УДК 667.637.4:666.3.135

O. I. Peredriy, Cand. Sci. (Tech.), Assoc. Prof.,
O. V. Pakholyuk, Cand. Sci. (Tech.), Assoc. Prof.

Lutsk National Technical University, Lutsk, Ukraine, e-mail: tov_visnik@mail.ru

RESEARCH OF HYDROPHYSICAL PROPERTIES OF COATINGS BASED ON FULL ALUMINOSILOXANE POLYMER

О. І. Передрій, канд. техн. наук, доц.,
О. В. Пахолюк, канд. техн. наук, доц.

Луцький національний технічний університет, м. Луцьк, Україна, e-mail: tov_visnik@mail.ru

ДОСЛІДЖЕННЯ ГІДРОФІЗИЧНИХ ВЛАСТИВОСТЕЙ ЗАХИСНИХ ПОКРИТТІВ НА ОСНОВІ НАПОВНЕНИХ ПОЛІАЛЮМОСИЛОКСАНІВ

Purpose. Determination of the indexes of outdoor resistance and water absorption for new protective coatings based on the aluminosiloxane polymer and the influence of the original composition on the physical properties of the coatings.

Methodology. During the research, we used methods that allow examining of the physical and mechanical properties of protective coatings and meet the national standards. Hydrophobic properties of the coating are characterized by the degree of wetting of the surface of coating material, which was evaluated by limiting wetting angle on phase boundary by the method of selective moistening.

Findings. It was proved that the aluminosiloxane polymercoatings have high insulating and protective properties, as the limiting wetting angle was more than 90 degrees for all compositions. Thewater absorption of the coated surface of steel equals 0.18–0.58, and in case of concrete,0.29–0.92 wt.%. The partial destruction of the coating appears at negative and alternating temperatures due to corrosion processes in the surface layers of the coating. The limiting wetting angle diminishes by 4–13 degrees for steel and 10–18 degrees for concrete. It was determined that the aluminosiloxane polymer-based coatings are characterized by high indexes of physical properties (outdoor resistance, water absorption) and sufficient temperature and fire resistance.

Originality. The influence of the full aluminosiloxane polymer-based coatings initial composition on the resistance to corrosion and outdoor stability.

Practical value. The suggested protective coating based on full aluminosiloxane polymer can be used in various industries. The role of oxide and silicate fillers in the protective coatings was evaluated to provide the task-oriented control over the performance properties of the coatings in a wide range of temperature.

Keywords: *coating, polyorganosiloxanes, protective efficiency, corrosion resistance, weather resistance, hydrophobicity, water absorption, limiting wetting angle*

Introduction. A promising way to protect building constructions of industrial objects from the action of aggressive factors is coating their surfaces with coatings that have to work durably and reliably under conditions of sharp fluctuation of temperatures. Building structures are protected with different coatings, which due to high attribute do not only increase the term of exploitation, but also provide the necessary complex of valuable physical, mechanical and chemical properties while adjusting the phase composition and structure as a whole.

One of the most effective protections is coating based on organic silicate materials which are products of chemical interaction of silicon connections, silicates and refractory oxides. Quite economical methods of preparing of initial compositions of organic silicate coating through mechanic-chemical dispersion of the filler in an environment of silicon-organic film-forming agent and putting them on paint technology create significant advantages over other types of coatings.

The lack of comprehensive data on physical and chemical processes that occur in the coatings affected by atmospheric factors does not give possibility to regulate their operating properties directionally.

Analysis of the recent research. The selection of constructional materials which operate being exposed to high temperatures and fire depends on the term and conditions of exploitation. Choosing coating composition, it is necessary to take into consideration not only the fire and heat resistance, but also weather resistance of finished coatings. The resistance of the coating to external factors can be increased by forming the corresponding phase composition and structure [1, 2], and by adjusting the coating of barrier type, which makes it almost impossible for oxygen to access the surface of the material [3, 4].

Technical and technical-economical properties of silicon coatings are predefined by thermodynamic stability of siloxane connection (Si—O). To protect metal constructions, polyorganosiloxanes are used. They combine thermal stability and chemical inertness of silicon-oxygen frame with high physical and mechanical properties [3, 5].

