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COMPARATIVE ANALYSIS OF THE QUALITY PROPERTIES OF OIL-BASED AND ALKYD COATING MATERIALS FOR WOOD

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ABSTRACT

A comparative analysis of the quality properties of coating materials based on linseed oil and alkyd film formers is provided in the paper. The advantages and disadvantages of linseed oil-based and alkyd-based coating materials are explored. Protective materials such as alkyd coating material for wood and drying linseed oil were applied on the compared pine-wood samples. The authors determined the drying time of linseed oil and alkyd coating materials on pine wood, the thickness of the dry film, heat resistance, lightfastness, as well as water resistance of protective and decorative coatings. Linseed oil-based coating materials form thin-layer coatings on the surface of wood, unlike coatings based on alkyd materials. Alkyd coating materials transitioned into a solid state faster than the linseed oil-based ones. Coatings based on linseed oil have a higher moisture resistance. Higher indicators of heat resistance were observed in coatings based on linseed oil materials.

Keywords: wood surface finishing, linseed drying oil, alkyd coating material, film thickness, heat resistance, lightfastness, water resistance.

INTRODUCTION

Despite the fact that a large number of new construction technologies have appeared in the world, timber structures have not lost their relevance and attractiveness. In this regard, the demand for wood materials and, accordingly, for materials that provide protection for wood, has increased. In order to achieve the best result in the construction of timber structures, in addition to strict adherence to the instructions and home construction technology, it is necessary to use high-quality wood. The service life of wood used in constructions and the maintenance of its natural appearance can be improved by well-designed construction systems, using more durable tree species and composite materials, and also suitable preservatives and anti-weathering coatings (Pánek and Reinprecht 2014). However, wood is a porous natural anisotropic material that mainly consists of cellulose fibres and a binder that promotes liquid absorption (Prieto and Kiene 2018; Onegin *et al.*, 2006).

One of the most widespread "diseases" of wood is destruction by rotting. It begins with the impact of moisture, temperature, ultraviolet rays, and other factors on wood. Such conditions lead to the growth of spores of fungi and other microorganisms on the surface of the wood or to the complete destruction of the main wood components by decaying fungi (Vidholdová *et al.*, 2022, Reinprecht and Vidholdová 2019, Vidholdová and Reinprecht 2019, Prieto and Kiene 2018, Rybin 2003, Onegin *et al.*, 2006, Tiralová and Reinprecht 2000).

The best way to protect the wood, in addition to antiseptics, is to create a protective and decorative coating on the surface of the wooden product. Finishing with coating materials allows the preservation of wood for a long time. It provides the wood with strength, moisture resistance, fire resistance, and also delivers an aesthetic appearance for an extended time. Vidholdová, and Slabejová (2019) evaluated adhesion on rotten wood and wood attacked by wood-staining fungus. Vidholdová *et al.,* (2017), Slabejová and Vidholdová (2019) determined whether there is a significant change in colour and roughness at pine wood surfaces exposed outdoors under winter conditions. The overlap of colour changes and the stability (adhesion) of alkyd-based systems and oil-based surface treatments were studied if applied to pre-weathered surfaces.

In order to create a high-quality and long-lasting coating, it is necessary to approach the selection of coating materials in a technically competent manner, taking into account the peculiarities of the product's operation, as well as the development of technological regimes and the organisation of the technological process of creating a protective and decorative coating. Drying time (film formation) is an exceptionally important indicator of the quality characteristics of coating materials (Arminger *et al.,* 2020, Brock *et al.,* 2014, Yaremchuk and Hmaryk 2012).

Currently, manufacturers of coating products offer a wide range of coating materials for timber structures that meet the requirements for quality of coatings and fungal resistance, too. Reinprecht *et al.,* (2019) evaluated the anti-decay potential of five essential oils against wood-decaying fungi. Vidholdová and Slabejová (2018) evaluated the environmental requirements of selected transparent wood coatings from the view of fungal resistance. However, in the present protection and finishing of timber structures, the main emphasis is placed not only on the high quality and availability of coating materials, but also on environmentally safe products. The research and development of effective and safe wood surface coatings with minimal use of harmful chemicals has become very important (Miklečić *et al.,* 2017).

