, due to the three-dimensional mesh structure and low tribotechnical characteristics, epoxy resin cannot be directly used as a wear resistant material. To improve its anti-friction and wear resistant characteristics, a combination of epoxy binder with various powders is actively used, which perform the function of reinforcing additives in epoxy composites. Today, many different fillers are known that can be used to improve the tribotechnical properties of epoxy polymers, especially with the help of a combination of fibers, nanoparticles and internal lubricants. The technology has demonstrated the effectiveness of using powder materials such as SiO_2, TiO_2, Al_2O_3, ZnS and solid lubricants (MoS_2 and graphite) that can significantly reduce the coefficient of friction and improve wear resistance compared to pure polymer [7].

Epoxy composite coatings containing fillers are widely used as anti-corrosion materials. In the work [8], a variable multilayer structure was developed to obtain a multifunctional composite coating from epoxy resin based on the method of stepwise coating by adding graphene and α-aluminum oxide. It was established that when the mass fraction of the filler increases to 0.15 %, the viscosity and thermal conductivity increase significantly, and the dielectric characteristics decrease to approximately zero. The entire corrosion process is controlled by an electrochemical reaction, and the fillers effectively block the corrosive environment, thus improving the anti-corrosion characteristics of the composite coating.

The addition of reinforcing additives (polymeric and mineral fillers) to epoxy resin improves the general characteristics of the composite, which allows them to be used as tribotechnical materials for industrial purposes. Improvement of tribotechnical properties (low coefficient of friction, increased wear resistance and non-stick properties) of epoxy coatings is carried out by introducing powder fillers of different content and granulometric composition. A significant reduction in wear intensity has been recorded for compositions containing polymer fillers such as polytetrafluoroethylene, polyethylene and fluorinated ethylene propylene due to their self-lubricating ability. Silica (SiO_2) particle size has been found to play a significant role, as large particles reduce the wear rate due to chemical bonding at the border «epoxy resign-filler». It was determined that not all fillers helped to increase the wear resistance of epoxy coatings. At the same time, SiO_2 particles with a smaller size negatively affect the wear resistance of the epoxy coating, causing breaks in the material during frictional loading [9].

For epoxy compositions containing finely dispersed fillers, it is advisable to use ultrasonic treatment, since high-frequency oscillations contribute to the destruction of agglomerates of particles with high surface energy. In unfilled epoxy polymers, segments of macromolecules of epoxy resin and hardener begin to oscillate under the influence of ultrasound, which intensifies the formation of chemical bonds. With prolonged processing for more than 10 minutes, there is an increase in residual stresses, which reduces the mechanical characteristics of epoxy polymers. Increasing the duration of influence of ultrasonic radiation to 10 minutes is effective in the case of treatment with a composition containing 6–8 wt. parts of the filler, which ensures the resistance of the epoxy composite to plastic deformation and destruction under the action of compressive loads. The strength of epoxy composites is increased by 20 % due to the formation of additional bonds between the components of the system and the presence of a stronger phase compared to the epoxy polymer matrix. In this case, a long treatment (10 min) is necessary to transfer sufficient energy for the composition. This ensures the destruction of agglomerates and uniform distribution of filler particles in the volume of the polymer matrix. Ultrasonic processing reduces the degree of defectiveness of the structure of epoxy composites by removing air inclusions that are retained during mechanical mixing of the composition components. The optimal content of titanium oxide powder is 4 wt. parts, since the impact energy of epoxy composites treated with ultrasound for 5 min increases by 20–25 % compared to unfilled epoxy polymers. As a result of ultrasonic processing, there is a uniform distribution of dispersed particles in the epoxy polymer matrix and the formation of an epoxy composite structure with a low stress state [10].

