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Model for Predicting Protective and Decorative Exterior Walls

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Abstract

A model of service life, taking into account the activation energy of the aging process, the intensity of exposure to ultraviolet radiation, temperature and humidity. Is shown by the example of the method of calculating the life of coatings according to the accelerated tests

Keywords: durability, the paint, the calculation model of aging

Introduction

Examination Survey results painted facades of buildings show that the actual service life does not always correspond to the planned. This leads to additional costs for the repair of building facades. The current empirical assessment of service life can not produce reliable data on the durability of coatings, due to the lack of theoretical development to assess the service life.

There are several approaches to forecasting the durability of coatings. In [1,2] it was proposed to evaluate the durability of coatings with regard to the internal stresses. However destruction of coverings is caused not by one kind of influence only voltage, but also humidity both solar illumination and other factors. In work [3] it is offered to estimate durability of coverings $\tau_н$ by results of the accelerated tests with use of linear dependence $\tau_н$ on duration of the accelerated tests $\tau_у$. However at application of various paints the linear model has a various kind. It reduces reliability of forecasting.

The analysis of the scientific and technical literature testifies, that questions of

forecasting remain actual. In this regard, the creation of an evidence-based method for predicting service life is an important scientific, technical and economic problem.
The aim is to develop a methodology for assessing the life of coatings exterior walls.

Methodology

Justification of the complexity of the mathematical model is difficult nature of the mechanism of aging coatings. In the operation of protective and decorative coatings exterior walls, the character of the aging mechanism, ie, at different stages of aging change of operational properties of coatings determine different components of the mechanism of aging. It may be:
- Chemical processes in coatings, occurring as a continuation of the curing process, external influences only change their speed, is the chemical processes in coatings, including on the surface of pigments and fillers, which are the result of external influences the reactants (oxygen acids, alkalis, water in the case of the hydrolysis, etc.) and activating factors (light, temperature) (for example - hlorvinilovye polymers);
- physicochemical processes leading to structural changes (supramolecular structure and phase).

However, in most cases, the destruction caused by the simultaneous occurrence of coatings few processes. Consider the aging process from the perspective of coatings thermo- fluctuation theory of strength polymers [4, 5]. According to the molecular model of fracture atoms in the tip of a crack due to thermal fluctuations from time to time acquire enough kinetic energy to rupture or recovery if there was a gap. Under the influence of climatic factors in the coating of internal stresses, the probability of breaking the bonds in the structure of the coating increases, and their recovery - is reduced. According to the molecular model of the value of the potential fracture energy needed to break the bond, is

$$U = U_o - v_a \sigma^x \quad (1)$$

where U_o - is the potential barrier tearing down
σ^x -action local stress;
v_a - the amount of fluctuation.
The magnitude of the potential energy needed to restore communication is

$$U^* = U_o + v\sigma^x \quad (2)$$

where U^* - a potential barrier recombination connection with $\sigma = 0$
At some value of stresses in the coating under the influence of climatic factors $U_o - v\sigma^x = U_o^* + v\sigma^x$, the crack does not grow, while there is a slight change in the decorative and protective properties (incubation period). At voltages $\sigma > \sigma^x$ observed crack growth, the speed of the process v is determined by the relation

$$v = v_1 - v_2 \tag{3}$$

where v_1 - the crack growth rate; v_2 -the velocity of the fracture closure
As $v_1 > v_2$ Since the rate of aging is determined by the rate of crack growth. The frequency of fluctuations in time of disconnection at the crack tip is

$$u = u_o \exp[-(U_o - v\sigma^x)/kT] \tag{4}$$

Since crack growth rate is $v_1 = \lambda u_1$, in view of formula (4)

$$v = \lambda u_o \exp[-(U_o - v\sigma^x)/kT] \tag{5}$$

The transition from the active to the incubation period is observed at step $\sigma > \sigma^x$.
In accordance with formula (5) coating lifetime may be defined by the formula

$$\tau = \int_{w_o}^{w_k} \frac{dw}{v} \tag{6}$$

where w_o, w_k -initial and final level of damage accumulation.

