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Selection and justification of protective coating systems for the protection of carbon steel pipe markings

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Вибір та обґрунтування комплексних лакофарбових покриттів для захисту маркування труб вуглецевого сортаменту

Abstract. Objective. *This study investigates the corrosion resistance of a complex paint-and-varnish coating applied to protect markings on pre-painted pipes. The aim is to select the optimal coating material for the corrosion protection of pre-painted and pre-marked pipes.* ***Methods.*** *The subject of the study is a set of paint-and-varnish materials applied to carbon steel pipes to protect their markings. Standard methods were used to assess the coatings' corrosion resistance, adhesion to the pipe surface, and abrasion resistance.* ***Results.*** *It was found that F410SP, SIGMAFAST 40, Alpina Yachtlack, Helios MIKS, and SK-1 possess the required corrosion resistance and adhesive strength for use as protective coatings for carbon pipe markings. Considering material consumption and drying time, Helios MIKS and SK-1 are recommended for industrial application.* ***Scientific novelty.*** *This study is the first to examine the effectiveness of transparent paint-and-varnish coatings for the anti-corrosion and mechanical protection of carbon pipe markings. These coatings provide long-term durability, legibility, and preservation of the markings during transportation, storage, and operation under harsh conditions, while also withstanding high temperatures, humidity, and UV exposure. When other marking methods are not feasible, the optimal selection of protective coating properties is essential to ensure the integrity of the surface layer without creating stress concentration zones or corrosion-prone areas.* ***Practical significance.*** *The study provides objective data on the potential for industrial use of paint-and-varnish materials available on the Ukrainian market to protect markings on carbon pipes.*
Key words: *carbon pipes, paint-and-varnish coatings, corrosion protection, adhesion, mechanical durability.*

Анотація. Мета роботи. *Дослідження корозійної стійкості комплексного лакофарбового покриття яке наноситься для захисту маркування попередньо пофарбованих труб. Завданням проведених досліджень є вибір оптимального лакофарбового матеріалу для антикорозійного захисту попередньо пофарбованих та замаркованих труб.* ***Методика.*** *Об'єктом дослідження є лакофарбові матеріали, які наносяться на вуглецеві труби для захисту маркування. Стандартними методами досліджена захисна дія таких покриттів проти корозійного руйнування, адгезія покриття до поверхні труби, стійкість до стирання.* ***Результати.*** *Встановлено, що матеріали F410SP, SIGMAFAST 40, Alpina Yachtlack, Хеліос MIKS та СК-1 мають необхідну корозійну стійкість та адгезійну міцність для використання в якості захисних покриттів маркування вуглецевих труб. З врахуванням витрат матеріалу та часу висихання для промислового застосування рекомендований матеріал Хеліос MIKS та СК-1.* ***Наукова новизна****. Вперше досліджено ефективність застосування прозорих лакофарбових матеріалів для антикорозійного та механічного захисту маркування вуглецевих труб, які забезпечують довговічність, зчитуванність та його збереження під час транспортування, зберігання та експлуатації трую у складних умовах, також витримують високу температуру, вологість та ультрафіолет. При неможливості маркування вуглецевих труб іншим шляхом, необхідно здійснювати оптимальний вибір властивостей захисного лакофарбового покриття, який забезпечує цілісність поверхневого шару, не створює зон концентрації напруги або осередків корозії.* ***Практична значущість.*** *Полягає в отриманні об'єктивних даних про можливість промислового застосування лакофарбових матеріалів, наявних на ринку України, для захисту маркування вуглецевих труб.*
Ключові слова*: вуглецеві труби, лакофарбові матеріали, антикорозійний захист, адгезія, механічна стійкість.*

Introduction

Metal corrosion is one of the most pressing problems in modern materials science and industry. According to international studies, annual losses from corrosion processes amount to several percent of global GDP, directly affecting enterprises' economies and the reliability of infrastructure. Pipe manufacturers face this challenge particularly acutely, as corrosion damage not only reduces the service life of products but also complicates their identification during transportation and operation.

Pipe marking is not merely a technical label. It is an integral element of the quality control and traceability system, determining the ability to promptly track the origin, characteristics, and compliance of products with standards. The loss of markings due to corrosion or mechanical damage can lead to significant financial and operational risks: from warehouse confusion to rejection of products by customers.

For this reason, the protection of markings should be considered a critically important task. The most promising method is the application of transparent paint and varnish material (PVM), which combine anti-

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corrosion effects with the preservation of clarity and readability of the inscriptions. However, the effectiveness of such coatings depends on a whole range of factors: the chemical composition of the PVM, application technology, coating thickness, interlayer adhesion, and resistance to aggressive environments.

Therefore, the scientifically justified selection of optimal paint-and-varnish materials for creating multilayer protective coatings on marked pipes is an urgent task. Such coatings ensure durability and the preservation of information under challenging conditions of storage, transportation, and operation.