Thermal properties of protective coatings have been investigated fully enough and diversely. However, by compounding the coating with additional ingredients it is possible to not only increase the indicated properties, but to enhance weather resistance of coatings as well, which will increase their durability and reliability considerably. Therefore, there is a necessity for the quantitative estimation of protective coating resistance to weather factors.

Thus, the article aims at solving this particular problem, which has not been studied sufficiently.

Objectives of the article. The purpose of this article is to study hydrophobic properties of protective coatings based on full aluminosiloxane polymers.

The objects of research. The object of the research involves compositions for protective coatings based on *aluminosiloxane* lacquer KO-978 with fillers (aluminium, zirconium (IV) oxides), kaolin, kaolin fibre and mineraliser (titanium (IV) oxide).The research of coatings was conducted on structural rimming steel (St3kp) and concrete linings. The physical and chemical methods of experimental research studies were used: X-ray analysis, chemical analysis, electronic-microscopic and electronic-graphical researches of the structures of coatings.

The main research and explanation of scientific results. As it is well known, durability and service ability of building materials and constructions are determined primarily by working temperature condition and resistance of protective coating to the effect of unfavourable weather conditions.

Under real-life conditions of exploitation, materials and wares are exposed to integrated effect of atmospheric actions, the accumulation of which increases corrosion greatly. This fact conditions necessity of quantitative assessment of protective coating resistance to atmospheric factors.

Weatherablity of coatings depends on the composition spread over the materials protected, on the method of their application, on temperature of hardening etc. The proposed compositions of protective coatings (Table 1) were applied to the pre-treated surfaces with a layer thickness of 0.4–0.6 mm. Solidification of the coating occurred at room temperature during 24 hours to achieve the maximal degree of micro hardness (at least 200 MPa).

Formation of coating is accompanied by the processes of wetting and spreading of suspension, and by formation of the contact area between the phases and origin of adhesive bond. Accelerated research studies to determine the weather resistance showed high insulating ability of coatings, which depends on the content of film-forming material and filler. Water absorption of coatings on concrete is 1.5–2 times as high as the similar index for steel St3kp due to lower wholeness that is determined by relief of surface (Table 2).

Boundary wetting angle for investigated coatings is greater than 90 degrees which confirms their high hydrophobicity (Table 3).

The study of dynamics of index changes of protective ability of coatings affected by atmospheric factors indicates the deterioration of their properties, especially for

Table 1

Initial protective coatings compositions based on full aluminosiloxane polymer

№	Contents KO – 978 wt %	Filler contents, wt %				
		$A1_2O_3$	ZrO_2	Kaolin	Kaolin fibre	TiO_2
1	20.0	40.0	35.0	–	5.0	–
2	30.0	30.0	36.5	–	3.5	–
3	40.0	20.0	38.0	–	2.0	–
4	25.0	40.0	10.0	20.0	5.0	–
5	30.0	40.0	11.5	15.0	3.5	–
6	35.0	35.0	18.0	10.0	2.0	–
7	25.0	40.0	14.0	15.0	5.0	1.0
8	30.0	30.0	22.0	12.5	3.5	2.0
9	35.0	25.0	25.0	10.0	2.0	3.0

Table 2

Water absorption of coatings

No. of coating composition	Water absorption after 48 hour of exposition, %	
	for St3kp steel	for concrete
1	0.58	0.92
2	0.45	0.63
3	0.14	0.27
4	0.52	0.77
5	0.43	0.62
6	0.18	0.29
7	0.43	0.57
8	0.41	0.62
9	0.32	0.51

Table 3

Boundary wetting angle of coatings

No. of coating compositions	Boundary wetting angle, degrees			
	for St3kp steel		for concrete	
	293 K	243 K	293 K	243 K
1	92	90	91	90
2	96	91	93	91
3	103	90	97	90
4	93	89	90	88
5	95	93	91	89
6	98	90	92	88
7	93	89	90	90
8	95	93	91	92
9	102	89	93	89

coatings filled with kaolin due to their high adsorption capacity.

Boundary wetting angles at the indicated temperature are 88–93 degrees that is 4–13 degrees less compared with the similar data at room temperature (Table 3). The maximal value of hydrophobicity is observed in protecting coating compositions No. 2,5 and 8.

