Research on service life prediction and decorative properties of acrylic paint in Vietnam's marine atmosphere by acceleration test

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ABSTRACT

Vietnam is located in a tropical climate zone, especially coastal climates that quickly destroy coating materials that protect steel structures. Therefore, the service life of coatings is always of concern to manufacturers and users. This article presents the results of surveying changes in gloss, color and service life prediction of acrylic paint by accelerated tests, that have simulated according to marine tropical conditions, which are correlated with the atmosphere at Dam Bay station (Hon Tre Island, Nha Trang city, Khanh Hoa province, Vietnam). Gloss is determined according to ISO 2813:2014, and color change is determined according to standard ASTM E308-12. The service life of the acrylic paint system is determined according to standard GOST 9.401-2018. Calculation results based on accelerated test data show that the corrosion time of the acrylic paint system reaches Ri 3 (according to ISO 4628-3:2016 assessment), the service life of acrylic paint Tar 5366 is 2.91 years, and acrylic paint AR-752 is 2.66 years.

Keywords: Acrylic paint Tar 5366; Acrylic paint AR-752; Accelerated Tests; Marine tropical climate; Decorative Properties; Service Life prediction.

1. INTRODUCTION

Vietnam is located in a humid tropical climate zone, so the issue of corrosion protection is extremely important. In the face of the complicated developments of global climate change, the solution of prevention and anti-corrosion for metal and alloy structures, which are worked in marine climates with protective coatings, is an effective solution. However, with the strong impact of sea water, especially in the tropical marine environment of Vietnam, the damage to the coating layer becomes more evident [1]. Studies have shown that in tropical environments, high humidity and heavy rain corrode and destroy materials many times more than in temperate climates. The reported levels of corrosivity are often higher than the maximum values specified in the ISO 9223 standard [2, 3].

Nha Trang Bay is an area with very high atmospheric salinity, which is higher than many other coastal areas in Vietnam. The impact of this parameter in relation to the durability of the material is always of concern to many researchers [4-6]. Acrylic paints come in many different types and are often used as coatings on wood, plastic, concrete surfaces, etc. In recent years, the use of acrylic paint for anti-corrosion purposes on metals has been extensively studied. Therefore, experimental studies to predict the service life of acrylic paint systems are of scientific importance. Accelerated testing studies have evaluated the degree of change in decorative properties (gloss, color) and service life prediction based on the change in these properties or the degree of rusting [7, 8]. Kariakina *et al.* established a correlation of gloss loss on the time test between the field and the acceleration test [7].

The correlation between accelerated and field tests is shown in figure 1 [7].

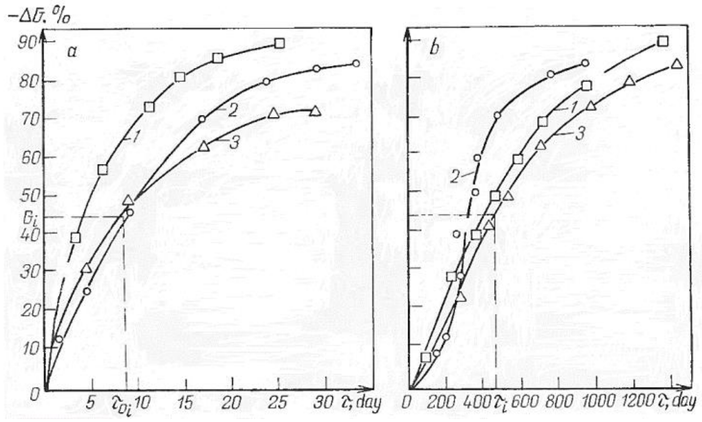


Figure 1. *The dependence of gloss loss (ΔG) of coating ПФ-115 on time test at accelerated test (a) and field test in Moscow (b)*
1- Green coating; 2- White coating; 3- Gray coating.