It is known that the most common materials for creating protective and decorative coatings on the timber structures are coating materials based on drying oils and alkyd resins. However, the use of oil-based materials for furnishing wood, and especially carpentry and building constructions, has a number of advantages: protection against blue mould and other fungi, protection of wooden structures from beetles, bark beetles, and other pests, protection from ultraviolet rays, high adhesive strength, resistance to changes in weather conditions, temperature, and condensation (Yaremchuk *et al.,* 2011). At the same time, the consumption of linseed oil is less than that of synthetic coating materials. These materials have protective properties that ensure high-quality operational properties of coatings in conditions of increased atmospheric load (Perdoch *et al*., 2022, Jebrane *et al*., 2017).

Alkyd coating materials are also very popular for finishing processes in carpentry and structures. Enamels were the most commonly used alkyd materials, especially in the creation of pigmented coatings. This is caused by the simple conditions of applying coating material, low cost, a wide range of colours, and the variety and availability of finishing materials on the market (Prieto and Kiene 2018, Lambourne and Strivens 2000, Rybin 2003). These materials have protective properties that ensure high-quality operational properties of coatings in conditions of increased atmospheric load. However, more research need to be done on which of the above materials has the best operational properties in terms of protective and decorative coatings on timber structures. Such studies enable better decision-making with the better choice of coating materials in timber construction.

The aim of this study was to establish the influence of consumption of alkyd-based and linseed oil-based coatings on drying time, the thickness of the film, heat resistance, lightfastness, and water resistance of surface-finished pine wood.

MATERIAL AND METHODS

Experimental studies were carried out according to the State Standard of Ukraine (DSTU), or according to established methods, which are necessary for conducting planned experiments. In order to achieve the study aims, a number of research experiments that provide performance characteristics of coatings for timber structures were completed and are described in Karyakina (1988).

The following materials were used for research:

- background material – heart wood of pine (*Pinus sylvestris* L.) samples (size 100 mm × 100 mm × 8 mm);
- representative types of coating material drying linseed oil-based for wood – Technical Specifications of Ukraine: DSTU ISO 150-2002;
- representative types of alkyd-based coating material for wood – Technical Specifications of Ukraine: TU U 24.3-21649420.035-2002;
- solvent / diluent – white spirit (TU U 20.3-378168244-002:2014);
- sanding paper (DSTU 6456-82).

The sanding of pine wood surface and surface finishes with linseed oil-based and alkyd-based products were made according to the recommendations listed in technical sheets.

The experimental studies were conducted to check the qualitative characteristics of coatings according to the following standards:

- DSTU ISO 9117-1:2009 Paints and varnishes. Control of drying. The measurement of the drying time of the coatings was carried out with a change in varnish and paint material consumption of 80, 100, and 120 g/m^2 and a change in drying temperature of 20, 50, and 80 °C. The measurement of the drying time of the coatings was carried out on samples of pine heartwood. Protective linseed oil and alkyd coating materials were applied to the surfaces of samples. In order to ensure sufficient accuracy of the test results, at least five experiments were conducted for each indicator, after which the average value was computed.
- DSTU ISO 2808:2019 Paints and varnishes. Determination of film thickness. The thickness of the films was determined using a MIC-11 instrument microscope. The measurement of the thickness of the coatings was carried out with a change in varnish and paint material consumption of 80, 100, and 120 g/m^2 and a change in drying temperature of 20, 50, and 80 °C. To create coating films, accelerated drying was used. The film thickness values were measured at the 10 positions given on each of the tested samples.
- DSTU ISO 2810:2020 Paints and varnishes. Testing of coatings on the influence of atmospheric conditions. The paint materials were tested for resistance to temperature, lightfastness, and moisture. The lightfastness of the coatings was studied when they were exposed to ultraviolet (UV) rays under a PRK-375 lamp, according to the methodology of this standard. The change in gloss was measured by a photoelectric gloss meter (FB-2). The colour change was assessed visually. Five experiments were conducted for each indicator, after which the average value was computed.

Statistical analyses were performed with the help of MS Excel 2016, using the mean value - average (Avg.) and standard deviation (SD).

RESULTS AND DISCUSSION

The results obtained from the drying time of the coatings are listed in Table 1. Research on the drying time of coating materials on samples made of pine wood showed that alkyd-based coating materials transition into a solid state is faster compared to the linseed oil-based ones. This is due to the fact that the bases of alkyd coating materials are polyester resins, and oily materials are included in their composition as modifiers. However, it should be noted that the difference in the drying time of alkyd-based and linseed oil-based coatings is significant, especially with forced drying of films under hot-air drying processes (50 °C and 80 °C) compared to air drying process at 20 °C. However, it should be noted that the difference in the drying time of coating of alkyd-based and linseed oil-based is insignificant, especially with forced drying of films (at 50 °C). Linseed oil-based coating materials penetrate deep into the pores of wood, leaving a thin film on the surface. It is important to note that the protective and decorative films created on the surface of pine wood changed the colour of the coating to a yellowish tint with linseed oil-based material application and a yellow-brown one with alkyd-based material. The intensity of the colour changes depends on the temperature during the drying of the coatings. Perdoch *et al*., (2022) found that the linseed oil on pine wood application caused a colour change visible to the naked eye in each case. The observation of the b monochromatic component that demonstrates the yellowing of the sample seems to be particularly significant.