It was established that the introduction of titanium oxide powder into the epoxy polymer matrix is more appropriate than chromium oxide powder, as the mechanical characteristics increase by 15–30 %. This is due to the ability of titanium oxide powder particles to form additional intermolecular bonds with macromolecules of the epoxy matrix. The optimal content of titanium oxide powder in the epoxy-polymer matrix is 6 wt. parts, resulting in the formation of an epoxy composite material with high adhesive strength, compressive strength, resistance to dynamic loads and degree of structuring. Epoxy composites with a lower content of this powder do not ensure the formation of a sufficient number of chemical bonds. When using a higher content, agglomeration of particles occurs, which leads to the formation of a defective structure. When forming epoxy composites with a low content of chromium oxide powder, there is no significant increase in mechanical properties compared to epoxy composites filled with titanium oxide powder, because the surface of chromium oxide powder particles contains a smaller number of active groups involved in the formation of chemical bonds. In the case of the formation of epoxy composites with a higher content of chromium oxide powder, the cohesive strength decreases, which is due to the uneven distribution of particles in the polymer matrix and the formation of a non-uniform structure [11].

The purpose of the work is to develop a technology for the formation of epoxy composite coatings containing refined powder of titanium (IV) oxide and a modifying additive in the form of a solution of polyvinyl chloride.

Research materials and methodology

ED-20 epoxy-diane resin (DSTU 2093−92) was selected as the starting material for the formation of the polymer matrix. The use of epoxy resins as a polymer binder for the formation of protective high-strength composite coatings is due to their low linear shrinkage (less than 2 %), the absence of low-molecular hardening products; high adhesion (exceeds the adhesion of most other resins), the possibility of obtaining epoxy resins in a solid or low-viscosity initial state (allows the use of various technological methods), high mechanical and electrical characteristics of epoxy polymers in a wide temperature range, the possibility of obtaining products and structures; high water and chemical resistance. Polyethylene polyamine PEPA (TU U 20.1-22944575-002−2017) was used to harden epoxy compositions. PEPA hardener is designed for structuring epoxy resins at room and lowered temperatures in conditions of high humidity.

Multifunctional components are used as fillers for epoxy composite coatings. Titanium (IV) oxide (TiO_2) is a white amorphous non-hygroscopic powder (GOST 19807−91). Functional capabilities of titanium (IV) oxide largely depend on the degree of dispersion of the material, morphology and crystal structure of its particles [12]. The powder fraction is 5−10 μm.

Technical cyclohexanone (CYC) $C_6H_{10}O$ is a colorless oily liquid with the smell of acetone, it is an organic compound. CYC is characterized by chemical properties of ketones. In properties, CYC is close to methyl ethyl ketone and acetone. Cyclohexanone vapors can form explosive mixtures with air.

Polyvinyl chloride (PVC) $[-CH_2-CHCl-]_n$ is a white powder consisting of 57 % bound chlorine and 43 % ethylene. Polyvinyl chloride belongs to the group of thermoplastic polymers, has high chemical resistance to alkalis, solvents, many acids and mineral oils. It does not burn in air, has low frost resistance (-15 °C). A significant disadvantage of polyvinyl chloride is low heat resistance (65 °C). Products based on polyvinyl chloride are characterized by particularly high atmospheric resistance, moisture resistance, mechanical strength, wear resistance and durability, good dielectric properties.

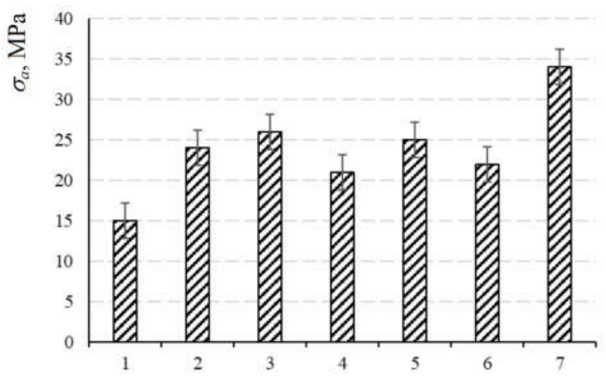
The boundary adhesive strength at normal tear was determined according to ISO 14916:2017. The studied material was applied to the end surface of metal rods with a conical protrusion in the place of grips. The research was carried out on a UMM-5 tearing machine with a moving speed of the lower traverse of 2 mm/min.

Impact strenght was determined by the Charpy method (ISO 179-1:2010). The method is based on a test in which a specimen resting on two supports is subjected to a pendulum impact, the impact line being midway between the supports and directly opposite the notch in the case of notched samples. The studied sample has dimensions of 10×10×60 mm.