Gao J. *et al.* conducted acceleration tests with conditions that were simulated to the marine atmospheric environment. This study evaluated the rate of aging characteristics of the acrylic polyurethane/epoxy/carbon steel system. Three stages of the accelerated test are designed to include: combined UV/salt spray for 4 h (55 ± 2 ºC) + 2 h UV treatment (55 ± 2 ºC), and salt spray treatment for 6 h (35 ± 2 ºC). UVA irradiation (with λ = 340 nm) used is 1.05 W/m^2, sodium chloride 5% solution [8]. The results were compared with the field tests and repeated accelerated tests in Wanning (Hainan, China). The results of this study demonstrated that, in the acceleration test, the coating's aging process of the coating is closer to the aging rules of the coating under field test conditions [8, 9].

2. MATERIALS AND METHODS

2.1. Materials and equipment

This research was conducted with acceleration tests on two types of acrylic paint:

Topcoat acrylic Jotun Jotashield (Tar 5366) (Jotun Vietnam paint Co., Ltd, Vietnam), some technical data are presented in table 1.

Topcoat acrylic AR-752 (Hai Au paint one member Co., Ltd, Vietnam), some technical data is presented in table 1.

Table 1. *Some main technical data of topcoat Tar 5366 and AR-752.*

Target name	Tar 5366	AR-752
Relative hardness (compared to standard glass panels), not less	0.36	0.35
Bending strength, mm	2	2
Adhesion, point	1	1
Impact resistance, kg.cm, not less	60	60

Anticorrosion acrylic primer JotaShield Primer and thinner Jotun Thinner No 7 (Jotun Vietnam paint Co., Ltd, Vietnam), which used is compatible with topcoat Tar 5366.

Anticorrosion acrylic primer AR-501 and thinner CS-02 (Hai Au paint one member Co., Ltd, Vietnam), which used is compatible with topcoat AR-752.

Xylene 99,0% (Xilong, China); butyl acetate 99,5% (Xilong, China);

Steel plate Ct-3 was cut into panels with size L x W x H = 150 x 75 x 2 mm, their surface roughness is from 0.50 to 1.14 µm.

Humidity heat test cabinet Clime Event C/1000/40/3 (Weisstechnik, Germany), Artificial weather testing chamber Ci 4000 (Atlas, USA), corrosion test cabinet CCX-3000 (Atlas, USA).

2.2. Sample preparation

Samples were prepared according to ISO 9227:2017. Acrylic primer and acrylic topcoat are applied to the surface of Ct-3 steel plates using a spray gun. The primer is applied in two layers (each layer at least 8 hours apart) and left to dry naturally for at least 24 hours, then the topcoat is applied (two layers, each layer at least 24 hours apart). The paint layers are dried naturally at room temperature for at least 7 days, then tests are carried out.

2.3. Test method

Atmospheric test were selected according to standard GOST 15150-69 [10]. These conditions are humid tropical climate (climate "TB") and outdoor working location (location "1"), these conditions are consistent with the climatic conditions of Dam Bay station. Table 2 presents the average annual climate characteristics in 5 years (from July 2016 to June 2021) at Dam Bay station [11].

Table 2. *Average annual climate parameters at Dam Bay station.*

Temperature, ºC	**Relative humidity, %**	**Solar irradiance, MJ/m^2**	**Annual precipitation, mm**	**Chloride deposition rate, mg/m^2.day**
27.3	80	6722	1677	52

