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Protective properties of anticorrosive coatings of steel thin-walled profiles for walling

Yu.G. Barabanshchikov[1], V.Yu. Kuznetsova [2*], V.A. Khakimova [3]

[1-3]*Peter the Great St. Petersburg Polytechnic University,29 Politechnicheskaya St., St. Petersburg, 195251, Russia*

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ABSTRACT

Light steel thin-walled structures (LSTS), in particular with thermoprofiles, are widely used in construction of buildings and structures of various applications. These structures possess high heat-saving parameters, at the same time, durability of these structures may be limited by low corrosion resistance of steel. According to the latest amendments in the documentary standards, zinc coated thermoprofiles without additional paint coating may be used as load-bearing structures only in non-aggressive conditions. In this investigation we have established that the use of zinc coated steel with additional paint coating is much more effective measure of protection of steel articles against corrosion than separate zinc and paint coating. As a result of methods for corrosion testing, it was established, that the most effective measure of protection of steel articles against corrosion in aggressive conditions is the use of zinc coated steel with additional paint coating. These samples have been just slightly corroded during the test period (230 days).

Content

Contact information:

1 +7(812)5341286, ugb@mail.ru (Yuriy Barabanshchikov, Ph.D., Professor)
2 * +7(931)9626627, kuznetsova_vy@mail.ru (Valeria Kuznetsova, Student)
3 +7(967)5211686, viktory.andreevna@mail.ru (Viktoria Khakimova, Student)

1. Introduction

So-called thermoprofiles (Fig. 1-2) are currently put into application in light steel thin-walled structures (LSTS). Their characteristic property involves longitudinal slit-like ports staggered in the profile wall. This perforation is designed to enhance resistance to heat flow when the profiles serve as part of walling. Along with the slot thermoprofiles, there are also the mesh ones available. Their technology makes it possible to obtain articles from initial part (stock) of smaller thickness while maintaining geometric dimensions of the profile and resistance to heat transfer [1, 2].

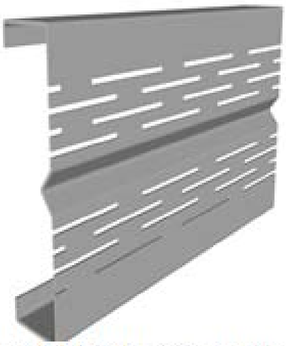

Figure 1. Slot thermoprofile.
URL: http://ekaterinburg.fis.ru/Termoprofil?good_id=10081099-termoprofil-stoechnyj-tps

Figure 2. Mesh thermoprofile.
URL: http://averssistem.ru/termoprofil

LSTS with thermoprofiles are widely used in various areas of construction: in both low- rise and high-rise civil construction [3], in construction of industrial buildings and structures, as part of load-bearing elements in smaller bridge structures, etc. [4]. Popularity of these structures is caused by their light weight, ease and despatch of installation, possibility to carry out installation at any season, ecological cleanness and higher heat-saving parameters [5-8]. Mechanical properties of thin-walled profiles make it possible to build fairly robust constructions of frame buildings and other structures [9-11]. At the same time, durability of these structures may be limited by low corrosion resistance of steel. Due to the profiles small thickness (0.8-2 mm), even slight depth of corrosion penetration may lead to significant loss of load-bearing capacity and stability of the structure. The perforation applied for thermoprofiles intensifies corrosion processes as it increases the area of contact with environment. Operating conditions in walling are particularly severe for LSTS since they involve excessive humidity and prevent drying out of construction materials [12,13]. These conditions are also complicated by condensate formation and the risk of moisture accumulation by porous materials [14]. Analysis of humidity of the exterior walls, where mineral wool boards are used as heat insulant, has shown it is necessary to take measures to reduce humidity [15]. In investigation [16], it has been established that operating conditions of thermoprofiles in walling involve the risk of intensive metal corrosion. The main factors causing corrosion processes, as stated in the investigation, are excessive humidity of materials and atmospheric oxygen. The rate of atmospheric corrosion is growing with increase of relative humidity. Furthermore, in most practical cases, the rate of metals corrosion is growing in a chemically polluted atmosphere, with the following gases: SO_2, SO_3, H_2S, NH_3, Cl_2, HCl, and the following solid particles: NaCl, Na_2SO_4, present in the air [17,18]. Another important factor affecting the rate of corrosion processes is temperature. At lower temperatures, corrosion processes are slowing down and may progress long enough. In investigation [19], it is also shown that metal corrosion is affected by mechanical stresses and forms of the structure.