The solution of equation (6) leads to the form

$$\tau = A\tau_o \exp[(U - v_\sigma)/RT] \tag{7}$$

Expression $(U - v_\sigma)$ of the activation energy is aging. It is an effective value and a combination of the activation energies of individual processes underlying aging coatings. The factor is variable depending on the humidity, the intensity of ultraviolet radiation UV

Consider the effect of humidity and ultraviolet radiation by a factor. As is known

$$\beta = \gamma W \tag{8}$$

where γ - coefficient of proportionality, taking into account the effect of humidity on the rate of hydrolysis of the film-forming agent
W - Humidity.
The rate of hydrolysis is proportional to the amount of adsorbed moisture, and can be described by the reaction equation of the first order

$$\beta = (1/t)\ln\{C_o / C\} \tag{9}$$

where C - concentration of the substance
The ratio of the aging time when changing humidity will describe the dependence

$$\tau_1 / \tau_2 = \{(1/\gamma W_1)\ln(C_o / C_1)\}/\{(1/\gamma W_2)\ln(C_o / C_2)\} = constk_1 \tag{10}$$

Duration to achieve the same degree of fracture based on the equation (10) can be determined by the equation

$$\tau_1 = \tau_2 k_1 \qquad (11)$$

As humidity reference value is offered to use the minimum humidity value achieved in the area of operation [6, 7].

The Results

Table. 1 shows the results of experimental and calculated data on the effect of humidity on the length of aging coatings on example of silicone paint KO-168. The calculated data showed good agreement with the experimental data. Degree consistency of estimated coefficients of pair correlation. In the calculation of the confidence probability of 0.95. The critical value of pair correlation coefficients for the 95% confidence probability and the number of degrees of freedom n = 5 was = 0.707. The calculated value of the coefficient of pair correlation = 0.902 was that much more critical and shows a high consistency between the experimental and calculated data.

Table 1
The duration of aging coatings KO-168 with the loss of gloss 20%

Type of substrate	The porosity of the substrate,%	Humidity,%			
		60		100	
Without UV-irradiation					
glass	0	1700/1698	941/933	1346/1350	727/724
porous cement	20,3	914/912	515/517	701/706	396/401

Note. Above the line shows the experimental data duration of the test, below the line – calculated data

In [6], the results of studies of kinetics of degradation of coatings under the action of light radiation are presented. The duration of the test to the same degree of damage depends linearly on the inverse radiation intensities

$$\tau_1 J_1 = \tau_2 J_2 = \tau_3 J_3 = const = k_2 \qquad (12)$$

Given equation (12) the duration of the aging to a predetermined degree of coating damage depends on the radiation intensity is determined by the relation

$$\tau_1 = \tau_2 k_2 \qquad (13)$$

The duration of the aging of coatings to the desired degree of destruction is determined by the ratio

$$\tau = \tau_o \exp[U / RT] k_1 k_2 \qquad (14)$$

With variable operating conditions $x(t)$, use the equation Bailey

$$\int_{o}^{\tau} dt/\tau = 1 \qquad (15)$$

where t - the durability of the coating operation under these conditions
τ - Coating durability under all operating conditions
In the transition from the integral form for a finite increments

$$\sum \Delta t/\tau = 1 \qquad (16)$$

The methodology for calculating the life of coatings used additivity principle that allows you to define constant operating conditions, equivalent to the total of their destructive effect to variable conditions of exploitation.
As constant conditions of exploitation: temperature – 273K; minimal achievable humidity; of intensity ultraviolet radiation in this climatic region. Equivalent time proposed to determine the formula

$$\tau_{экв} = (W_{\min}/W_{тек})(J_{\min}/J_{тек})\tau_o \exp[-U/R(1/T_{тек} - 1/T_o)] \qquad (17)$$

where $T_{тек}$ - the current operating temperature
Algorithm for determining the duration of the aging of coatings to the desired degree of destruction is as follows.
1. Determine for a given climatic region, in accordance with the mathematical model (14) during the year, which is equivalent to the total destructive effect with respect to the constant parameters (temperature , humidity , radiation intensity). You must first determine the value of the effective activation energy U.
Determine the intensity of climatic tests with the regime and the number of test cycles

$$t_2 = N\tau_{экв} \qquad (18)$$

where N - the number of test cycles;
$\tau_{экв}$ - the intensity of one cycle of climatic test ,day.
Determine the lifetime of the formula

$$\tau = \frac{t_2}{t_1} \qquad (19)$$

Below is an example of calculating lifetime polyvinyl-acetate-cement (PAC) and silicone (KO-166) coatings. When calculations were made using the average monthly value of the intensity of ultraviolet radiation with wavelengths less than 400 nm, relative humidity for a moderately cold climate. Preliminary studies and calculations found that the activation energy of PAC coating is U = 92,230kDzh / mol, covering KO-166 -94.54 kJ / mol.