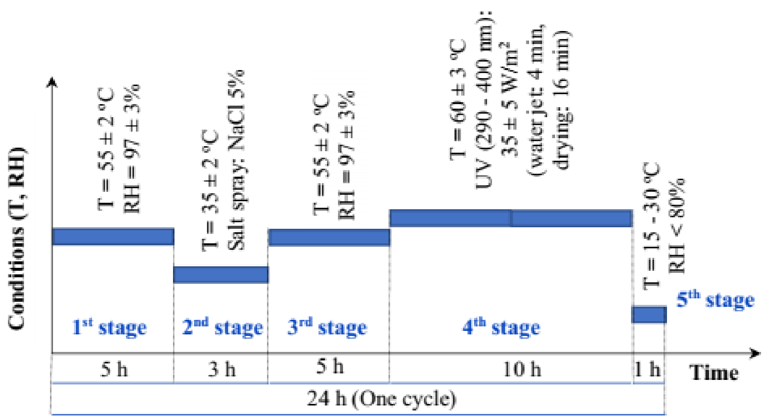


Figure 2. *Stages in acceleration test.*

Acceleration testing of coatings is conducted according to GOST 9.401-2018 with test method № 9. This is a cyclic acceleration test method that simulates the impact of field and tropical marine atmosphere. Each cycle (corresponding to 24 hours) includes the following stages:

First stage (for 5 hours): Temperature T = 55 ± 2 ^oC and relative humidity RH = 97 ± 3%;

Second stage (for 3 hours): Temperature T = 35 ± 2 ^oC and salt fog with NaCl 5% solution;

Third stage (for 5 hours): Temperature T = 55 ± 2 ^oC and relative humidity RH = 97 ± 3%;

Fourth stage (for 10 hours): Temperature T = 60 ± 3 ^oC, UV radiation (290 - 400 nm) 35 ± 5 W/m^2, operating according to formula 4 - 16 (water jet for 4 minutes, drying for 16 minutes);

Fifth stage (for 1 hour): Temperature T = 15 - 30 ^oC and relative humidity RH < 80%.

2.4. Analysis

The gloss of the coating is determined according to ISO 2813:2014 [12], was measured at an angle of 60^o by the Rhopoint 20/60/85 instrument.

The color of the coating is determined according to ASTM E308-12, was measured by X-rite Ci62 with color coordinates (L*, a*, b*) [13].

Parameters of gloss and color are evaluated with a frequency of 7 cycles/time. The assessment frequency can be conducted with a smaller number of cycles depending on the condition and degree of variation of the above parameters.

The degree of corrosion is determined according to GOST 9.407-2015 [14], and determined through each test cycle and was recorded at the moment of the beginning of the appearance of corrosion by points. In this study, the moment the corrosion reached "Point 3" (or Ri 3 - according to the ISO 4628-3:2016 assessment), corresponding to the total corrosion area, is not more than 1%, the accelerated testing process ended.

Service life of coating (τ_y) is evaluated according to GOST 9.401-2018 with an acceleration coefficient of 18 for a group of operating condition T1 (Outdoor tropical climate - according to GOST 9.104-2018 [15]) and (τ_y) is determined according to the following formula [16]:

$$\tau = \frac{k_y . \tau_y}{365}$$

Where k_y is the acceleration coefficient. In this study, the acceleration coefficient was taken equal to 18 for operating conditions T1. τ_y is the number of accelerated test cycles at which the corrosion resistance reaches Ri 3 (total corrosion area is not more than 1%, according to ISO 4628-3:2016 assessment).

3. RESULTS AND DISCUSSION

3.1. Initial data for the test sample

Parameters of dry film thickness (this is the total thickness of the primer and topcoat), gloss and color of acrylic paint AR-752 and Tar 5366 are summarized in table 3.

Table 3. *Parameters of acrylic coatings before the accelerated testing.*

Type of acrylic paint	Thickness, µm	Gloss, GU	Color, LAB		
			L*	a*	b*
AR-752	85.0	82.70	93.98	-1.18	0.87
Tar 5366	88.0	90.05	27.22	-0.045	0.095

3.2. Change in gloss with aging time

The material surface is mostly impacted by weathering, which causes a loss of initial gloss. Therefore, it makes sense to analyze surface changes, especially since they are easy to measure and relatively accurate. Gloss value is used effectively to evaluate in coatings: matrix durability, the stability of topcoats, etc. The gloss results evaluated thus bring about a significant improvement in the gloss maintenance process.

