Effectiveness of corrosion protection of reinforced concrete with thermoplastic powder coatings

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Abstract. In modern construction, there is a persistent trend of increasing levels of corrosive aggressiveness, which negatively affects the reliability and durability of reinforced concrete buildings and structures. Achieving their effective protection from corrosion under the complex influence of various destructive environmental factors, while considering environmental protection regulations, as well as the economic and technological aspects of sustainable development, determines the focus of scientific research towards the use of innovative, durable protective coatings, among which thermoplastic coatings hold one of the leading positions. When creating such materials, the key feature is ensuring the long-term preservation of the operational characteristics of building products and structures, with the implementation of environmentally safe and economically viable production technologies.

A traditional method of protecting construction products and structures from corrosion is the application of liquid paint materials based on organic compounds. The drawback of these materials is the presence of solvents in their composition, which inevitably leads to their emission during production and application, with a corresponding catastrophic impact on the environment. In connection with the tightening of health and environmental safety requirements in the industrial finishing industry, the ecological aspects of the production and use of paint materials, especially regarding the content of volatile organic compounds (VOCs), heavy metals, and other harmful substances, are gaining paramount importance. This emphasizes the expansion of scientific research in the development of protective thermoplastic coatings that meet dual requirements: environmental friendliness and durability.

Keywords: reinforced concrete, thermoplastic powder coatings, polyvinylidene fluoride, corrosion resistance, efficiency.

INTRODUCTION

The corrosion process of reinforced concrete in aggressive environments can be viewed as a complex of heterogeneous chemical processes involving the interaction of concrete with aggressive components, the rate of which is mainly determined by the diffusion rate of aggressive substances and the chemical reactions themselves. In the case of reinforced concrete corrosion, the rate of chemical reactions is significantly slower than the diffusion rate of aggressive substances within the porous structure of concrete. Therefore, the decisive factor in ensuring corrosion resistance in most cases should be considered the permeability of the structures. This explains why the most functional and effective protection for reinforced concrete from aggressive environments is the creation of an isolation or barrier at the phase boundary "aggressive environment-reinforced concrete," which practically eliminates the possibility of their interaction.

The study of the effectiveness of corrosion protection of reinforced coating with thermoplastic powder coatings with the addition of fillers and the establishment of their optimal concentration is an unresolved component of corrossion resistance and, accordingly, determines the need for such studies

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The main advantage of coatings based on mineral binders is their relatively low cost, simplicity in manufacturing technology, and preparation. According to a number of studies [1…3], it has been found that chemical modifiers of various natures are used to create barrier protective coatings based on Portland cement, which help improve the stability of the newly formed products during hydration, compact the macrostructure, and provide water-repellent properties to the coating. The main directions for modifying the newly formed products are the reduction of the alkalinity of silicates and the increase in the number of aluminosilicate phases in the binder composition, which enhances the micro- and macrostructure of the coating.

Their main drawbacks include insufficient corrosion resistance in highly aggressive environments, a decrease in coating adhesion to the substrate over time, and a high influence of human factors during their preparation at the construction site, which leads to a reduction in the material's operational characteristics. Additionally, there is a tendency for frequent restoration of these coatings through reapplication after cleaning the previous layer, which, in turn, increases the cost of repair work.

In contrast to mineral binders, coatings based on organic substances are characterized by relatively high crack resistance and stability of deformative phenomena. However, they may deteriorate over time due to exposure to solar radiation and highly aggressive corrosive environments [4…6], depending on their type. Therefore, these coatings are selected based on the operating conditions of the reinforced concrete structure and the requirements for the protection system [7]. In practice, the most widely used coatings are those based on alkyd, phenolic formaldehyde, chlorinated vinyl resins, organosilicon compounds, vinyl chloride copolymers, polyvinyl acetals, fluorine-containing polymers, epoxy resins, polyesters, polyurethanes, furyl resins, naphthopolymer resins, polyethylene, and others [8].

To a greater extent, epoxy resin-based coatings are used for the protection of reinforced concrete structures, accounting for about 30% of the total global production of all types [9].