Accelerated testing was performed under the regime: 4 hours - freezing at -40 ° C, 2 hours - thaw in air at a temperature of 40C and a relative humidity of 60%, 2 hours - moisture at a temperature of + 20 ° C, 16 hours - ultraviolet radiation at a temperature of + 20^o C and a relative humidity 70%. The results of the calculation are given in Table 2.

Table2

Equivalent $\tau_{экв}$ coating operation with respect to 0 ° C in different climatic zones

month	Moscow	Yakutsk	Vladivostok
1	2	3	4
January	0,61/0,58	0,001368/0,001125	0,34/0,323
February	0,695/0,67	0,0065/0,0056	0,56/0,54
March	5,64/5,54	0,318/0,288	6,74/6,65
April	28,525/19,34	15,86/15,85	28,52/28,92
May	90,32/94,2	39,41/40,2	98,87/75
June	191,32/202,29	169,38/178,32	131,30/137,35
Jul	300,99/320.63	325,05/346,80	278,54/295,85
August	181,00/191,65	149,95/157,95	294,63/315,79
September	51,0/56,5	29,97/30,26	111,92/116,74
October	3,05/12,41	1,93/1,88	29/30,42
November	2,44/2,4	0,0327/0,029	2,78/2,78
December	0,664/0,65	0,002/0,0017	0,492/0,47
in total	860,35/906,86	716,25/771,6	871,75/1010,84

Note. Above the line shows the values for PAC coating below the line - coating KO-166.

Polyvinyl-acetate-cement coating (PAC) coating

When the air temperature -40 ° C during tests, equivalent time at 0 ° C is

$$\tau_{экв} = \frac{4}{24} exp(\frac{92230}{R} : (\frac{1}{273} - \frac{1}{233})) = 0{,}00013 day$$

When the air temperature of 20C and a relative humidity of 100% is equivalent to the time

$$\tau_{экв} = \frac{2}{24} * \frac{100}{90} exp(\frac{92230}{R} : (\frac{1}{273} - \frac{1}{293})) = 1{,}58 day$$

When the air temperature + 20 ° C. 70% relative humidity and exposure to ultraviolet radiation equivalent time is

$$\tau_{экв} = \frac{16}{24} * \frac{70}{90} * \frac{912}{333} exp(\frac{92230}{R} : (\frac{1}{273} - \frac{1}{293})) = 22{,}58 day$$

Therefore, a test cycle is equivalent to 34.16 days. at 273°K. The number of test cycles at 120
34,16*120=4099,84 day
The service life of coatings is equivalent to
- Moscow

$$\frac{4099{,}84}{860{,}35} = 4{,}78 year$$

-Yakutsk

$$\frac{4099{,}84}{716{,}25} = 5{,}72 year$$

-Vladivostok

$$\frac{4099{,}84}{871{,}75} = 4{,}7 year$$

Organic silicon coating KO-168

When the air temperature -40°C during tests, equivalent time at 0 ° C is

$$\tau_{экв} = \frac{4}{24} exp(\frac{94500}{R} : (\frac{1}{273} - \frac{1}{233})) = 0{,}00013 day$$

When the air temperature -40°C and a relative humidity of 60% is equivalent to the time

$$\tau_{экв} = \frac{2}{24} * \frac{60}{90} exp(\frac{94500}{R} : (\frac{1}{273} - \frac{1}{313})) = 11{,}51 day$$

When the air temperature of 20°C and a relative humidity of 100% is equivalent to the time

$$\tau_{экв} = \frac{2}{24} * \frac{100}{90} exp(\frac{94500}{R} : (\frac{1}{273} - \frac{1}{293})) = 1{,}58 day$$

One test cycle is equivalent to 37.32 days at a temperature of 273°K. The number of test cycles is 200
37,32*200=7465,59day
The service life of coatings is equivalent to
in Moscow

$$\frac{7465{,}59}{906{,}86} = 8{,}24 year$$

- Yakutsk

$$\frac{7465{,}59}{771{,}6} = 9{,}65 year$$

-Vladivostok

$$\frac{7465,59}{1010,84} = 7,38 year$$

Results of field tests have confirmed that the discrepancy between the predicted and the real life does not exceed 15%

Findings

Formulated the scientific and methodological basis of forecasting resistance of protective and decorative coatings exterior walls building. A model of aging coatings, taking into account the type and structure of the coating, the intensity of the impact of climatic factors.

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