The results of determining the gloss of the coatings over time (number of testing cycles) in the accelerated test are presented in figure 3.

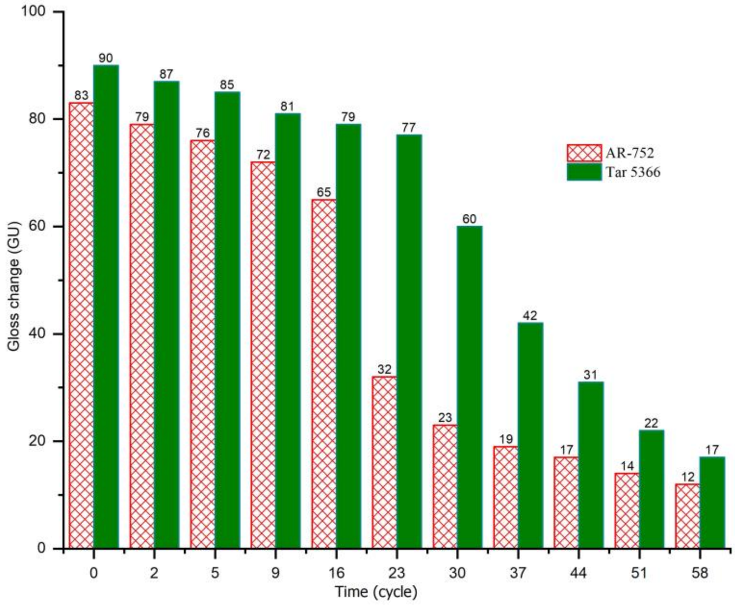


Figure 3. *Gloss change of two coatings during time in accelerated testing.*

Results in figure 3 show that the gloss of the coatings all have similar changes during the testing cycles. The gloss of paint Tar 5366 occurs faster from the 23rd to the 37th cycle, it has dropped by approximately 45.45%. The gloss of paint AR-752 decreases fastest from the 16th to the 23rd cycle (approximately 50.77% decrease). The gloss of the paint changes more slowly in the other cycles. The gloss reached 12 units (for paint AR-752) and 17 units (for paint Tar 5366) at the 58th cycle of the accelerated test.

3.3. Color change with aging time

Changes in the color of a material depend on changes in the chemical composition of the material and often reduce the value of the material. Materials often consist of a mixture of different products. Therefore, a color change caused by a change in the pigments or matrix is not an indication of what the change is.

Color changes in coating AR-752 and Tar 5366 at different times (number of cycles) of the accelerated tests are presented in figure 4.

The data in figure 4 shows that the color change of two coatings followed similar rules in the first stage and this change is slower in the later stage. However, the color of coating AR-752 changes faster than that of the coating Tar 5366. The greatest change of gloss occurs from the 9th cylce to the 30th cycle. During the 44th cycle of accelerated testing the color change of coating AR-752 was reduced by 10.23 units, while the color of coating Tar 5366 was reduced by 7.33 units. Color change of paint AR-752 transforms faster than paint Tar 5366, the color value is determined up to the 44^{th} cycle, the following cycles the surface of the coating AR-752 is destroyed, and this color value was not measured by X-rite Ci62 instrument.