Based on the above analysis, it can be stated that a significant number of systems for protecting construction products and structures from the effects of aggressive environments have been developed in recent decades [10, 11], most of which are quite effective. However, given that the present time has been marked by increasing demands to limit VOC emissions and the introduction of high environmental taxes, along with rising costs affecting the financial stability of enterprises, this has accelerated the transition from solvent-based paints and coatings to systems containing 100 % solid content. These systems can not only play an aesthetic role in improving the appearance of a product but also contribute to achieving high operational properties for coatings based on them [12…15].

Therefore, fact that coatings based on powder coatings can be fully restored during their operation is an additional factor that enhances the economic attractiveness of their use, while maintaining protection for human health and the environment.

THE PURPOSE OF THIS WORK

The purpose of this work is to study the effectiveness of corrosion protection of reinforced concrete with thermoplastic powder coating with a different types of polymers

MATERIALS AND METHODS OF

RESEARCH

Thermoplastic polymers of various types were chosen as film-forming agents, including polyvinylidene fluoride (PVDF), polyethylene, polypropylene, and nylon resins, which are the most common representatives of binding agents for the possibility of obtaining thermoplastic powder coatings. As control compositions, a liquid paint coating system based on a mixture of epoxy-alkyd resin (ASG-0-701) was used, which is traditionally used for the anticorrosive protection of reinforced concrete structures.

The application of these systems to the surface of reinforced concrete samples was carried out using the flame spraying method (Fig. 1), in which a flame jet is used to apply polymer powder. According to this method, the spray gun creates a flame torch to which the powder coating is fed. The powder then passes through the flame, transforming into a liquid phase, and upon reaching the surface of the concrete sample, it spreads out, forming the coating. The thermal impact lasts only a few seconds, thus not damaging the surface of the sample and not causing thermal deformation.

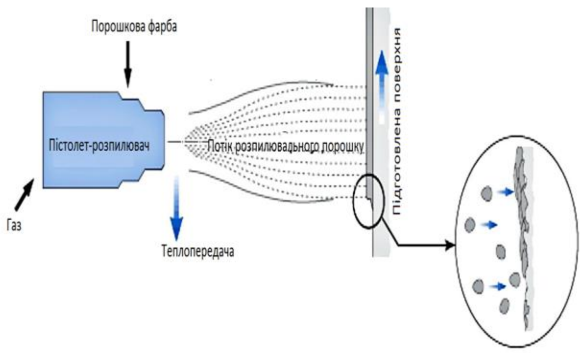

Figure 1. Gas flame spraying.

The study of adhesive flow on the substrate surface was conducted according to [16]. The essence of the method lies in measuring the spread length of a compressed adhesive of a given mass on a sloped substrate surface at an angle of 65° under constant temperature and curing time in an oven. As a result of this test, the flow of the adhesive on the substrate surface is expressed in millimeters. The spread length of the compressed adhesive is an indicator of the coating's viscosity at the specified temperature.

Adhesion of the coating to the substrate was determined according to [17]. The essence of the method involves attaching the test plate to the punch, then setting up a tensile device on the surface of the coating. A tensile force is applied at a rate of 0.1 MPa/s, perpendicular to the plane of the painted surface, to determine the adhesion value of the coating using the pull-off method.

Impact resistance was determined according to [18]. The essence of the method is that the plate with the powder coating is fixed in the testing device in such a way that the coating is positioned downward in relation to the testing surface of the device.

RESEARCH RESULTS

The results of the studies show that the physicomechanical characteristics of the investigated thermoplastic coating systems are superior to those of traditional liquid paint coatings and significantly change depending on the type of film-forming agent and its main characteristics. Thus, the coating based on a liquid epoxy-acrylic system (control composition) is characterized by the following properties: the adhesion by the pull-off method is 6 MPa (Fig. 2), impact resistance is 21 cm/kg (Fig. 3), and wear resistance, measured by the weight loss of the coating, is 79 grams (Fig. 4). Meanwhile, the coating based on a powder nylon system (EL 8061 MD) is characterized by a pull-off adhesion of 8 MPa, which is 33% higher compared to the epoxy-acrylic system, while impact resistance increases by 67%. The wear resistance, measured by the weight loss of the coating, is 34 grams, which is also 134% higher. This may be due to the fact that during the film formation of powder systems under high temperatures, strong interfacial bonds are formed at the film-substrate interface as a result of physical adsorption of macromolecules onto the active sites of the substrate surface from the melt. This, in turn, contributes to achieving high physicomechanical properties of the coating.