Due to the fact that timber structures are operated in conditions of increased atmospheric exposure, where environmental factors affect the coating material, the thickness of the protective and decorative film is an important indicator of quality. Therefore, it was appropriate to investigate the thickness of the protective and decorative coating created on the surface of pine wood with linseed oil-based and alkyd-based coating materials (Karyakina 1988, Yaremchuk 2011).

Tab. 1 Drying time of the coating depending on temperature and material consumption.

Type of coating material	Temperature (°C)	Coating material consumption (g/m^2)	Drying time (min)
			Avg. (SD)
Linseed oil-based	20	80	1381 (7.7)
		100	1426 (10.9)
		120	1489 (8.1)
	50	80	50 (2.3)
		100	54 (3.5)
		120	69 (3.6)
	80	80	58 (2.5)
		100	60 (2.4)
		120	64 (3.7)
Alkyd-based	20	80	1320 (8.8)
		100	1370 (10.6)
		120	1390 (9.9)
	50	80	40 (2.2)
		100	45 (2.9)
		120	50 (3.8)
	80	80	37 (2.3)
		100	43 (2.7)
		120	49 (3.5)

Note: Individual mean value – average (Avg.) and standard deviation (SD) were determined from 5 values.

The obtained film thickness values are listed in Table 2. After the analysis of the studies conducted on the thickness of protective and decorative coatings created with alkyd-based and linseed oil-based materials, it is possible to conclude that the thickness of the film varies significantly depending on the drying temperature. Although an increase in the drying temperature of the linseed oil-based coating material applications corresponds to a slight decrease in the thickness of the coating, this indicates that with an increase in temperature (before the coating materials transition into a gel state), the viscosity of the material decreases, and accordingly, its permeability into the pores of wood increases.

Alkyd coating materials form a thicker film compared to oils, which confirms the previous conclusions, however, alkyd-based coating materials have a modified polyester resin in their composition, which does not penetrate as deeply into the wood pores as oil-based coating materials. Providing long-term protection for wooden structures against the effects of high humidity, sunlight, and temperature changes requires the use of high-quality finishing materials. The study of the resistance of coatings to the influence of atmospheric conditions is a very important and relevant task (Karyakina 1988, Lambourne and Strivens 2000).

Tab. 2 Thickness of the coating film on pine wood.

Drying temperature (°C)	Coating material consumption (g/m^2)	Film thickness (μm)	
		Linseed oil-based	Alkyd-based
		Avg. (SD)	Avg. (SD)
20	80	38 (7.7)	44 (6.4)
	100	44 (8.9)	53 (8.7)
	120	53 (10.8)	68 (8.1)
50	80	37 (8.8)	46 (5.2)
	100	42 (7.6)	56 (6.9)
	120	56 (11.4)	70 (9.3)
80	80	34 (6.9)	44 (7.9)
	100	40 (8.5)	56 (8.4)
	120	51 (9.2)	71 (9.1)

Note: Individual mean value – average (Avg.) and standard deviation (SD) were determined from 30 values.

Coatings based on linseed oil and alkyd materials were tested for resistance to temperature, lightfastness, and moisture. The temperature resistance, lightfastness, and moisture resistance of protective and decorative coating films were determined according to the methodology described in the standard DSTU ISO 2810:2020. The data obtained from the experiment are shown in Tables 3 to 5.

Tab. 3 Temperature resistance of the coating film on pine wood.

Type of coating material	Coating material consumption (g/m^2)	The temperature limit of the coating stability (°C) Avg. (SD)
Linseed oil-based	80	85 (0.3)
	100	85 (0.2)
	120	83 (0.4)
Alkyd-based	80	70 (0.2)
	100	65 (0.1)
	120	65 (0.3)

Note: Individual mean value – average (Avg.) and standard deviation (SD) were determined from 5 values.