Investigation of the structure operation, which is a combination of LSTS and foam concrete, has shown [20] that contact of steel profiles with the porous medium containing moisture increases the rate of metal corrosion.

Based on investigations [21], we conclude that the medium formed inside walling with thermoprofiles is corrosive.

Comparison of corrosion processes under contact of LSTS with various insulating materials, that has been carried out in domestic buildings for 10 years [22,23], has shown that mineral wool produces less effect on corrosion than fibered glass and cellulose fiber does.

Thus, in cases where thermoprofiles are used in external walling it is necessary to solve the problem of steel corrosion. This becomes especially important with contact areas of thermoprofiles and heat insulating material containing sorption and capillary moisture with the gases dissolved therein, products of decomposition of the heat insulant and other materials. This moisture, which is ionic conductive, becomes an ideal medium for electrochemical corrosion processes.

Air environment in most regions of Russia is characterized by significant pollution and high humidity. According to Code of Practice (SP) 28.13330-2012, this is an aggressive environment for metal structures. For example, the city of St. Petersburg is an industrial metropolis with a developed network of highways. Therefore, its atmosphere contains a large number of pollutants, such as nitrogen dioxide, carbon monoxide and solid particles of salts [24]. There are also high values of relative air humidity observed in the city. Therefore, the conditions of St. Petersburg make it necessary to take measures to prevent corrosion of thermoprofiles in LSTS.

In order to protect steel profiles against corrosion, they are exposed to hot dip galvanizing in the process of manufacturing. This is regarded to provide protection of steel profiles against corrosion for at least 30 years in case their operating conditions are observed [25]. According to Code of Practice (SP) 28.13330.2012 and Recommendations on engineering, fabrication and erection of structures made of cold-formed zinc coated steel profiles, given by Research and Design Institute of Construction Metal Structures (TsNIIPSK) named after Melnikov, the elements used as the load-bearing ones shall be protected by additional paint coating. LSTS without this coating may be used only in non-aggressive air environment with relative humidity of less than 65%. In St. Petersburg, with its average annual relative humidity of about 75% [26], it is not allowed to use LSTS without additional paint coating.

The use of paint coating in addition to the zinc one involves considerable additional costs and elongation of construction period, while efficiency of this measure may not correspond to the costs.

Resolving this issue requires special researches.

The purpose of our investigation is to assess efficiency of paint coating as an extra protection of zinc coated metal profiles against corrosion in terms of their service in walling. In order to achieve this purpose we have developed methods for corrosion testing of steel samples of thermoprofiles that are in contact with heat insulating material.

2. Methods

In our investigations, we have used the corrosion test pattern, as shown in Figure 3.

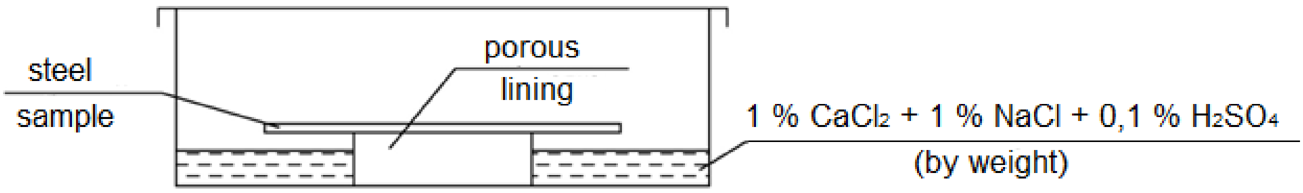

Figure 3. The pattern for corrosion testing of thin-walled steel articles in contact with porous material (heat insulant)

The samples of thin sheet steel are laid on the lining of flexible polyurethane (foam rubber), imitating heat insulating material. The samples are placed in a hermetically sealed tub with aggressive solution. The surface area of the sample is larger than the area of the porous lining (insulant) it is resting on. Thus, the peripheral area of the sample is exposed to vaporous agents. In the sealed tub, the limit value of equilibrium moisture is set, with the possibility of condensation and subsequent evaporation of moisture under temperature fluctuations. The solution of the following composition is used as an aggressive environment: 1 % $CaCl_2$ + 1 % NaCl + 0.1 % H_2SO_4 (by weight). The solution level does not reach the bottom sample surface by 1/3 of the porous lining height. The foam rubber used as a porous lining absorbs and retains water fairly well. The liquid rises to the sample by the porous lining capillaries, wets the metal surface and partially evaporates. This pattern makes it possible to carry out alternating impact on metal (humidification – drying out) under natural day and night temperature fluctuations.