Literature Review and Problem Statement

Marking of pipe products, applied either before or after painting, is a critical component for identification, quality control, and operational safety. However, the marking inscriptions or symbols—especially colored paints or inks—often become the "weak link" because they are exposed to external influences (moisture, UV radiation, temperature changes, corrosive agents) [1]. To safeguard the marking, a transparent paint and varnish material (PVM) is typically applied over it, forming a multilayer protective system: base paint coating → marking paint/ink → transparent varnish [2].

Within such a system there exist critical interactions:

Metal − paint: adhesion to the metal substrate; reaction of the metal with paint components or solvents;

Paint − ink: compatibility of polymeric or pigment systems; ability of the ink to "penetrate" into or adhere onto the paint or surface; formation of a defect-free interface;

Paint/ink − varnish: adhesion, inter-layer reactions, varnish permeability;

Internal structure of the coating itself: pores, microcracks, uneven thickness, which can allow moisture, oxygen, chloride ions, etc., to reach the metal and cause localized corrosion [3,4].

Effective protection requires several conditions: high interlayer adhesion to avoid delamination under humidity, thermal cycling, or mechanical stress [5]; absence of chemical interactions among components that could impair transparency, alter the marking, or reduce protective ability [6]; compactness of the material with no through-pores or microcracks [7]; and an optimal thickness of surface and intermediate layers. Very thin coatings are often ineffective, since even without visible defects diffusion of aggressive species can lead to under-film corrosion [8], while excessively thick coatings may be uneconomical and reduce adhesion strength due to internal stresses, thermal expansion mismatch, poor curing or shrinkage, and crack formation under stress [9].

The literature demonstrates considerable variation in defining the "optimal" PVM thickness—ranging from about 20 µm to more than 100 µm—depending on coating composition, layer structure, substrate, and service environment [1,2,7]. This indicates the absence of a universal standard. Instead, thickness is determined by the chemical composition of paints, varnishes, and inks; the method of application (spraying, dipping, rolling, electrophoretic deposition, etc.) [4,10-11]; and service conditions such as temperature, humidity, environmental aggressiveness (salts, chlorides, acidity), mechanical loading, and UV exposure [3,6].

The problem addressed in this study is therefore the determination and justification of the composition of a multilayer protective paint and varnish coating, its thickness, and the interactions among its layers, which together would ensure reliable protection of marking at minimal cost, particularly for pre-painted pipes.

Materials and Research Methods

As samples for the research, pipe sections made of carbon steel pipe with a diameter of 177.8 mm were used. The length of the pipe sections was 300 mm.

The preparation of the pipe section surface before applying coating materials was carried out according to the requirements of TI HT – 32 – 2022. The surface was first visually inspected. If residues of lubricants, dust, dirt, or loose scale were present, they were removed with a dry cloth. After mechanical contaminants were removed, the surface was degreased with "solvent 646". Coating materials were then applied to the dried surface.

Painting of the prepared sample surfaces was performed with a brush in a single pass using the alkyd primer-enamel Magnum 120W (black color), which is most commonly used for this purpose at pipe plants in Ukraine. After the complete drying of the primer-enamel, the EBS marking was applied. On top of the dried EBS, transparent protective coatings were applied with a brush in a single pass; their names and purposes are given in Table 1. The appearance of the prepared samples is shown in Fig. 1.

Figure 1 – Appearance of the samples prepared for research

Table 1 – General information about transparent coating materials

No.	PVM	Description
1	Protective compound SK-1 transparent	Transparent varnish for creating a durable protective coating, intended for the temporary protection of metal pipe surfaces from corrosion during short-term storage and transportation.
2	Finish alkyd glossy enamel F410SP	Intended for the temporary protection of metal surfaces of pipes, wire, constructions, and other products from corrosion during their long-term storage and transportation.
3	Transparent varnish Helios MIKS	Acrylic solvent-based varnish for decorative protection of mineral surfaces with a “wet stone” effect. Designed to create a protective and decorative coating with a “wet stone” effect.
4	Finish coating SIGMAFAST 40	Thick-layer coating based on modified alkyd resins. Suitable for protection against atmospheric exposure, fast-drying, and retains gloss and color well. Does not contain lead or chromate compounds.
5	Alkyd-urethane varnish Alpina Yachtlack	Weather-resistant, transparent varnish for coating boats, yachts, and other vessels operating in fresh and seawater, free of aromatic hydrocarbons.

Using the prepared samples, the following parameters were determined:

the actual consumption of coating material during application;

drying time to tack-free and to full cure according to DSTU ISO 9117-1:2015;

appearance of the coating surface according to DSTU ISO 4628-1:2015;

appearance of the marking, which must comply with TI NT-32-2022. The marking must be legible, clear, contrasting, and resistant to abrasion;

resistance of the marking ink to abrasion. The method consists in measuring the length of the abraded area under the action of a weight wrapped in cotton fabric, moved along the sample;

average coating thickness. This was evaluated the day after painting, based on the mass of the applied coating material and the coated surface area;

adhesion (after full polymerization of the coating in 24 hours) according to DSTU ISO 2409:2015 by the cross-cut method;

corrosion resistance under the influence of climatic factors in a salt spray chamber according to DSTU ISO 9227:2015. The degree of corrosion damage was evaluated according to SOU MPP 25.220-281-1:2009.