Overall, the physico-mechanical characteristics of coatings based on polyolefin film-forming agents are higher compared to the traditional liquid system. However, in comparison with the nylon system, the feasibility of using them changes depending on the main characteristics of the film-forming agent. For example, the use of a low-density polyethylene (LDPE) LD 259 system results in a coating adhesion (8 MPa) comparable to that of the powder nylon system. Additionally, the impact resistance of the coating increases by 9%. However, the hardness of the LDPE LD 259-based coating is 17% lower, and the wear resistance, measured by the weight loss of the coating, is 49 grams, which is 44% lower compared to the nylon system. This effect can be explained by the fact that the film-forming agent in the form of low-density polyethylene has higher melt flow index and viscosity compared to nylon. This, in turn, improves the flow of the film system over the substrate surface during the curing process, enhances the interaction of the polymer's functional groups with the active centers of the substrate, and consequently increases adhesion and impact resistance of the coating. However, the decrease in viscosity and the corresponding increase in the melt flow index of the film-forming agent negatively affects the coating's stiffness, which leads to a deterioration in its hardness and wear resistance.

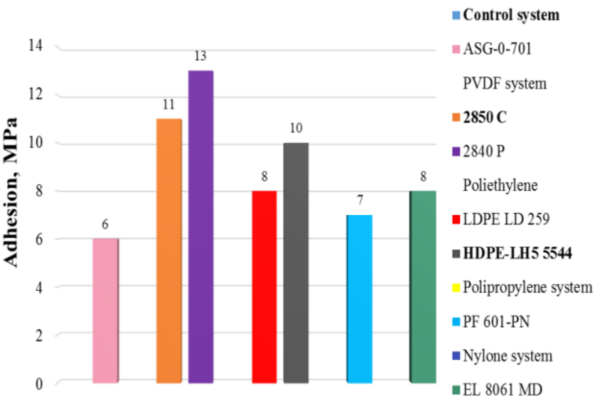

Figure 2. Adhesion of coatings by the peel-off method

The use of high-density polyethylene (HDPE-LH5544) contributes to an increase in coating adhesion up to 10 MPa and provides high impact resistance (45 cm/kg), which is higher compared to the control composition (adhesion – 6 MPa, impact resistance – 21 cm/kg) and the system based on low-density polyethylene (adhesion – 8 MPa, impact resistance – 38 cm/kg). At the same time, the wear resistance of the coating is 50% higher compared to the control system based on traditional liquid coatings, but 6% lower compared to the system based on low-density polyethylene.

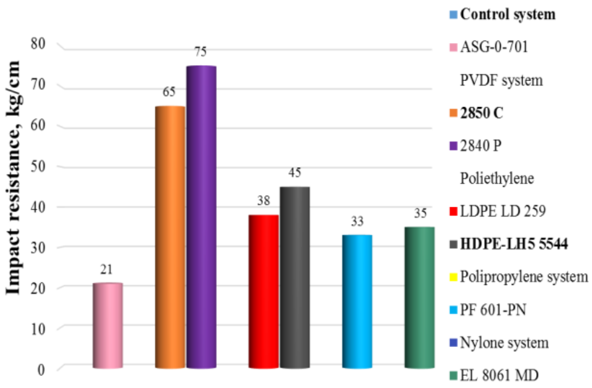

Figure 2. Impact resistance of coating

At the same time, the use of a polyolefin film-forming agent in the form of polypropylene leads to a coating adhesion of 7 MPa, which is 16% higher compared to the control composition, but the lowest among the polyolefin-based systems studied. Meanwhile, the hardness and wear resistance of the coating are significantly higher and reach the level of the nylon-based system – the coating hardness, measured on the Shore scale, is 59 MPa, and the wear resistance, measured by the weight loss of the coating, is 29 grams. This confirms the influence of the characteristics (viscosity and melt flow index) of the film-forming agent on the formation of the physicomechanical properties of the coating – a decrease in the melt flow index of the polyolefin film-forming agent increases the hardness and wear resistance but reduces adhesion and impact resistance of the coating.