An indicator of corrosion degree is the weight loss of the dry sample determined after removal of reaction products and salt residues. The sample surface condition is also assessed based on the results of visual inspection. The corrosion process kinetics is monitored by periodic weighing of the metal samples (once per week), with an accuracy of 0.01 g. The corrosion rate is determined by the formula (1):

$$v = \frac{m_0 - m_1}{F \cdot t} \qquad (1)$$

where v – is the rate of corrosion, g/(m^2·weeks);
m_0 – is the initial weight of the sample, g;
m_1 – is the weight of the sample after corrosion, g;
F –is the area of corrosion surface of the sample, m^2;
t – is the time of corrosion, weeks.

We have tested four kinds of thin-walled steel samples, two samples of each type (Fig. 4-a):

1 and 2 – zinc coated steel 08PS-HP, GOST R52146-2003, with polymer coating;

3 and 4 – zinc coated steel 08PS-HP, GOST R52246-2004, GOST 14918-80, without protective coating;

5 and 6 – hot-rolled steel 08U-Z, GOST 9045-93, GOST 19904-90, without any coating;

7 and 8 – steel 08U-Z, GOST 9045-93, GOST 19904-90, with nitrocellulose paint coating.

The weight of zinc coating of steel 08PS-HP is not less than 275 g/m^2, which corresponds to the zinc layer thickness of 20 micron on both sides of the sheet (Grade 1 of the zinc coating thickness according to GOST 14918-80).

The dimensions of samples are 10x10x0.1 cm.

The dimensions of the porous lining are (9x6x2.5) cm.

The area of contact of the sample and the porous lining is 54 cm^2.

The temperature in the laboratory is maintained within 18-22 °C.

All types of samples have been tested simultaneously in the same tub (Fig. 4-a).

3. Results and discussion

The test results are shown in Fig. 4-6. Fig. 4-b,c shows the samples appearance in 7 months after the testing initiation.

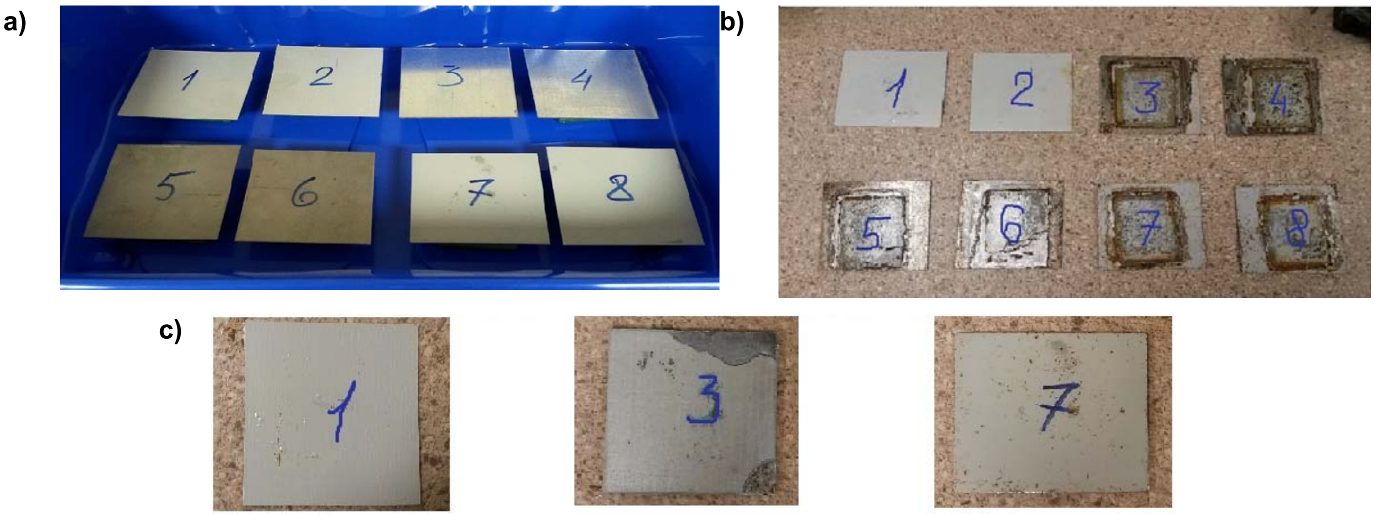

Figure 4. The corrosion testing of the steel samples:
a) corrosion tub with the samples; b) view of the samples from the side adjacent to the porous lining; c) view of the samples from the opposite side.
Types of coatings of the steel samples: 1,2 - zinc coating with additional paint coating;
3,4 - zinc coating; 5,6 - no coating; 7,8 - paint coating