Operating properties of filled silicon-filled organic coatings substantially change under conditions of long-term effect of negative temperatures (exposure 240 hours, T = 243 K, lining St3kp) (Fig. 1).

Thus, the protective coating resistance to the effect of negative temperatures mainly depends on the content of aluminosiloxane polymer and kaolin.

As it is shown in Fig. 1, the dependence of the relative degree index of screening (X^1) on exposure duration for the coatings with compositions No. 2,5 and 8, which have the most stable properties under the influence of negative temperatures, has a clearly definite extreme character. During the first 48 hours of exposure the X^1 index reaches a minimum and in the interval from 48 to 96 hours starts growing considerably, followed by a gradual decline. The value of relative degree of screening is stabilized after 150 hours of exposure, and after 240 hours its value is 0.42–0.48.

Thus, the action of negative temperatures slightly affects the protective coating. Boundary wetting angles decrease no more than on 4–13 degrees and for most coatings exceed 90 degrees that is explained by the action of mineral filler which considerably reduces the diffusion of water.

Along with the destroying effect of water, the destruction of the coating material is possible at negative temperatures. Laboratory research studies found that the cyclic action of alternating temperatures influences hydrophobicity more considerably (Table 4).

Analyzing the results of research studies of coating weather resistance, it is necessary to note that the action of weather factors does not cause deep destruction of protective coatings. The basic processes of oxidation occur only in the surface layer of the polymer without a considerable decrease in the filler content.

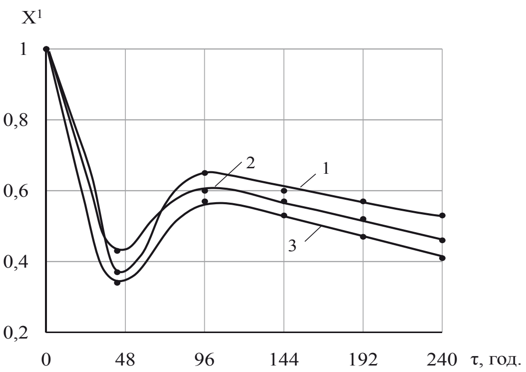


Fig. 1. Dependence of the relative degree of screening on the exposure duration for the coatings with compositions: 1 – No. 2; 2 – No. 5; 3 – No. 8 on St3kp at negative temperature (243 K)

The fact that corrosive processes occur in the surface layers of the coating is confirmed by the change of their roughness (Table 5). Tests were conducted under dry – 60 % humidity and moist – 90 % humidity conditions for 1 year.

After one-year testing under conditions of dry and moist environments the maximal increase in roughness of R_a and R_z was found for composition No. 9 (by 1.9 times) and minimum for composition No. 5 (by 1.3 times). The maximum and minimum roughness indexes were respectively 0.683 and 0.487 microns (under dry conditions). Under moist (wet) conditions the maximal increase in roughness is determined for composition No. 6 (by 5.1 times), the minimum one is for composition No. 1 (by 2.2 times). The values of maximal and minimum roughness are 1.331; 1.573 microns, respectively. Corrosive processes under wet conditions occur more intensively, which is demonstrated by higher values of R_a and R_z.

The increase in the roughness index is confirmed by the change of surface microstructure of protective coatings (Fig. 2).

This process is the most intensive on the coating surface of composition No. 5. The destruction occurs on separate areas of 200 × 400 microns. Adhesive contact with the metal surface for all investigated protective coatings is strong and its destruction as a result of environmental effect was not identified.