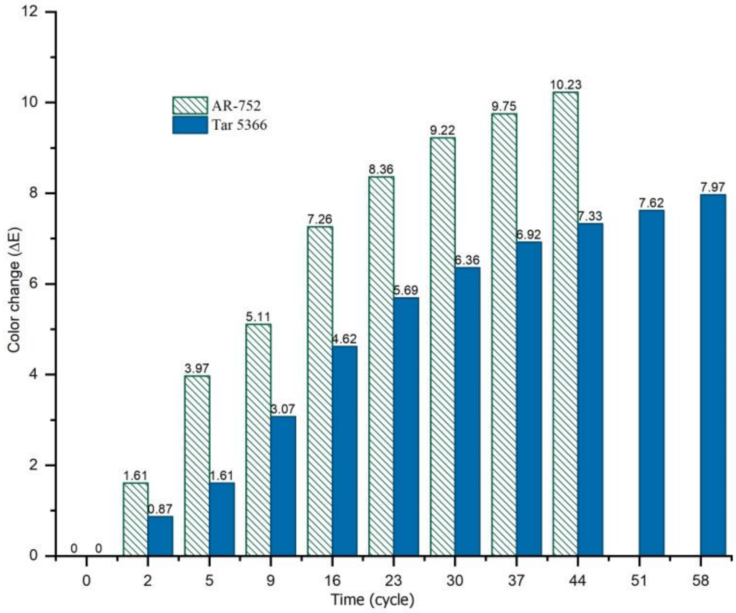


Figure 4. *Color change of two coatings during time in accelerated testing.*

In addition, in this study, the adhesion of two acrylic paints on steel Ct-3 is determined according to ISO 2409:1992 [17]. These results are compared with initial data and field tests, and they are summarized in table 4.

Table 4. *Adhesion of paints (Tar 5366 and AR-752) (point) for accelerated and field test.*

Type of acrylic paint	Initial adhesion	After 58 cycles of accelerated test	After 36 months of field test
AR-752	1	5	5
Tar 5366	1	5	5

The results in table 4 show that the adhesion of the two paints is very low when the surface of the coatings is strongly destroyed.

3.4. Service life prediction of the coatings

The accelerated test results showed that, when the corrosion resistance of the coating AR-752 reached Ri 3, the number of cycles recorded was 53, while the coating Tar 5366 was 59 cycles.

Therefore, the service of the acrylic coating AR-752 (τ_{AR}) is $\tau_{AR} = \frac{18 \text{ x } 54}{365}$ = 2.66 years.

Service life of the acrylic coating Tar 5366 is $\tau_{Tar} = \frac{18 \text{ x } 59}{365}$ = 2.91 years.

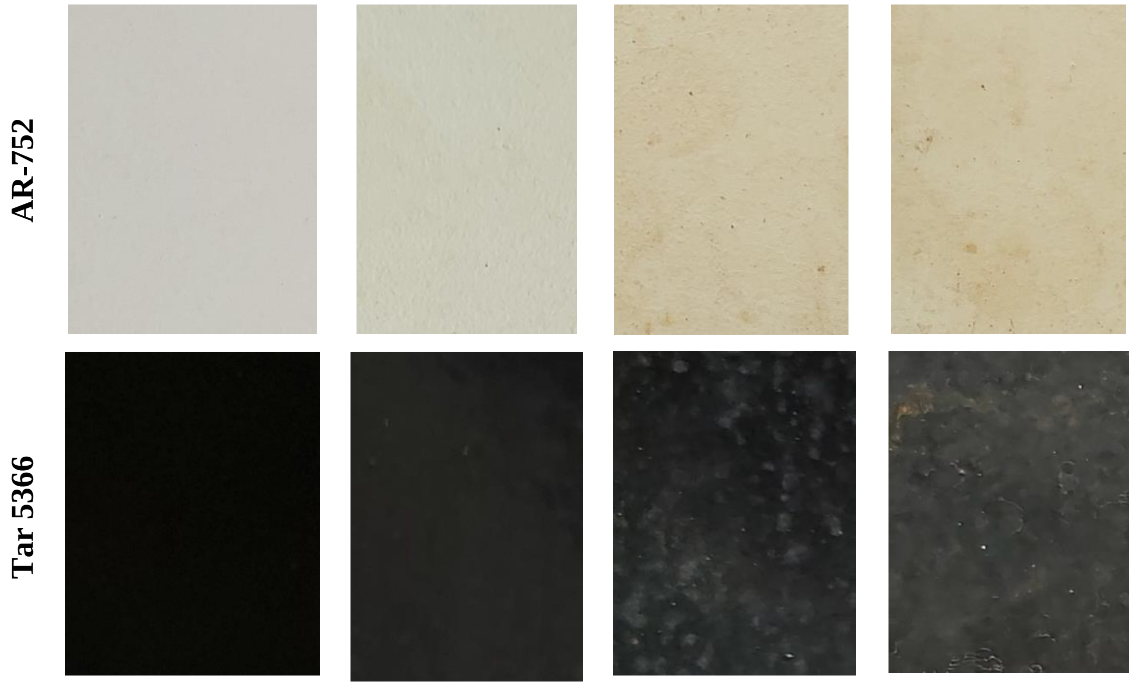
According to the field test data performed by Chu M. T. *et al.* [11], the time in which the corrosion resistance reaches Ri 3 is $\tau_{AR(ft)}$ = 2.92 years, and $\tau_{Tar(ft)}$ = 3.17 years.