Based upon the samples appearance, the control samples without protective coating (samples 5 and 6), and samples 3 and 4 of zinc coated steel suffer the largest area of corrosion. However, the latter samples are mainly corroded on the lower side and their upper side is affected only in small areas (sample 3 in Fig. 4-d), while the control samples with no protective coating were affected by corrosion process on both surfaces. The highest resistance to corrosion was shown by the galvanized samples with additional paint coating (samples 1 and 2), where the aggressive environment caused only minor blistering of paint on both sides (sample 1 in Fig. 4-d).

Among monolayer coatings (samples 3 and 4), zinc coating proved less resistant than paint coating (samples 7 and 8). It is probably caused by electrochemical corrosion. Corrosion on the upper surface of zinc coated steel sample 3 (Fig. 4-d) "took away" a layer of zinc coating. While on the upper surface of sample 7 with paint coating there is only shallow pitting metal corrosion.

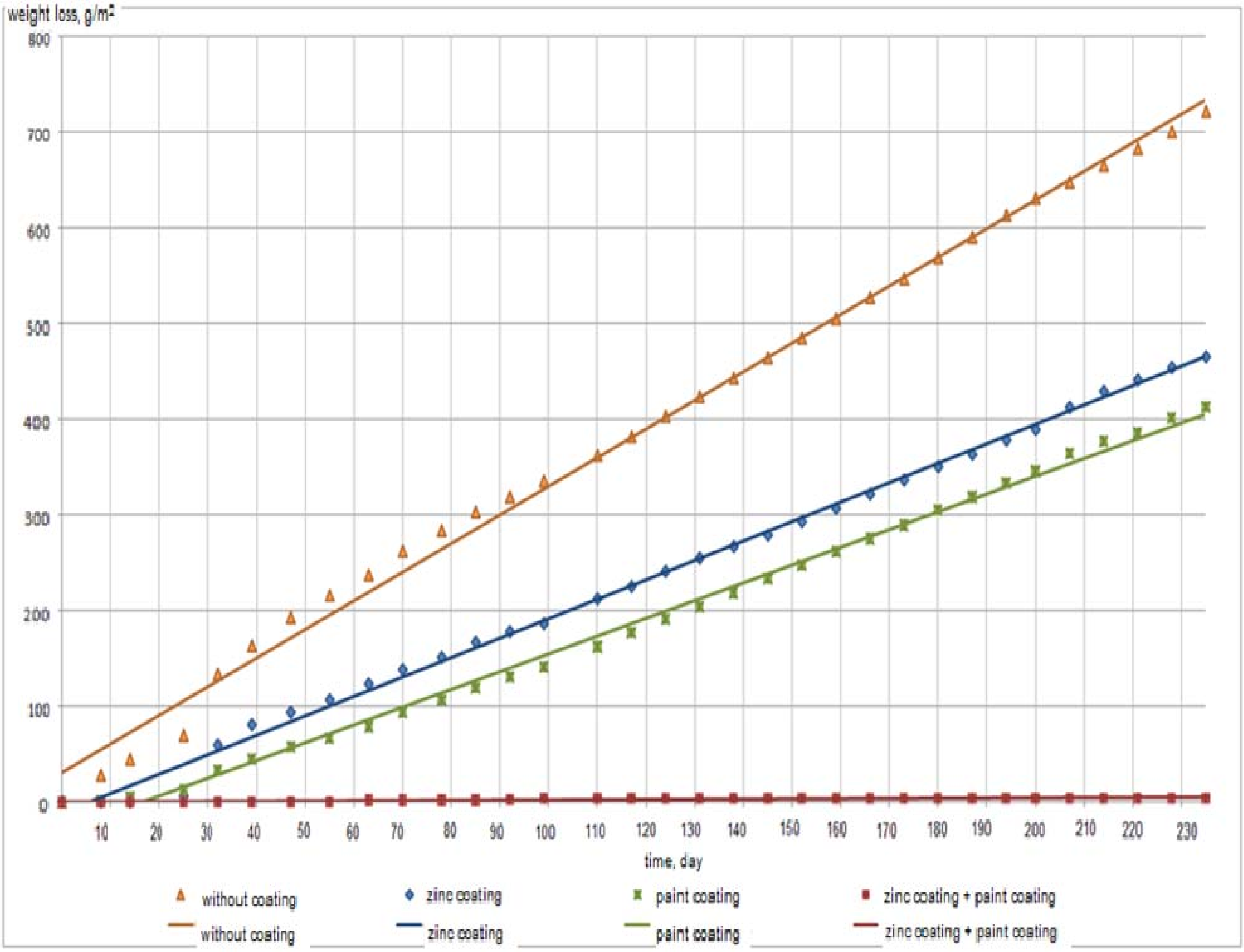

Figure 5. The samples weight loss over time

The results (Fig. 5 and 6) show that the metal weight loss due to corrosion is increasing over time almost linearly, that is explained by removal of corrosion products and insignificant changes of the reaction surface area. The spike of corrosion speed of samples 3-8 (Fig. 6), observed at day 33, is caused by sulfuric acid H2SO4 added to the aggressive solution. Thereafter, almost constant average rate of corrosion is established for all the samples. This rate is the highest for the control samples without any coating and amounts to about 20 g/(m2·week). The rate of corrosion, established after 60 days for the samples with zinc and paint coating, amounts to about 14 and 13 g/(m2·weeks) respectively. Corrosion of the samples with double protection (zinc coating and paint coating) becomes visible after 150-160 days. The values of the samples weight loss for the period of 230 days are as follows: for the control samples without any coating (samples 5 and 6) - 720 g/(m2·weeks); for zinc coated steel samples (examples 3 and 4) - 460; for pained samples (samples 7 and 8) - 400; for samples of zinc coated steel with additional paint coating (samples 1 and 2) - 0.5 g/(m2·week).

Thus, the results of both visual inspection and measuring of the samples weight loss and corrosion rate over time have shown that the most effective measure of protection of steel articles against corrosion in aggressive conditions is the use of zinc coated steel with additional paint coating.