The coating was applied to a plate-base made of low-carbon steel with a size of 80×15 mm and a thickness of 0.25−0.3 mm.

Results and their discussion

It was experimentally established that the adhesive strength is significantly affected by the composition preparation technology (Fig. 1). Epoxy composite coatings filled with highly dispersed titanium (IV) oxide powder (mode 1) have the lowest adhesive strength, since the adhesive strength is mainly determined by the number of chemical bonds between the reactive groups of the system components.



1 – ED-20 + PEPA + TiO_2;
2 – PVC + CYC + TiO_2 + ED-20 + PEPA;
3 – ((PVC + CYC) 30 min + TiO_2) + ED-20 + PEPA;
4 – (PVC + CYC + TiO_2) + ED-20 + PEPA;
5 – (PVC + CYC) + TiO_2 + (ED-20 + PEPA);
6 – (PVC + CYC + TiO_2) + (ED-20 + PEPA);
7 – two-layer coating

Figure 1 – Adhesive strength of epoxy composite materials formed according to the following modes

The increase in this characteristic by 37 % occurs due to the formation of additional chemical bonds in the case of the use of a modifying additive (polyvinyl chloride dissolved in cyclohexanone), to which filler, epoxy resin and hardener were gradually introduced (mode 2).

In the case of exposure of polyvinyl chloride powder in cyclohexanone for 30 minutes (mode 3) at a temperature of 20–25 ºC, complete dissolution of given additive occurs, as a result of which the adhesive strength of epoxy composites increases by 10 %.

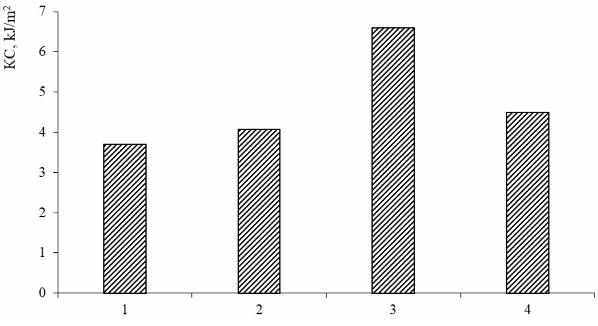
During exposure for 30 minutes (mode 4) of the composition containing polyvinyl chloride powder, titanium (IV) oxide powder and cyclohexanone, the adhesive strength decreases slightly, as the filler particles are saturated with solvent molecules. Accordingly, blocking of reactive hydroxyl groups on the surface of particles is created, which prevents the formation of chemical bonds. In addition, cyclohexanone molecules can be partially removed in the process of heat treatment, which causes the destruction of the polymer network bonds or the creation of a stress state.

Preparation of the composition according to the mode 5 is similar to the mode 3, with the difference in which the complex composition was formed from two systems. The composition of the first system included polyvinyl chloride dissolved for 30 minutes in cyclohexanone followed by the introduction of titanium (IV) oxide powder. The second system included an epoxy binder containing epoxy resin and hardener. After separate mixing of these systems, they were combined with subsequent mechanical mixing. As a result, the adhesive strength increased slightly compared to the formation mode 4, but was lower compared to the formation mode 3, when epoxy resin and hardener were sequentially introduced into the first composition. From a technological point of view, the formation mode 3 is more convenient and provides higher values of adhesive strength. It is obvious that in the case of the introduction of the second system, which consists of epoxy resin and hardener, to the composition containing the solvent, a partial destruction of chemical bonds occurs.

In the case of preparation of the composition according to the mode 6, which is the obtaining of a complex composition by combining two systems. The first system is obtained by successive introduction of components (polyvinyl chloride powder, titanium (IV) oxide powder and cyclohexanone) and exposure for 30 minutes. The second system is obtained by combining epoxy resin with a hardener. In this case, the higher values of adhesive strength, compared to the formation mode 4, are explained by the better interaction of the reactive groups of the epoxy resin with the hardener than with other components of the composition.