Therefore, the deviation of the accelerated test method is:

$$\Delta_{AR} = \frac{\tau_{AR(ft)} - \tau_{AR}}{\tau_{AR(ft)}} \text{ x } 100\% = \frac{2.92 - 2.66}{2.92} \text{ x } 100\% = +8.9\%$$

$$\Delta_{Tar} = \frac{\tau_{Tar(ft)} - \tau_{Tar}}{\tau_{Tar(ft)}} \text{ x } 100\% = \frac{3.17 - 2.91}{3.17} \text{ x } 100\% = +8.2\%$$

Some images of accelerated test samples after a number of cycles are illustrated in figure 5.



Initial sample *After 16 cycles* *After 37 cycles* *After 51 cycles*

Figure 5. *Surface images of accelerated test samples.*

Some field test results for two acrylic paints (AR-752 and Tar 5366) at Dam Bay station are summarized in table 5 [11].

Table 5. *The gloss and color change of paint AR-752 and Tar 5366 by field test.*

Type of acrylic paint	Gloss change		Color change	
	12 months	36 months	12 months	36 months
AR-752	53	17	3.77	8.92
Tar 5366	37	5.8	2.83	7.44

Some images of field test samples at Dam Bay station (from July 2016 to June 2021) are illustrated in figure 6 [11].