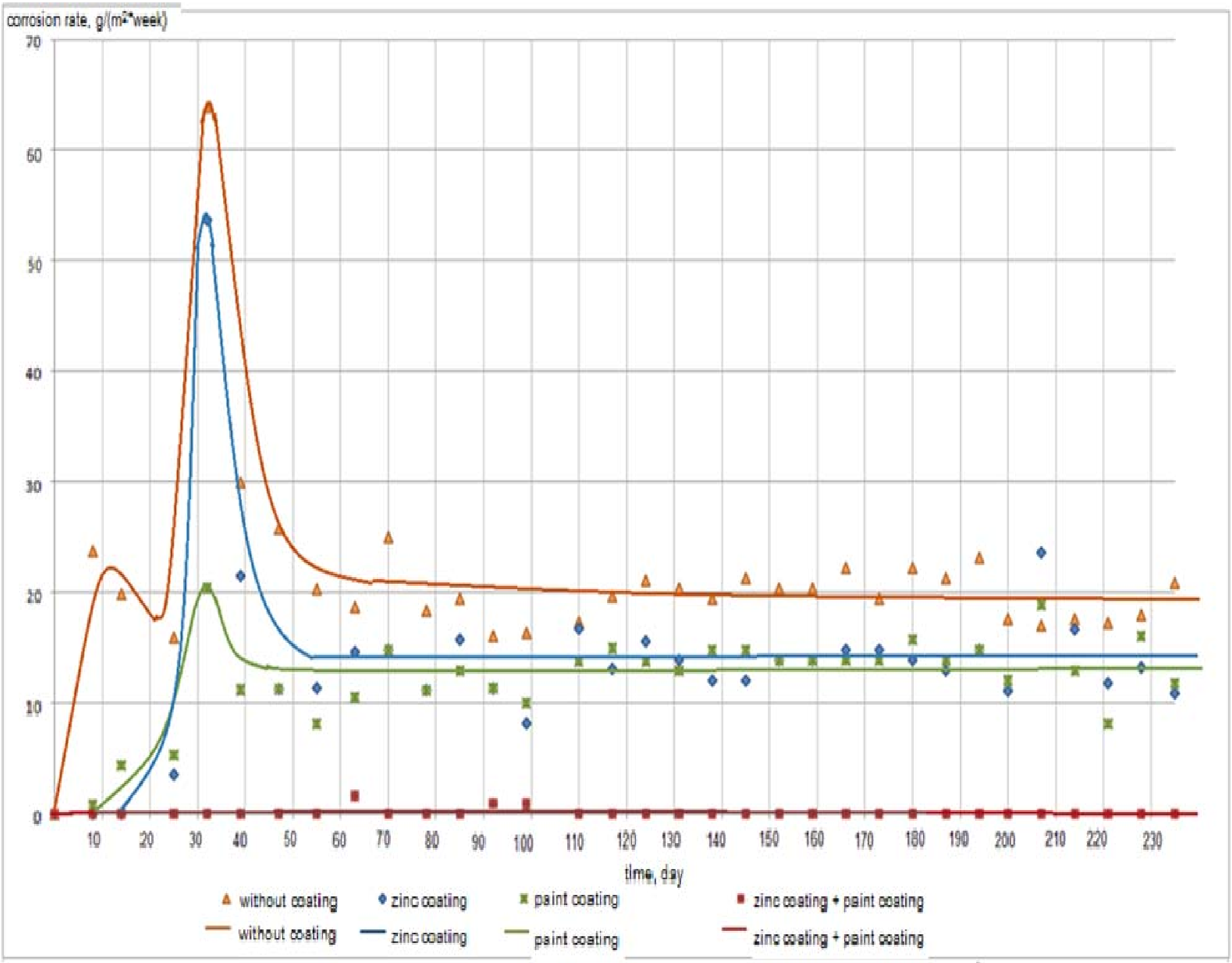

Figure 6. The steel corrosion rate over time

4. Conclusions

1. Method of corrosion testing, corresponding to operating conditions of thin-walled profiles in walling, was developed.

2. It was established that the most effective measure of protection of steel articles against corrosion in aggressive conditions is the use of zinc coated steel with additional paint coating. These samples have been just slightly corroded during the test period (230 days). In other cases, we have obtained the following average values of the weight loss during the same period: for steel samples without any coating - 720 g/(m^2·week); for zinc coated steel - 460; for steel with paint coating - 400 g/(m^2·week).

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Защитные свойства антикоррозионных покрытий стальных тонкостенных профилей для ограждающих конструкций

Ю.Г. Барабанщиков[1], В.Ю. Кузнецова[2], В.А. Хакимова [3]

[1-3]Санкт-Петербургский политехнический университет Петра Великого, 195251, Россия, г. Санкт-Петербург, Политехническая ул., 29.

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ИСТОРИЯ

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КЛЮЧЕВЫЕ СЛОВА

Тонкостенные оцинкованные стальные профили;
термопрофиль;
коррозия;
испытания на коррозию;
лакокрасочное защитное покрытие.

АННОТАЦИЯ