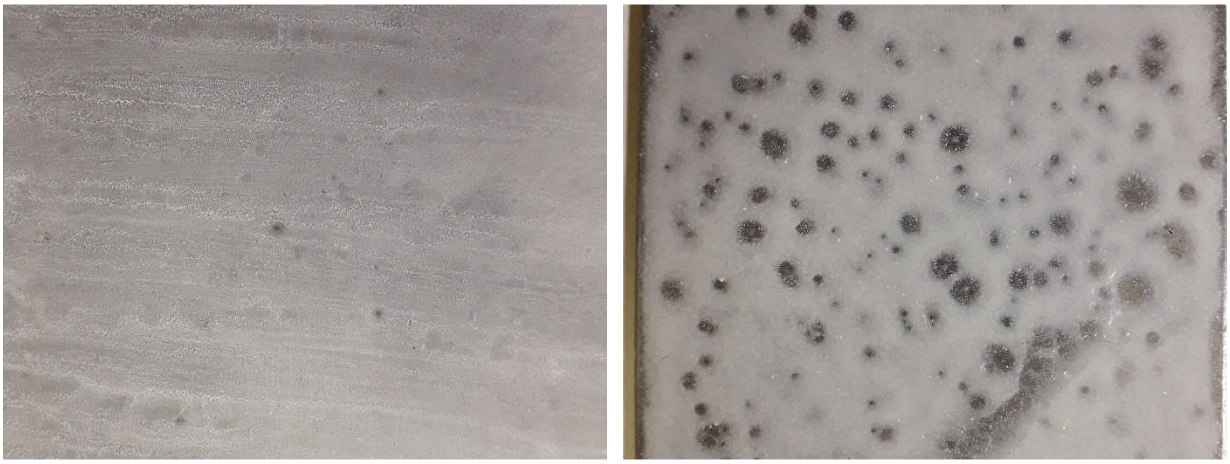
The highest values of adhesive strength were obtained for two-layer coatings (mode 7), in which the lower (adhesive) layer contains chromium (III) oxide powder, and the upper (operational) layer consists of a modified epoxy polymer binder filled with treated titanium (IV) oxide powder. The high adhesive strength of the two-layer coating is due to the presence of the adhesive layer, which ensures the formation of a significant number of chemical bonds between the surface of the substrate and the epoxy polymer matrix, as well as the high adhesive and cohesive strength of the operational layer, which consists of a modified epoxy composite.

The impact strenght of epoxy composite materials, formed as a result of the stepwise introduction of components with mechanical mixing at each stage, is the lowest (3.8 kJ/m^2) (Fig. 2), since the solvent in this case directly interacts with the surface of the filler and does not provide dissolution polyvinyl chloride, which is in the epoxy polymer matrix in the form of powder particles. The increase in impact strenght by 40–45 % occurs as a result of exposure of PVC powder in cyclohexanone followed by the introduction of TiO_2 powder, which ensures the saturation of the surface of the filler particles with polyvinyl chloride macromolecules, which form additional chemical bonds and perceive dynamic loads due to the ability to change the configuration of macromolecules without destruction.



1 – PVC + CYC + TiO_2 + ED-20 + PEPA;
2 – ED-20 + PEPA + TiO_2;
3 – (PVC + CYC) + TiO_2 + (ED-20 + PEPA)
4 – (PVC + CYC + TiO_2) + (ED-20 + PEPA)

Figure 2 – Toughness of epoxy composite materials



a) b)

a – the brush; b – the method of pneumatic spraying

Figure 3 – General view of epoxy composite coating applied

a) b) c)

a – mechanical; b – 10 % H_2SO_4; c – HNO_3

Figure 4 – General view of the surface of the substrate after processing

The formation of an epoxy composite coating, which contains treated titanium (IV) oxide powder, is complicated, which is explained by the condition of the surface of the substrate. The presence of contamination and inhomogeneity of the surface (protrusions and depressions) leads to the non-wetting of the surface by the binder under the condition of applying the coating with a brush and the formation of a defective coating (Fig. 3, *a*) containing craters with a diameter of 1−2 mm. In the case of applying the method of pneumatic spraying of the composition, the diameter of the craters increases to 4–7 mm (Fig. 3, *b*), since the composition is supplied in a mixture with air under pressure, which leads to the loss of the integrity of the coating layer on the lyophobic surface of the substrate.