Table 4

Boundary wetting angle of coatings after cyclic effect of alternating temperatures of 24 cycles

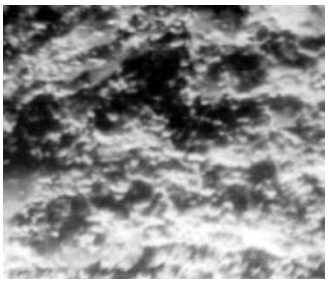
No. of coating composition	Boundary wetting angle, degrees	
	for St3kp steel	for concrete
1	81	79
2	88	86
3	95	93
4	75	73
5	89	84
6	87	83
7	85	81
8	86	83
9	98	85

Table 5

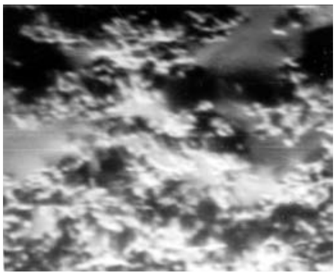
Coating roughness indexes during tests

No. of coating composition	Index R_a (numerator) and R_z (denominator), mkm	
	under dry conditions	under moist conditions
1	0.323/0.521	0.412/0.912
2	0.357/0.537	0.391/1.141
3	0.412/0.683	0.382/1.240
4	0.352/0.487	0.253/1.007
5	0.381/0.510	0.268/1.217
6	0.351/0.612	0.308/1.573
7	0.287/0.492	0.408/0.978
8	0.312/0.572	0.398/1.127
9	0.308/0.603	0.348/1.331

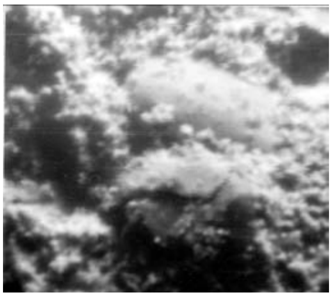
Note: R_a is the roughness value before the test; R_z is the roughness value after testing.



a



b



c

Fig. 2. The surface microstructure of protective coating (composition No. 5) after testing (× 1000): a – original; b – under dry conditions; c – under wet conditions

Conclusion: the results of accelerated research studies of atmosphere resistance of filled silicone coatings show their high insulating ability that depends on the content and nature of both film-forming material and filler.

The research studies determined that the coatings on the base of full aluminosiloxane polymers are characterized by high physical property indexes (weather resistance and weather absorption) at preservation of sufficient temperature and fire resistance.

Recommendations for further researches in this area are not only to determine operating properties of protective coatings which are aluminosiloxane polymer-based, but to estimate their environmental safety.

Reference / Список літератури

1. Merezhko, N.V., 2000. *Vlastyvosti ta struktura napovnennykh kremniiorhanichnykh pokryttiv* [Properties and structure of full silicone coatings]. Kiev: KDTEU.

Мережко Н.В. Властивості та структура наповнених кремнійорганічних покриттів: монографія / Мережко Н.В. / Київ. держ. торг.-екон. ун-т. – К., 2000. – 257 с.

2. Yemchenko, I.V. 2004. Composite protective coatings. *Visnik LCA,* no. 6, pp. 158–163.

Ємченко І.В. Композиційні захисні покриття / І.В.Ємченко // Вісник ЛКА (серія товарознавча). – 2004. – Вип. 6. – С. 158–163.

3. Givlud, N.N. and Emchenko, I.V., 2005. Coatings for high-temperature structural materials protection. *Mekhanika i Fizika Ruinuvannia Budivelnykh Materialiv i Konstruktsii*, no. 8, pp. 472–476.

Гивлюд М.М. Покриття для високотемпературного захисту конструкційних матеріалів / М.М.Гивлюд, І.В.Ємченко // Механіка і фізика руйнування будівельних матеріалів та конструкцій: зб. наук. праць. – Л.: Каменяр, 2005.– С. 472–476.

4. Peredriy, O.I., 2010. The study of the physical properties of coatings filled siloxane polymer. V*isnyk Natsionalnoho Universytetu*, no. 5 (140), pp. 44–48.

Передрій О.І. Дослідження фізичних властивостей наповнених силіційорганічних покриттів / О.І.Передрій // Вісник Хмельницького національного університету. – 2010. – № 5.– С. 44–48.

5. Peredriy, O.I., 2014. Increase thermal- and heatresistant of coatings based on full aluminosiloxanepolymer. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, no. 2 (140), pp. 64–68.

Передрій О.І. Підвищення термо- та жаростійкості захисних покриттів на основі наповнених поліалюмосилоксанів / О.І.Передрій // Науковий вісник НГУ. – 2014. – №2 (140). – С. 64–68.