Protective-decorative coating films formed on pine wood, made of alkyd and oil-based coating materials, showed sufficiently high resistance to temperature. Higher indicators of

heat resistance were observed in coatings based on linseed oil. This may be due to the fact that linseed oil-based coatings have a lower film thickness compared to alkyd-based coatings. According to the research results, the coating material consumption does not significantly affect the heat resistance of the film.
To establish the light resistance of protective and decorative films, the degree of loss in glossiness and colour change of the coatings was determined as gloss units (GU). Linseed oil-based and alkyd-based coating materials applied to pine wood samples were tested with material consumptions of 80, 100, and 120 g/m^2. The results of lightfastness experiments are listed in Table 4.

The obtained results of lightfastness studies confirm the high lightfastness of finishing materials proposed for the creation of protective and decorative coatings of pine wood for building structures. However, linseed oil-based materials showed higher lightfastness than alkyd-based materials. According to the performed research experiments, the colour of the protective and decorative coatings slightly changed after UV-irradiation. This may indicate that pine wood is not light-resistant and darkens under the influence of sunlight. Vidholdová *et al.*, (2017) confirm the darkening was from 17% up to 25%. Findings in this work agree with those reported by Rüther and Jelle (2013) and Oberhofnerová and Pánek (2016).

Tab. 4 Resistance of the coating film to the UV irradiation impact.

Type of coating material	Coating material consumption (g/m^2)	Duration of irradiation (min)	Glossiness (GU) Avg. (SD)	Visual colour change
Baseline (initial data)	80, 100, 120	0	35	Golden
Linseed oil	80	40	35 (0.4)	No change
	100	40	35 (0.2)	No change
	120	40	35 (0.3)	Slight darkening
Baseline (initial data)	80, 100, 120	0	46	Yellow-brown
Alkyd	80	40	46 (0.2)	No change
	100	40	46 (0.3)	Slight changes
	120	40	44 (0.1)	Slight darkening

Note: Individual mean value – average (Avg.) and standard deviation (SD) were determined from 5 values.

One of the factors that ensure the performance properties of products and coatings is their resistance to water and high relative humidity. Since the external walls of timber structures are under the constant influence of harsh weather conditions, the determination of such an indicator as water resistance is very important when studying the quality characteristics of coating materials.

Tab. 5 Water resistance of the coating film on pine wood.

Type of coating material	Coating material consumption (g/m^2)	Duration of exposure of samples in water (h)	Glossiness (GU) Avg. (SD)	Surface destruction (visually observed)
Baseline (initial data)	80, 100, 120	0	35	Smooth and even surface
Linseed oil-based	80	24	32 (0.6)	No change
	100	24	35 (0.4)	No change
	120	24	35 (0.3)	No change
Baseline (initial data)	80, 100, 120	0	46	Smooth and even surface
Alkyd- based	80	24	40 (0.4)	Slight cloudiness, small seeds/specks
	100	24	43 (0.5)	Minor surface changes, single bubbles/blisters
	120	24	44 (0.4)	Slight turbidity

Note: Individual mean value – average (Avg.) and standard deviation (SD) were determined from 5 values.

The results of the water resistance research on protective and decorative coatings showed that coatings based on linseed oil have a higher resistance to the effects of moisture and water. However, as studies have shown, thin-layer films are less moisture-resistant. Thin-layer films lose their lustre due to moisture, and this may indicate the possibility of further destruction of the coating. To ensure higher water resistance of protective and decorative coatings applied to building structures made of pine wood, it is advisable to create films of greater thickness. Studies have shown that the best indicators of the performance characteristics of coatings are achieved at a coating material consumption of 100 g/m^2, which produces films that are more resistant to environmental factors.

Conversely, when applying oil treatment to wood in processes of thermal modification, they found better weathering performance of wood. Also, Nejad *et al.* (2019) investigated the weathering performance of exterior penetrating stains when applied to oil-treated wood. They found better colour stability, an overall better general appearance ranking, and lower moisture uptake in heat-treated woods than coated-untreated wood samples.

CONCLUSION

Research on the performance properties of linseed oil-based and alkyd-based coating materials for finishing timber structures made of pine wood showed that linseed oil-based coating materials form thin-layer coatings on the surface of wood, unlike coatings based on alkyd materials. However, coatings based on linseed oil materials form protective films with higher heat, water, and ultraviolet light resistance. Research on the drying ability of selected coating materials indicated that alkyd-based materials transition into a solid state (form an adhesive film) faster. Nevertheless, the difference in the film formation time of the coating is inconsequential, so the comparative characteristics of these materials are not significantly affected by this indicator.

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