In order to eliminate defects of the surface of the substrate, various types of processing were carried out, which consisted in removing protrusions, leveling the surface and ensuring the specified roughness. The use of grinding with a grain size of 150 mesh does not allow obtaining a sufficiently low surface roughness, in addition, due to the presence of traces of processing in the form of parallel lines in different directions on the surface (Fig. 4, *a*), which cause an additional appearance of surface inhomogeneity. Therefore, after mechanical processing, it is advisable to carry out chemical processing, which consisted in etching the polished surface with a 10 % solution of sulfuric acid. At the same time, sufficient uniformity of the surface was obtained (Fig. 4, *b*), however, to reduce the duration of the etching process and ensure higher uniformity (Fig. 4, *c*), it is advisable to use concentrated nitric acid.

As a result of the mechanical treatment of the surface, the sizes of the coating craters decreased (Fig. 5, *a*) due to the increase in surface homogeneity. The epoxy composite coating applied to the surface of the substrate after treatment with a 10 % sulfuric acid solution is more uniform and contains a significantly smaller number of craters (Fig. 5, *b*). The best outcome was obtained as a result of treating the surface of the substrate with concentrated nitric acid for 2–3 minutes, which ensures the formation of an epoxy composite coating with a small number of craters (Fig. 5, *d*), which are eliminated by introducing a larger amount of solvent to increase the fluidity of the composition.

The appearance of craters and coating defects can also be caused by the incorrect use of a solvent, which

a) *b)* *c)*

a – mechanical; b – 10 % H_2SO_4; c – HNO_3

Figure 5 – General view of epoxy composite coating with surface treatment of the substrate