Мета. Визначення показників атмосферостійкості, водопоглинання нових захисних покриттів на основі поліалюмосилоксану та встановлення впливу складу вихідної композиції на фізичні властивості покриттів.

Методика. При дослідженнях використовували передбачені діючими державними стандартами методи, що дозволяють вивчити фізико-механічні властивості захисних покриттів. Гідрофобні властивості покриття характеризуються ступенем змочування поверхні матеріалу покриттям, який оцінювали за величиною крайового кута змочування на межі розділу фаз з використанням методу вибіркового змочування.

Результати. Встановлено, що покриття на основі наповненого поліалюмосилоксану мають високі ізолюючі та захисні властивості, оскільки крайовий кут змочування для покриттів усіх складів є більшим за 90 градусів, значення водопоглинання покриттів на сталі дорівнює 0,18–0,58, а на бетоні – 0,29–0,92 мас.%. Часткова деструкція покриття відбувається за від'ємних та знакозмінних температур за рахунок корозійних процесів у поверхневих шарах покриття, при цьому крайовий кут змочування зменшується на 4–13 та 10–18 градусів відповідно для сталі та бетону. Встановлено, що покриття на основі наповнених поліалюмосилоксанів характеризуються високими показниками фізичних властивостей (атмосферостійкості та водопоглинання) при збереженні достатньої температуро- та вогнестійкості.

Наукова новизна. Встановлено вплив складу вихідної композиції на атмосферостійкість та корозійну стійкість покриттів на основі наповнених поліалюмосилоксанів.

Практична значимість. Розроблені захисні покриття на основі наповнених поліалюмосилоксанів можуть використовуватися в різних галузях промисловості. Встановлений вплив оксидних і силікатних наповнювачів у складі захисних покриттів, що забезпечує можливість цiленаправленого регулювання їх експлуатаційних властивостей у широкому інтервалі температур.

Ключові слова: *покриття, поліорганосилоксани, захисна ефективність, корозійна стійкість, атмосферостійкість, гідрофобність, водопоглинання, крайовий кут змочування*

Цель. Определение показателей атмосфероустойчивости, водопоглощения новых защитных покрытий на основе полиалюмосилоксана и установление влияния состава исходной композиции на гидрофизические свойства покрытий.

Методика. При исследованиях использовали предусмотренные действующими государственными стандартами методы, которые позволяют изучить физические свойства защитных покрытий. Гидрофобные свойства покрытия характеризуются степенью смачивания поверхности материала покрытием, которую оценивали по величине краевого угла смачивания на границе раздела фаз с использованием метода выборочного смачивания.

Результаты. Установлено, что покрытия на основе наполненного полиалюмосилоксана имеют высокие изолирующие и защитные свойства, высокие гидрофобные показатели, поскольку краевой угол смачивания для покрытий всех составов составляет больше 90 градусов, значение водопоглощения покрытий на стали равно 0,18–0,58, а на бетоне – 0,29–0,92 масс.%. Частичная деструкция покрытия происходит при отрицательных и знакопеременных температурах за счет коррозионных процессов в поверхностных слоях покрытия, при этом краевой угол смачивания уменьшается на 4–13 и 10–18 градусов соответственно для стали и бетона. Установлено, что покрытия на основе наполненных полиалюмосилоксанов характеризуются высокими показателями гидрофизических свойств (атмосферостойкости и водопоглощения) при сохранении достаточной температуро- и огнестойкости.

Научная новизна. Установлено влияние состава исходной композиции на атмосферостойкость и коррозионную стойкость покрытий на основе наполненных полиалюмосилоксанов.

Практическая значимость. Разработанные покрытия на основе наполненных полиалюмосилоксанов могут использоваться в различных отраслях промышленности. Установлено влияние оксидных и силикатных наполнителей в составе защитных покрытий, что обеспечивает возможность целенаправленного регулирования их эксплуатационных свойств в широком интервале температур.

Ключевые слова: *покрытия, полиорганосилоксаны, защитная эффективность, коррозионная стойкость, атмосферостойкость, гидрофобность, водопоглощение, краевой угол смачивания*

Рекомендовано до публікації докт. техн. наук Л. І. Байдаковою. Дата надходження рукопису 02.04.15.