Research Results

The results of the studies of transparent coating materials for the markings protection are presented in Table 2. In the same table, for evaluating the effectiveness of the third coating layer, the test data of the painted and marked pipe surface (without the applied protective layer) are also provided.

Table 2 – Results of conducted studies of transparent coatings (LCM) for marking protection

No.	Name of LCM	Coating consumption, g/m²	Dry-to-touch time, min, at 6 °C	Full drying, min, at 6 °C	Mark readability after application	Mark clarity	Adhesion to substrate, grade	Abrasion after 450 cycles, %	Area of corrosion damage on pipe surface with marking and substrate after 24 h, %	Area of corrosion damage on pipe surface with marking and substrate after 120 h, %
0	Sample without protective LCM for marking	–	–	–	Readable	Clear	0	80	0	95
1	Protective compound SK-1 transparent	98.75	7	14	Readable	Clear	1	10	0	8–20
2	Finish alkyd glossy enamel F410SP	275.86	46	89	Readable	Clear	1	10	0	15–20
3	Transparent varnish Helius MIKS	44.79	12	25	Readable	Clear	0	10	0	20–25
4	Finish coating SIGMAFAST 40	304.35	67	104	Readable	Clear	1	10	0	20–25
5	Alkyd-urethane varnish Alpina Yachtlack	108.7	156	1440	Readable	Clear	1	10	0	15

Discussion of Results

The analysis of the data presented in Table 2 should be carried out with consideration of both the technological and service properties of the investigated materials.

An important technological parameter of paint and varnish materials (PVM) is drying time. This parameter is primarily critical in terms of workshop productivity. The obtained data show that drying times of the studied PVMs differ significantly. For example, complete drying of the preservative composition SK-1 occurs within 14 minutes (at 6 ℃), whereas polymerization of the alkyd–urethane varnish Alpina Yachtlack takes 1440 minutes. This difference is explained by the different compositions of the binders and solvents used in these materials. PVMs numbered 2–4 also exhibit variation in both tack-free and full drying times. This may be related to differences in solvent volatility as well as the thickness of the applied coating layer. From the standpoint of ensuring high productivity in the PVM application section of the pipe workshop, the preservative composition SK-1 demonstrates the most favorable performance. In all cases, once the protective film had dried, the markings remained clear and easily readable.

Another important characteristic of protective PVMs is the abrasion resistance of the marking. All tested materials reliably protect the markings from mechanical damage during loading, transportation, and similar operations.

One of the key service properties is coating adhesion to the substrate. Data from Table 2 confirm that coating adhesion to the substrate meets the standard (0–1 grade) in all cases. Thus, the composition “primer-enamel Magnum 120W – ink EBS – transparent PVM” provides sufficiently reliable adhesion to the substrate. It may be stated that the protective ability of the obtained complex coatings depends on their capillary and diffusion permeability, as well as the presence of macroscopic defects. Clearly, such defects adversely affect the protective properties of the PVM. The investigation of the selected materials demonstrated that all of them provide approximately the same anticorrosive protective ability.

It was established that after 24 hours of testing in a salt spray chamber, no corrosion damage of the pipe metal was observed with any of the varnishes. After 120 hours of exposure, the degree of surface damage in the marked pipe sections ranged from 8% to 25%, which is considerably lower compared to unprotected markings. Given the severity of the test conditions, such results are considered positive for all investigated materials.

At the same time, when selecting a material, it is necessary to account for its processability and specific consumption. Taking the lowest material consumption of 44.79 g/m² (for transparent varnish Helios MIKS) as the baseline, the consumptions for materials No. 1, 2, 4, and 5 are higher by factors of 2.2, 6.1, 6.7, and 2.4, respectively. Considering these results and the relatively similar market prices of the materials in Ukraine, the use of transparent varnish Helios MIKS appears most appropriate, though the preservative composition SK-1 and alkyd–urethane varnish Alpina Yachtlack may also be applied. However, given the significantly longer polymerization time of the latter, the final recommendation for the protection of carbon steel pipe markings is to use transparent varnish Helios MIKS and preservative composition SK-1.

Conclusions

1. It has been established that the application of transparent paint-and-varnish materials significantly enhances the corrosion resistance of the complex coating system on carbon steel pipes, which includes the base coating Magnum 120W, EBS marking, and a protective varnish layer. This confirms the critical role of transparent LCM in preserving the integrity and functionality of pipe markings.
2. The study demonstrated that all examined transparent materials (SK-1, F410SP, Helios MIKS, SIGMAFAST 40, Alpina Yachtlack) reduce the level of corrosion damage and ensure the mechanical durability of markings compared to unprotected surfaces. However, their effectiveness varies in terms of technological parameters and economic feasibility.
3. From the standpoint of industrial applicability, the most optimal materials are Helios MIKS transparent varnish and SK-1 preservative compound, which combine satisfactory anti-corrosion properties with low material consumption and acceptable drying times. These materials are therefore recommended for industrial use to protect markings on carbon steel pipes.

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