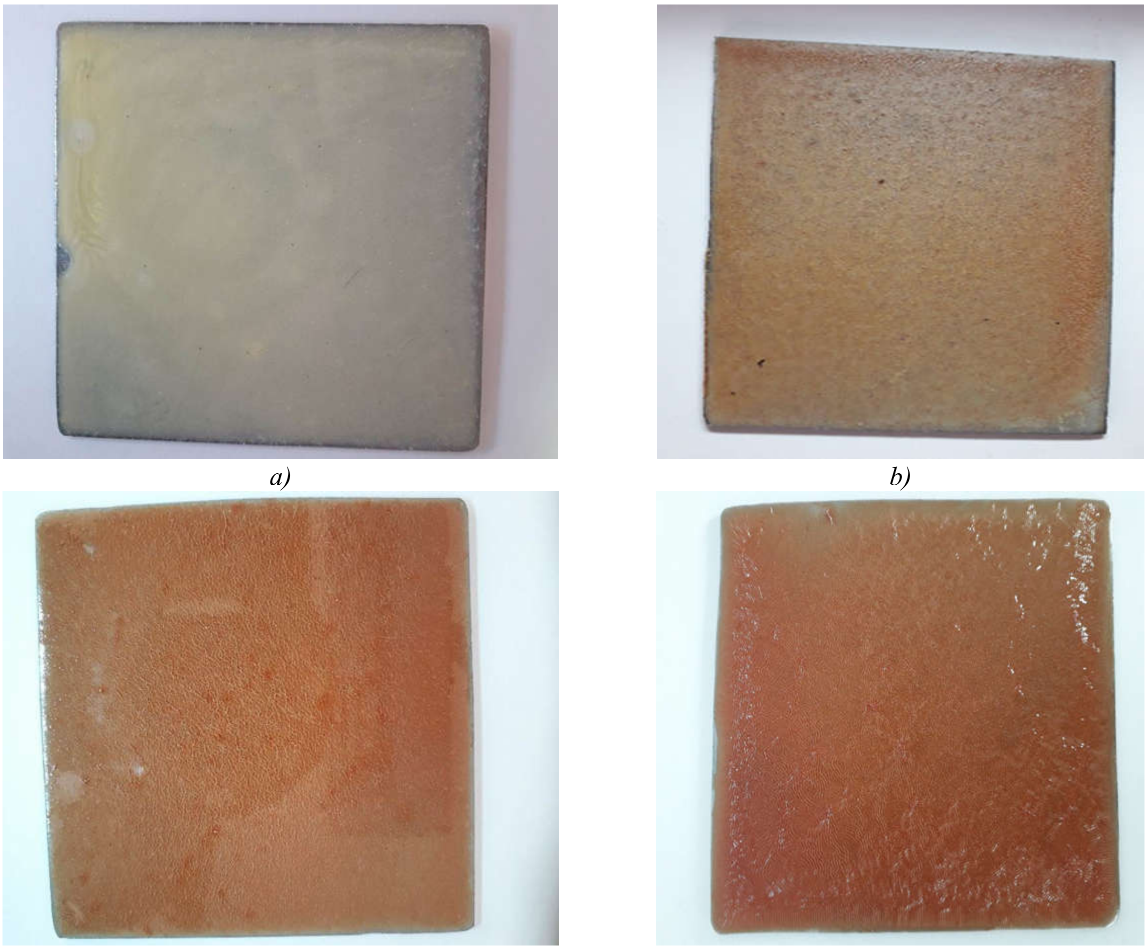
a) *b)*

a – brand «647»; b – cyclohexanone

Figure 6 – General view of a layer of epoxy composite coating modified with polyvinyl chloride with a solvent content

leads to coagulation of the finely dispersed composition containing the treated titanium (IV) oxide powder. Epoxy composite coatings, which were formed by pneumatic spraying of the composition, the viscosity of which was regulated by the "647" solvent, are discontinuous and contain a large number of craters due to the low wettability of the substrate surface (Fig. 6, *a*). The use of cyclohexanone ensures the uniform formation of an epoxy composite coating (Fig. 6, *b*) due to the complete dissolution of polyvinyl chloride. The given additive is a modifier of the epoxy polymer matrix and a finisher of finely dispersed titanium (IV) oxide powder, which is previously dissolved with cyclohexanone to a gel-like state and introduced into the composition of the epoxy binder.

Epoxy composite coating containing highly dispersed titanium (IV) oxide powder is more technological because it does not contain a modifying additive (cyclohexanone). In the case of applying this composition by pneumatic spraying, a uniform, homogeneous coating is formed (Fig. 7, *a*), the viscosity of which is regulated by a solvent of brand "647". The difficulty of applying epoxy composite coatings, containing prepared finely dispersed titanium (IV) oxide powder, is that part of the powder coagulation occurs, which causes the formation of large agglomerates (Fig. 7, *b*), which protrude on the surface of the coating and reduce the quality of the surface. The use of cyclohexanone reduces the ability of powder particles to coagulate, but there is a need to filter the prepared solution. This operation allows to separate large fractions of particles and leave in the solution finely dispersed prepared particles that ensure the formation of a homogeneous coating (Fig. 7, *c*). The increased content of the solvent contributes to a better distribution of the filler particles in the modified epoxy polymer binder, however, the excessive content leads to the composition flowing from the curved surface and the formation of shagreen (Fig. 7, *d*) in the process of intensive evaporation of the solvent during the heat operation.


a) *b)* *c)* *d)*

a – filled with TiO_2; b – TiO_2 + PVC (without filtering);
c – TiO_2 + PVC (with filtering); d – TiO_2 + PVC (with an excessive content of solvent)

Figure 7 – General view of epoxy composite coating

In the case of applying an epoxy composite coating directly to the surface of the product, the surface is not wetted by the epoxy polymer binder, as a result of which the integrity of the coating is lost. Therefore, it is advisable to treat the surface of the product first mechanically, by grinding with an abrasive size of 150 mesh or by sandblasting with electrocorundum with a grain size of 10−12, and then by a chemical method using alkali (NaOH) to level the surface and dissolve the resistant oxide film.

The use of an adhesive layer based on modified epoxy composites filled with chromium (III) oxide powder is due to the formation of an intermediate layer with a thickness of 50-60 μm, which has high adhesion to the substrate and acceptable damping properties, and also provides a technological function for the formation of color contrast, because during application of the operational layer of white coating, it is difficult to detect areas with unequal thickness.