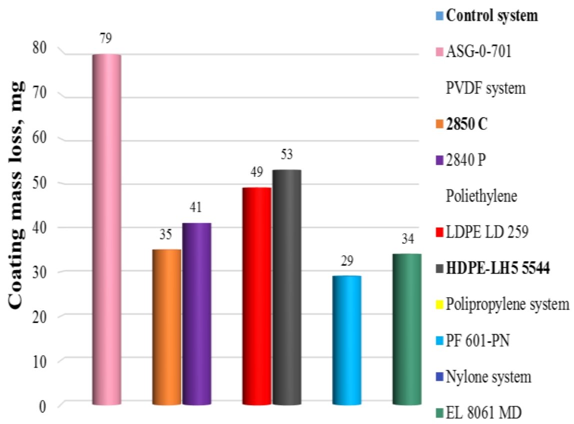

Figure 3. Abrasion resistance of coatings

A similar trend is observed when using a system based on polydifluoride film-forming agents. Thus, the use of polydifluoride 2850 PC (melt flow index – 15 g/10 min, viscosity – 8000 mPa·s) contributes to an increase in coating adhesion (11 MPa) and impact resistance (65 cm/kg), which is 83% and 209% higher, respectively, compared to the traditional liquid system (control composition).

Thus, the research results indicate that the use of powder systems of different chemical nature provides higher physicochemical properties of coatings compared to the traditional system based on liquid epoxy-acrylic resin. This, in turn, justifies considering such systems as an alternative for protecting reinforced concrete structures from mechanical impacts. It has been shown that the change of film-forming agents in powder systems affects the formation of coating properties differently, depending on their type and characteristics (melt flow index, viscosity). To ensure optimal physicochemical properties of the coating, the most effective is the use of a polydifluoride film-forming agent with a melt flow index of 25 g/10 min and dynamic viscosity (Brookfield) of 5000 mPa·s. On the other hand, reducing the melt flow index and increasing the viscosity of the resin negatively affects adhesion and impact strength but contributes to an increase in hardness and wear resistance of the coating.

The results of the corrosion resistance tests (Figures 5 and 6) show that the use of the control composition based on liquid epoxy-acrylic resin leads to the highest delamination value among the studied systems, which is 13.2 mm, as well as an expansion of metal corrosion up to 10.2 mm when exposed to salt fog for 720 hours. The sample studied is characterized by a rust degree of Ri5, which corresponds to a rusted area of 40-48%. Analysis of the obtained results indicates that the anticorrosive coating based on epoxy-acrylic resin corresponds to the corrosion resistance class C1.

The use of polyolefin powder systems significantly reduces coating delamination, rust degree, and the width of metal corrosion compared to the control system. Their effectiveness depends on the molecular weight of the film-forming agent. For instance, the use of systems based on low-density polyethylene in the form of LDPE LD 259 (molecular weight – 50,000 g/mol) results in a delamination width of 6.72 mm and metal corrosion expansion of up to 4.7 mm when exposed to salt fog for 720 hours, which are lower values compared to the control composition. The rust degree of the studied system corresponds to the Ri3 class, indicating a rusted area of 1%. The corrosion resistance category corresponds to class C2 (low) with a high durability class (M) ranging from 7 to 15 years.