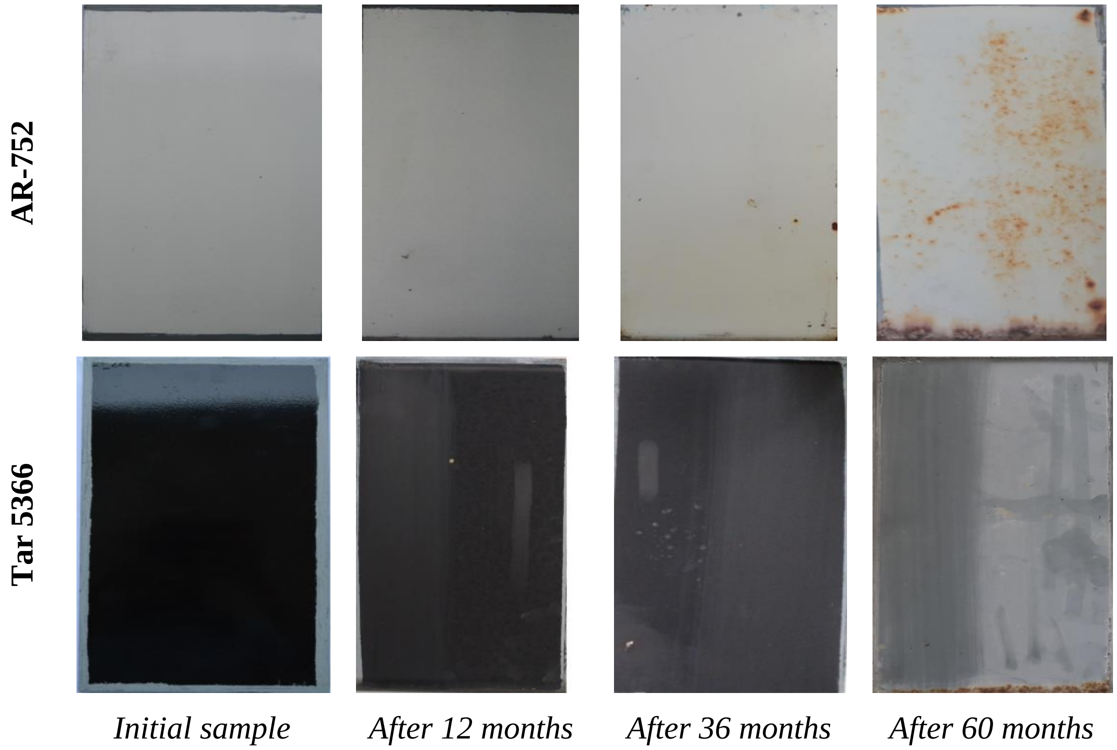


Figure 6. *Surface images of field test samples.*

4. CONCLUSIONS

This study established an accelerated test mode simulating tropical marine climate conditions based on a set of 3 standards of the Russian Federation (GOST 15150-69, GOST 9.401-2018 and GOST 9.104-2018). Acrylic coatings AR-752 and Tar 5366 are subjected to accelerated testing in outdoor tropical marine climate conditions (method No 9 according to GOST 9.401-2018 and outdoor use conditions T1 according to GOST 9.104-2018) shows that the gloss and color change decrease rapidly in the first test cycles (up to the 30th cycle), then this change decreases more slowly. The service life of the acrylic coating AR-752 is 2.66 years (with the deviation of the accelerated test method is + 8.9%), and service life of the acrylic coating Tar 5366 is 2.91 years (with the deviation of the accelerated test method is + 8.2%). With the results of this work, it is possible to make recommendations to manufacturers and users regarding the service life of acrylic paint systems.

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TÓM TẮT

Nghiên cứu tuổi thọ và các tính chất trang trí của sơn acrylic trong điều kiện khí hậu biển nhiệt đới Việt Nam bằng thử nghiệm gia tốc

Việt Nam nằm trong vùng khí hậu nhiệt đới, đặc biệt là khí hậu vùng biển đã nhanh chóng phá hủy vật liệu sơn phủ bảo vệ kết cấu thép. Do đó, vấn đề tuổi thọ của lớp sơn phủ luôn được các nhà sản xuất và người sử dụng quan tâm. Bài báo trình bày kết quả khảo sát sự thay đổi độ bóng, độ biến màu và dự báo tuổi thọ lớp sơn acrylic bằng thử nghiệm gia tốc, các thử nghiệm gia tốc được mô phỏng theo điều kiện khí quyển biển nhiệt đới tại trạm thử nghiệm tự nhiên biển Đầm Báy (đảo Hòn Tre, Tp. Nha Trang, tỉnh Khánh Hòa, Việt Nam). Độ bóng được xác định theo ISO 2813:2014, độ biến màu được xác định theo tiêu chuẩn ASTM E308-12. Tuổi thọ của hệ sơn acrylic được tính toán theo tiêu chuẩn GOST 9.401-2018. Kết quả tính toán theo các dữ liệu thử nghiệm gia tốc cho thấy, thời điểm ăn mòn của hệ sơn acrylic đạt mức Ri 3 (theo đánh giá ISO 4628-3:2016), tuổi thọ của sơn acrylic Tar 5366 là 2,91 năm, của sơn acrylic AR-752 là 2,66 năm.

Từ khoá: Sơn acrylic Tar 5366; Sơn acrylic AR-752; Thử nghiệm gia tốc; Khí hậu nhiệt đới biển; Các tính chất trang trí; Dự báo tuổi thọ.