The operating layer is applied on top of the adhesive layer in three stages with structuring of each layer at a temperature of 70 ºC for 15 minutes and air cooling at room temperature. The total thickness of the operational layer is 150−170 μm.

Conclusions

Epoxy composite coatings consisting of a modified epoxy polymer binder filled with treated titanium (IV) oxide powder have the highest values of adhesive strength. At the same time, the adhesive strength is determined by the technological aspects of the process of treating particles of titanium (IV) oxide powder with polyvinyl chloride macromolecules, which is obtained by dissolving polyvinyl chloride powder (3 wt. parts) in a solvent (cyclohexanone) with exposure for 10–15 minutes at a temperature of 20–25 ºC. This ensures effective saturation of the surface of titanium (IV) oxide powder particles with polyvinyl chloride macromolecules, which allows obtaining a homogeneous composition suitable for forming an operational layer. The use of the cyclohexanone solvent in the optimal amount (15 wt. parts) ensures the uniform formation of the epoxy composite coating due to the complete dissolution of polyvinyl chloride, which is both a modifier of the epoxy polymer matrix and a finisher of finely dispersed titanium (IV) oxide powder, which ensures a 40–45 % increase in the impact strength of the modified epoxy composites.

The high adhesive strength of the two-layer coating is due to the presence of an adhesive layer containing chromium (III) oxide powder, which provides technological properties and high mechanical characteristics of the adhesive layer by forming a significant number of chemical bonds between the surface of the substrate and the epoxy polymer matrix, as well as high adhesive and cohesive strength of the operational layer, which consists of epoxy composite modified with polyvinyl chloride.

The use of a multi-stage technology of the composition preparation based on a modified epoxy resin provides high wear resistance of epoxy composite coatings to the impact of abrasive particles, compared to the basic epoxy polymer coating, because they contain a finisher powder of titanium (IV) oxide, which is characterized by high hardness and contributes to the formation of strong chemical bonds with the modifier, which, accordingly, does not cause powder particles chipping. Developed modified two-layer epoxy composite coatings filled with finished titanium (IV) oxide powder have high corrosion resistance and resistance to cyclic temperature changes, which is associated with high adhesion strength of the coating to the substrate and high flexibility of polyvinyl chloride macromolecules.

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УДК 621.763

Технологія формування модифікованих епоксикомпозитних покриттів для захисту конструкцій нафтогазового комплексу

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В роботі визначено адгезійну міцність сформованих за різними технологічними режимами епоксикомпозитних покриттів, які містять дрібнодисперсний порошок оксиду титану (TiO_2) та розчинений в циклогексаноні полівінілхлорид. Найвищі значення адгезійної міцності отримано для двошарових покриттів, в яких нижній шар (адгезійний) містить порошок хром (III) оксиду, а верхній (експлуатаційний) шар складається з модифікованого епоксиполімерного в’яжучого наповненого апретованим порошком титан (IV) оксиду. Оптимізовано режими формування епоксикомпозитних покриттів, для яких отримано вищі значення адгезійної міцності. Вищі значення ударної в’язкості на 40–45 % отримано для епоксикомпозитів, для яких технологія формування включала витримку порошку полівінілхлориду в циклогексаноні з наступним введенням порошку TiO_2. Це забезпечує насичення поверхні частинок наповнювача макромолекулами полівінілхлориду, які утворюють додаткові хімічні зв’язки та сприймають динамічні навантаження. Практичне призначення розробленого епоксикомпозитного покриття полягає у захисті конструкцій, обладнання та устаткування нафтогазового комплексу від впливу гідроабразивних потоків під час транспортування нафти та нафтопродуктів, що являє собою комплексний вплив агресивних речовин, води та температури, які спричиняють появу ділянок руйнування на внутрішніх поверхнях трубопроводів та обладнання. Складність нанесення епоксикомпозитних покриттів, що містять апретований дрібнодисперсний порошок титан (IV) оксиду полягає в тому, що відбувається коагуляція частинок порошку. Застосування циклогексанону підвищує технологічність композиції шляхом зменшення здатності частинок порошку до коагуляції.

Ключові слова: адгезійна міцність, полівінілхлорид, порошок титан (IV) оксиду, циклогексанон.