Легкие стальные тонкостенные конструкции (ЛСТК), в частности с использованием термопрофилей, широко применяются при возведении зданий и сооружений различного назначения. Такие конструкции обладают высокими теплосберегающими показателями, в то время как их долговечность может быть ограничена невысокой коррозионной стойкостью стали. Согласно последним внесенным в нормативную документацию изменениям оцинкованные термопрофили без дополнительного лакокрасочного покрытия допускается применять в качестве несущих конструкций только в условиях неагрессивной среды. В данной работе установлено, что применение оцинкованной стали с дополнительно нанесенным лакокрасочным покрытием является значительно более эффективной мерой защиты стальных изделий от коррозии, чем по отдельности цинковое и лакокрасочное покрытие. В результате проведения коррозионных испытаний было установлено, что наиболее эффективной мерой защиты стальных изделий от коррозии является применение оцинкованной стали с дополнительно нанесенным лакокрасочным покрытием. Такие образцы практически не подверглись коррозии в течение всего времени испытания (230 суток).

Контакты авторов:

1 +7(812)5341286, ugb@mail.ru (Барабанщиков Юрий Германович, д.т.н., профессор)
2 * +7(931)9626627, kuznetsova_vy@mail.ru (Кузнецова Валерия Юрьевна, студент)
3 +79675211686, viktory.andreevna@mail.ru (Хакимова Виктория Андреевна , студент)

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