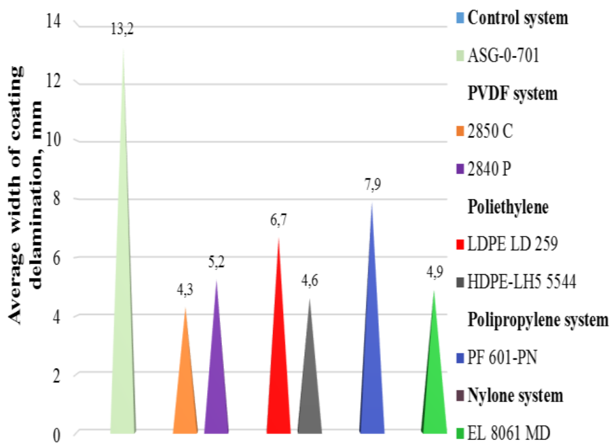

Figure 5. Average width of coating delamination

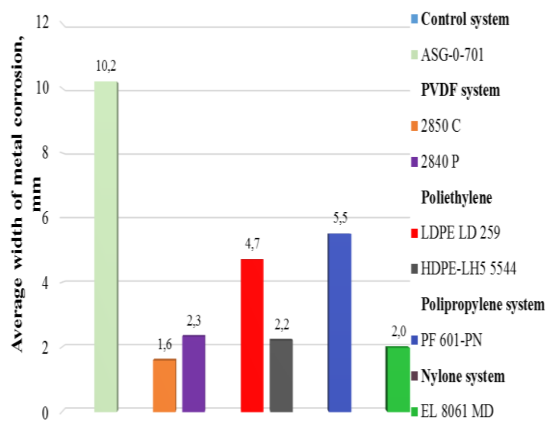

Figure 6. Adhesion of coatings by the peel-off method

A similar pattern is observed when using systems based on polydentofluoride film-forming agents – a decrease in the molecular weight of the film-forming agent leads to a reduction in the corrosion resistance of the coating. For instance, the use of systems based on a polydentofluoride film-forming agent in the form of 2850 PC (40,000 g/mol) results in a delamination width of 4.3 mm and metal corrosion expansion of up to 1.59 mm when exposed to salt fog for 720 hours. The rust degree of the studied system corresponds to class Ri1, indicating a rusted area of 0.05%. The corrosion resistance category corresponds to class C4 (high) with a high durability class (N) ranging from 15 to 25 years.

CONCLUSIONS

The analysis of the research results indicates that, according to the classification of corrosion resistance categories, the use of thermoplastic powder systems provides higher corrosion resistance of the coating compared to the traditional liquid acrylic resin-based system. This, in turn, supports the consideration of such systems as an alternative for the anticorrosion protection of reinforced concrete structures. Specifically, the traditional liquid anticorrosion coating based on alkyd resin corresponds to the corrosion resistance category class C1 and a low durability class (L) of up to 7 years, while the studied powder anticorrosion coatings correspond to the corrosion resistance category class C3…C4 and a durability class (N) of 15 to 25 years.

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Ефективність захисту від корозії залізобетону термопластичними порошковими покриттями

Олесь ЛАСТІВКА

Анотація. В сучасних умовах будівництва проявляється стійка тенденція підвищення ступеню корозійної агресивності з негативною дією на надійність і довговічність будівель та споруд. Досягнення їх ефективного захисту від корозії при комплексній дії низки руйнівних впливів навколишнього середовища з урахуванням норм законодавства про охорону довкілля, економічних та технологічних аспектів сталого розвитку, обумовлює спрямованість наукових досліджень в напрямку використання новітніх, довговічних захисних покриттів серед яких одне з провідних місць займають полімерні композиції. При створенні таких матеріалів ключовою ознакою є забезпечення довготривалого збереження експлуатаційних характеристик будівельних виробів і конструкції з впровадженням екологічно-безпечних та економічних технологій їх виробництва. Традиційним способом захисту будівельних виробів та конструкцій від корозії є нанесення на їх поверхню рідких лакофарбових матеріалів на органічній основі, недоліком яких є вміст у їхньому складі розчинників, що неминуче призводить до їх емісії при виробництві та нанесенні, з відповідним катастрофічним впливом на екологію довкілля. У зв'язку з посиленням вимог щодо охорони здоров'я та безпеки навколишнього середовища в індустрії промислового оздоблення, екологічні аспекти виробництва і використання лакофарбових матеріалів, особливо стосовно вмісту летких органічних сполук (ЛОС), важких металів та інших шкідливих речовин, набувають першочергового значення. Це підкреслює розширення наукових досліджень у розробці захисних термопластичних покриттів, які відповідають подвійним вимогам: екологічності та довговічності.

Ключові слова: залізобетон, термопластичні порошкові покриття, полівініліденфторид, корозійна стійкість, ефективність.